Ecological Mangrove Rehabilitation
A Field Manual for Practitioners

Over the years, there have been many different attempts to restore mangroves. Some of these efforts have been gargantuan, involving several thousand hectares of coastal lands. Other efforts have been small in comparison, with perhaps less than a hectare of mangroves restored. Yet, in these efforts, both large and small, the lessons learned in this important process are vital in re-establishing otherwise rapidly vanishing mangrove forests. Without taking those necessary steps now to restore mangroves, our planet's coastal regions will be seriously impacted by erosion, declining fisheries, vanishing wildlife, and displaced indigenous coastal peoples.

There are many different techniques and methods utilized in planting mangroves. Because some of these have resulted in identifiable successes or failures, we wish to present herein a detailed process of mangrove rehabilitation which has proven successful in its application in various locations at various scales. Ecological Mangrove Rehabilitation engages communities to consider social, economic and ecological factors before undertaken mangrove restoration, and relies on monitoring to inform corrective actions over time. This EMR manual also presents summary descriptions of particular case studies from around the world, which are representative of both successful and failed attempts at mangrove restoration.

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EMR

ECOLOGICAL MANGROVE REHABILITATION

ROY R "ROBIN" LEWIS III & BEN BROWN

A FIELD MANUAL FOR PRACTITIONERS

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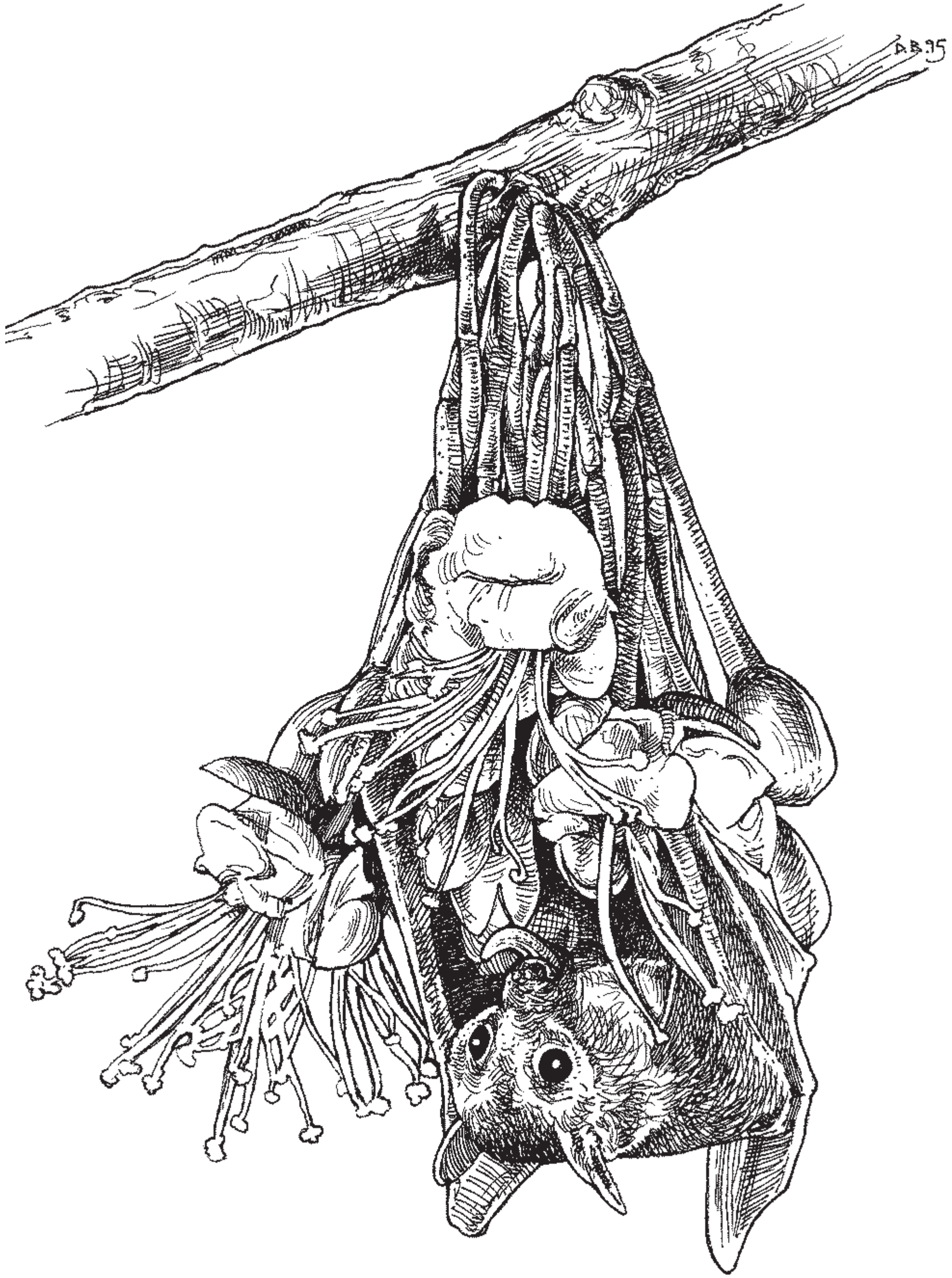

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First Edition

This manual is available on-line at:
www.mangroverestoration.com
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Restoring Coastal Livelihoods is a 5 year project in South Sulawesi, Indonesia, in partnership with local government and over 70 coastal communities. Mangrove Action Project - Indonesia, as part of the RCL project, was tasked with 400 hectares of Ecological Mangrove Rehabilitaiton, as well as advocacy at regional and national levels to reform poor mangrove restoration practices. As part of this advocacy strategy, a National EMR Seminar was held in 2013, led by Roy Robin Lewis, co-author of this manual and founder of the EMR method. This manual was completed in time for presentation of an initial draft for comment, at a Regional RCL Seminar held at and in partnership with the Center for International Forestry in Bogor.

We are proud to launch this manual, which provides detailed instruction for the professional mangrove rehabiltiation practitioner. This first draft of the EMR Manual is meant for comment and discussion, which will bring about a finalized first draft in March, 2014.

The authors intend to update this manual periodically, pending adequate time and resources. In order to make needed improvements, we need your input. Feel free to send input to the authors or Mangrove Action Project - Indonesia at any time, for consideration in future iterations of this manual.

Thank you for your consideration, time and support.

Ben Brown
Roy R. "Robin" Lewis
2014

Table of Contents

1

INTRODUCTION

1. Background
2. Purpose of the Manual
3. Design of the Manual
4. Overview of this Manual
5. What is EMR?
6. Terminology - Rehabilitation, Restoration & Other Terms of the Art

1.1 Background
It is estimated that between 1980 and 2000, 180,000 ha of mangroves were degraded or destroyed each year. (FAO, 2007) While the rate of loss decelerated to around 100,000 ha/yr in the 21st century (ibid), both mangrove conservation as well as rehabilitation are clearly imperative.

Unfortunately, most mangrove rehabilitation efforts world-wide, fail to re-establish mangrove forests. The majority of these efforts are over-simplified planting projects, largely attempts to force mangroves to grow in intertidal mud-flats, usually below Mean Sea Level – where mangroves simply do not grow.

This takes place for a pair of reasons;

1. Land tenure and ownership issues make it difficult to put mangroves back where they belong, that typically being areas that were converted due to unclear policy and inadequate prior management.
2. Poor understanding of the ecological requirements of mangroves, and the processes which lead to their establishment and early growth.

This manual intends to provide insight to both the socio-political problem of land tenure as well as issues of properly understanding the ecological underpinnings of successful mangrove rehabilitation from point 2. This manual takes the reader through a process of assessment, design, implementation and reflection around social, economic and ecological factors which contribute to the failure or success of a mangrove rehabilitation effort. By understanding both pitfalls and recommended practices around mangrove rehabilitation, it is our hope that the rather simple, but enigmatic practice of restoring mangrove forests is approached more scientifically and rationally and that practitioners become more reflective about their actions.

1.2 Purpose of the Manual
This manual is designed as a much enhanced update of a previous EMR Manual – which illustrated the 5 basic steps of Ecological Mangrove Rehabilitation, as set out by Roy "Robin" Lewis III of Florida (Lewis et al. 2006). The purpose of this manual is to provide practitioners with activities, tools and options to be used in assessing, designing, implementing and monitoring a mangrove rehabilitation project.

The Mangrove Action Project is a network, with nodes and members from across the tropical and sub-tropical globe where mangroves and people live together. This manual was produced by the MAP-Indonesia office, and as such, many examples and case studies were derived from Indonesia. Examples and case studies were also provided from Florida, where R.R. Lewis has been practicing for four decades, but you will also find EMR case studies from some of MAP's network members across the globe in Chapter 10.

MAP Indonesia may not fully know the wealth of mangrove rehabilitation approaches currently available worldwide. Accordingly, MAP seeks to continually improve upon its mangrove rehabilitation approach, discovering and sharing skills, knowledge and experiences world-wide.

1.3 Design of the Manual
The focus of this manual is to bring a practitioner through the major steps of a mangrove rehabilitation project. These steps are based on the marriage of Kolb's Learning Cycle (Fig 1.1) with a common project cycle (Fig 3.1 in chapter 3). The combination of these two cycles result in an iterative project cycle – with a focus on learning and adaptation. The application of this, enables the practitioner to move from mangrove rehabilitation, to long-term management. The form of long-term management that MAP recommends is adaptive (changing based on previous learning) and collaborative (taking place in a multi-disciplinary way with numerous stakeholders). This is known as Adaptive Collaborative Management.

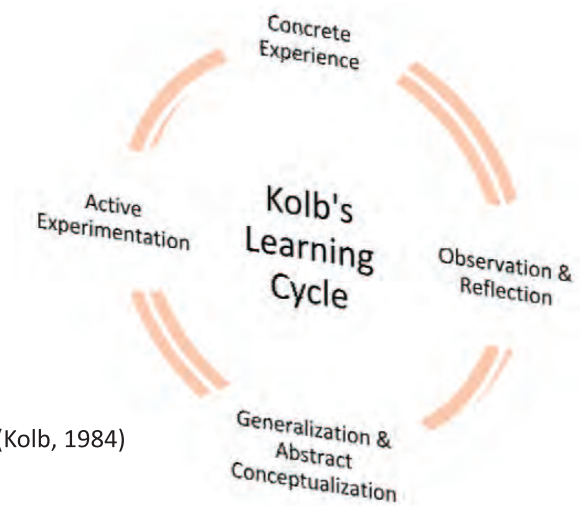

Figure 1.1
D.A. Kolb's Learning Cycle (Kolb, 1984)

The manual has been designed to provide descriptions of approaches and also activities that help readers understand key concepts and build important skills. It is designed to be a practical manual that allows a user to engage a group in undertaking activities, with supporting references, materials and handouts. The emphasis is upon collecting qualitative and quantitative data during an assessment phase that allows the reader to better understand mangrove rehabilitation challenges, in order to develop an appropriate design and work plan for successful mangrove rehabilitation.

Figure 1.2 Action-research and Problem Solving.

Activities in this manual build from ***field investigations*** which help understand the habitat requirements of mangroves (such as mapping the positions of the lowest naturally occurring seedlings in the tidal frame with use of GPS - top right), to ***community action taking*** such as improving drainage of a disused shrimp pond (middle) or human assisted propagule dispersal (below).

The manual has been designed to examine biophysical parameters, as well as social and economic parameters which comprise a system which includes both mangroves and people. By measuring key environmental, social and economic parameters, the reader can better understand how to enhance key parameters (which are currently disturbing natural mangrove regeneration) building towards a more resilient mangrove system.

1.4 Overview of This Manual

Each chapter is the product of a method of mangrove rehabilitation, and more generally, community based mangrove resource management, that MAP uses in its programs internationally. These methods have been developed both by MAP network members (which include coastal community members, educators, citizens, scientists, and government leaders), and also by the wealth of sustainable community development and natural resource management methods which have been developed over the past half century.

The manual is organized as follows:

Chapter 1, This Introductory chapter has three main parts. The first describing the Purpose of the Manual, and an outline of its chapters. This chapter next introduces the principles of Ecological Mangrove Rehabilitation, and closes with a discussion of the difference between Rehabilitation and Restoration, as well as introducing several more terms of the art.

Chapter 2, presents Key Ecological Principles Underpinning EMR. These principles elucidate how mangroves distribute their propagules and colonize appropriate mangrove substrates. The lesson applies equally to the development of natural forests as well as the re-colonization of degraded areas.

Chapter 3 is a brief chapter on Program Design. It takes the reader through a quick depiction of the flow from pre-assessment and assessment activities, to mangrove rehabilitation design and planning, through implementation and into a cycle of monitoring and mid-course corrections.

Chapter 4 is the first of three assessment chapters. Preliminary Assessments are rapid surveys, designed to quickly understand if a certain area has mangrove rehabilitation potential, both from a bio-physical point of view (ecological viability), as well as a socio-political point of view (land tenure and stakeholder support).

Chapter 5 provides a myriad of Biophysical Assessment Activities. This chapter is largely written in curriculum format, to assist the reader to leading trainings and in-field activities. Some of the activities in this chapter will be required to create an EMR plan, while others are recommended to achieve a greater understanding of the physical process at the site, and as a baseline in order to monitor success. The four sections of this chapter include; 1) ecological assessments, 2) hydrological assessments, 3) an analysis of disturbances (preventing natural re-colonization of the mangrove area) and 4) biological assessments. This final section on biological assessment includes a trio of activities, the most important of which – a benthic index of biological integrity – has not been well developed yet.

Chapter 6, entitled Assessing Resilience, introduces a number of social and economic factors that, added to the above biophysical assessment help paint a holistic picture of the level of resilience of the mangrove-human social-ecological system to be rehabilitated. A long list of potential indicators of resilience is presented, along with a simple scoresheet. Each EMR project is encouraged to chose and define its own set of resilience indicators, both to inform EMR design and for monitoring purposes.

Chapter 7, Participatory EMR Planning, is a brief chapter delineating 6 steps that a facilitator can follow to lead a group through the process of EMR design and planning.

Chapter 8 is all about Implementation. The chapter begins with information on site preparation, before delving into information and examples of hydrological and ecological repair. A brief treatment of running and as-built survey, maintenance and mid-course corrections follows. The chapter closes with a number of real examples of the combination of hydrological and ecological repair techniques. The reader will have another opportunity to learn from real examples, in greater detail, in Chapter 10 on case studies.

Chapter 9 is a short treatment of EMR monitoring. MAP has already developed a complete technical manual on assessments, surveys and monitoring which can be accessed at the download section of www.mangroverestoration.org. Instead of an exhaustive replication of monitoring methods (which are very similar to the material presented in the assessment chapters), this chapter discusses key point of monitoring. It begins with a discussion entitled Why Monitor? This is followed by a discussion of the differences between technical monitoring and participatory monitoring. Examples of both are provided from one of MAP Indonesia's recent projects in South Sulawesi. The chapter closes with a return to the learning cycle, and the iterative nature of monitoring to inform mid-course corrections and future mangrove forest management. The references section of this chapter contains enough materials to point the interested practitioner in the right direction

Chapter 10 is the final chapter of this manual, and contains EMR case studies from around the world. MAP requests that any and all EMR practitioners send in their own cases studies, for potential inclusion in the next version of this manual. The case study on Tanakeke Island, Sulawesi, uses the template that all future case studies should follow.

1.5 What is EMR?

Ecological mangrove restoration (EMR) is defined as: "an approach to coastal wetland rehabilitation or restoration that seeks to facilitate natural regeneration in order to produce self sustaining wetland ecosystems."

EMR is a general approach (not a mandated method or sequence of steps), that is designed to provide a logical sequence of tasks that are likely to succeed in restoring or creating mangrove habitat with a diverse plant cover similar to that of a natural reference mangrove forest, with functional tidal creeks connected to upland freshwater flows if available, and supporting a diverse faunal community. All of the above is designed to persist over time without significant further human intervention. Planting of mangroves may be needed in certain circumstances, but in most cases we have studied, volunteer mangroves (not planted) will provide the diverse forest cover over time. The contemporary practice of EMR includes local stakeholder engagement and negotiation in order to achieve agreement about shared objectives and restoration methodologies.

The initial five steps of EMR was first published as an abstract of a presentation by Lewis and Marshall (1998) at the 1998 World Aquaculture Society meeting in Las Vegas, Nevada, USA. Further revisions were made by Lewis (2005) and Brown and Lewis (2006). With the publication of an updated approach by Lewis (2009) the number of steps was increased to six with the addition of a "site selection" process. With this current updated version we have increased the number of steps to eight, but it is important to remember that these are only "suggested steps" and each EMR project is unique, with individual problems and opportunities.

For example, in many cases there is little or no real site selection process, but instead a local community may have a specific site already selected and need guidance in how to manage the EMR process. In this case, our current step 4 (select a site) is moot. All the authors understand this but also firmly believe that some guidance on a logical approach to successful EMR is essential as a starting point, since the history of mangrove forest management and restoration is replete with failed efforts (see Stevenson et al. 1989, Lewis 2005 and Samson and Rollon 2008). In fact, we all believe the failures far exceed the successes, with as much as 80-90% of the projects not meeting their goals (if any exist) or simply failing to establish a biodiverse ecologically functioning mangrove forest.

EMR focuses on removing the barriers which may prevent nature taking its course by interventions that restore or create the topography and hydrology which wetland plants and animals require. EMR may also intervene by delivering propagules and in specific cases provide complementary planting of species known to thrive in the particular conditions which exist.

EMR recognizes that wetland species are found in identifiable habitats and does not promote rehabilitation or establishment in locations where these conditions do not exist or cannot be created.

EMR exists because its practitioners recognize the value of wetland goods and services to people. They also recognize that people are in most cases a part of the coastal environment and that unless these users agree to the perpetuation of the wetland it will be degraded or converted to alternate purposes, oftentimes dictated by wealthier individuals at the detriment to the public-at-large .

1.6 Terminology: Rehabilitation, Restoration and other Terms of the Art

For purposes of this manual, the term "restoration" has a very broad meaning. It generally follows the definition of Lewis (1990a):

> "Returned from a disturbed or totally altered condition to a previously existing natural or altered condition by some action of humans."

"Rehabilitation" is similar to restoration in that the goal is not to return to some previous condition as defined by measurable reference criteria, but conversion of an altered wetland to some beneficial use as defined by locally agreed upon goals and criteria. An example might be the conversion of abandoned aquaculture ponds to tidally influenced open water but not the mangroves that originally existed.

In this manual, we have attempted to primarily use the term rehabilitation, owing to the relative difficulty of achieving pure restoration. Sometimes, however, we have invariably used the words restoration and restore, but in a broader sense, that does NOT always indicate a return to some historical pre-human impact condition, nor a return to the exact conditions that existed before some change occurred.

Of course any attempt at pure restoration is bound to fail as the exact pre-human impact conditions of a mangrove forest are rarely known, so a proper measurable success criterion to define success of restoration could not be accurately determined if the goal is to produce a forest like those that existed hundreds of years ago. For this reason we emphasize quantitative comparison of a restoration or rehabilitation site to an adjacent reference site supporting more less natural mangroves characteristic of the local area.

Both restoration and rehabilitation may also mean returning a site with existing but stressed mangrove forest cover to a more hydrologically connected system prior to a die-off of trees occurring due to extended flooding, or hypersaline conditions. This approach requires being able to measure the existing hydrology and determine if stress is present and intervene prior to a mangrove die-off.

Another term of the art is "mangrove forest creation." Creation generally refers to the conversion of uplands to wetlands. Planting mangroves on a mudflat that historically did not support mangroves is a similar type of effort, which could properly be called "mangrove forest afforestation." Most mangrove afforestation efforts are not successful as documented by Samson and Rollon (2010) in the Philippines (but has worked in the Sudarbans and Guyana). Mangrove creation through excavation of uplands to mangrove wetland elevations and connecting these to tidal flow can work but is very expensive due to the excavation costs.

Finally, the term "mangrove forest enhancement" or "replenishment" is often used to describe some sort of planting within existing mangroves for the purpose of improving existing ecological conditions. These are also called "enrichment plantings." There is no scientific evidence that any of these enhancement efforts really enhance the exiting functions or benefits of mangroves. Often they may actually further degrade the system, if for example, planting of mangroves takes place if areas within mangroves that are devoid of mangroves. Often these are important habitat areas for wading birds to feed for example, or they may be tidal flushing channels, and their planting while successful, may ultimate doom the forest to reduced tidal flooding, encroachment into channels and the final death of the forest due to human-induced hydrologic restrictions.

Although the above foray into differing terminology may seem like an exercise in semantics, it is important that appropriate terminology be used around mangrove rehabilitation. Oftentimes, a single guiding document will determine the fate of an activity or series of activities. The differences between rehabilitation, restoration, creation, afforestation and enhancement could very well be the deciding factor in the viability and success of a multi-million dollar project.

2

KEY BIOPHYSICAL FACTORS

UNDERSTANDING THE BIOPHYSICAL FACTORS THAT CONTROL MANGROVE SEEDLING ESTABLISHMENT AND SURVIVAL

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2.1 INTRODUCTION

Mangroves are unique plants, adapted to survive in a stressful environment that is continuously changing throughout the day, as the tides moves in and out. Mangroves have to be able to tolerate these dynamic and stressful physical processes in order to establish, survive and grow.

We can often observe the role of biophysical processes and their effect on the distribution of mangrove trees. Take Figure 2.1 as an example, from a rehabilitation site in Sumatra. *Rhizophora* propagules were planted throughout this brackish water aquaculture pond (***tambak***). After planting, they grew well towards the back of the tambak, but struggled to grow, or died at the front. What differences between the back and the front of the tambak cause these differences in mangrove establishment and survival? How can establishment and survival be so different over such a small area? Why haven't natural mangrove propagules colonized this area?

To identify what is causing this difference in survival, we need to understand:

a. If mangrove propagules are able to disperse to a new intertidal surface in order to colonize
b. the physical processes operating on this new intertidal surface that affect mangrove establishment and growth, notably tidal inundation and waves, and
c. the tolerance that different mangrove species may have to these physical processes.

Tolerance is species-specific; the species of some genera such as *Avicennia* and *Sonneratia* are able to tolerate harsher physical conditions such as longer periods of tidal inundation. These are known as pioneer species because they are the first species able to colonize the pioneer mangrove zone, where tidal inundation and waves are highest. Hence, these species would be more appropriate for low elevation rehabilitation zones, where flooding is highest. Other species may be more suitable for other locations, for example *Lumnitzera* is better able to colonize other areas such as the edge of the tambak wall.

Understanding the biophysical processes that control mangrove survival, and understanding which species may be the best suited for a rehabilitation site are two key components of EMR. Successful EMR relies on working with, not against the local biophysical conditions that occur at the rehabilitation site. Three biophysical

Figure 2.1. A mangrove restoration site in Sumatra, 2010. Planted *Rhizophora* trees are growing well at the back, but *Rhizophora* propagules planted in front have never been able to establish. Why?

processes processeswill be discussed in this chapter, which must be considered for successful rehabilitation:

1. There must be enough propagules available in the local area to disperse to the rehabilitation site
2. Once propagules have travelled to the rehabilitation site, they must find a location that is high enough relative to the tide level that they do not drown;
3. Propagules must find a location where waves and currents do not dislodge the seedlings

These three factors – propagule supply, tidal flooding and waves/currents are interlinked (Figure 2.2). Propagule supply and dispersal into a rehabilitation site require water flow by waves and currents. Waves and currents and tidal flooding are also linked. Tidal flooding increases the landward reach of waves and currents.

In this chapter we will investigate these biophysical processes in the form of questions that should be asked of every potential rehabilitation site. Many of the following ideas are summarized from three scientific papers:

1. Lewis 2005. Ecological engineering for successful management and restoration of mangrove forests. Ecological Engineering 24, 403-418
2. Lewis 2009. Methods and criteria for successful mangrove forest restoration. In: Perillo, Wolanski, Cahoon and Brinson (Eds). Coastal Wetlands: an Integrated Approach. Elsevier. Pgs 787-800.
3. Friess et al. 2012. Are all intertidal wetlands naturally created equal? Bottlenecks, thresholds and knowledge gaps to mangrove and saltmarsh ecosystems. Biological Reviews 87, 346-366.

These papers are freely available from the following websites:

- www.mangroverestoration.com/html/downloads.html
- www.themangrovelab.com/publications

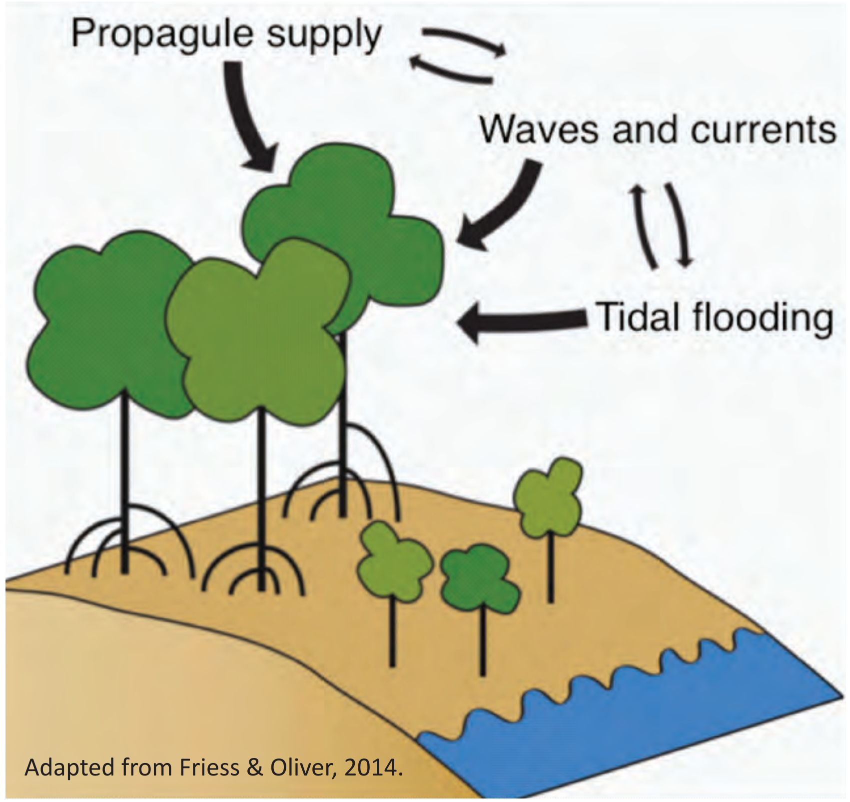


Figure 2.2 Some of the important biophysical processes that affect mangrove establishment, survival and growth.

In particular, Lewis (2005 and 2009) describe 6 key steps for successful EMR which are closely related to the biophysical processes that we will discuss in this chapter. These 6 Steps for successful EMR are summarized below:

1. Understand the individual species ecology (reproduction, dispersal, seedling establishment)
2. Understand the hydrological patterns that control seedling distribution and establishment
3. Assess human modifications that may be preventing natural colonization
4. Spend a sufficient amount of time selecting the most appropriate restoration site possible, using information from Steps 1-3. As well as assessing physical and ecological parameters as above, this step also involves anticipating and resolving community issues such as land tenure and land use, to allow long-term access to the site.
5. Design the restoration to restore appropriate hydrology and natural recruitment
6. Only actively plant propagules and seedlings if step 4 will not be successful or rapid vegetation cover is required

Various aspects of these 6 steps will be discussed in the following three (3) key questions that should be asked and investigated for any new rehabilitation site.

2.2 Three Key Biophysical Questions

Question 1 - How close is your rehabilitation site to other natural mangrove stands?

This question relates to Steps 1 and 4 of the EMR criteria. Successful EMR should not require a huge amount of planting, but can often be naturally colonized by propagules coming into the site from surrounding natural mangrove stands. A rehabilitation site will only be naturally colonized by mangroves if propagules are available to be transported into the site. So there are two requirements:

1. That natural mangrove stands are located in close proximity to the rehabilitation site;
2. That water flows connect natural mangrove stands and the rehabilitation site.

Propagules Can Float

Mangrove propagules are predominantly dispersed by water, through a mechanism called ***hydrochory***. (See Fig 2.3) To achieve this, the propagules of many mangrove species have special adaptations in order to float in water. Many of these adaptations are described by Tomlinson (1986) in his book *The Botany of Mangroves*. For example, *Avicennia* propagules trap air bubbles in small root hairs or between underneath the pericarp (seed coat). *Rhizophora* propagules are composed of large air-filled cells

Figure 2.3 Hydrochory is the natural process by which mangrove propagules are dispersed on tidal waters. *Avicennia* seedlings are excellent pioneers, establishing themselves on open intertidal surfaces (bottom left), while in Bintuni Bay Papua we see a virtual carpet of mangrove seeds and fruits on the mature forest floor.

called aerenchyma. The large seed of *Xylocarpus* species (the "cannon ball" mangrove) is made of a corky material that floats. Because different species have different adaptations to aid flotation, this means that they float for different lengths of time: the flotation period is species-specific. Unpublished experimental results of Southeast Asian mangrove species have shown that *Avicennia* species can float for an average of 6 days, while *Rhizophora* species may float for an average of 22 days or as long as 163 days, and still remain viable.

Propagule Flotation + Water currents = Dispersal

The flotation period gives us information on how long a propagule stays afloat, and thus how long it could potentially disperse for. However, propagules rely on water currents in order to disperse away from the parent tree and on to new mangrove patches. Water currents are driven by many factors, such as the tides, wind and differences in salinity. Thus, it is crucial that natural mangrove stands are situated close enough to a rehabilitation site and in the correct water flow direction, so that

propagules can disperse into the new area before they sink or do not become viable. Understanding the reproductive ecology of the target mangrove species to be restored is a key step in the EMR process (Lewis 2005).

Why is This Important for Rehabilitation?

Utilizing natural propagule dispersal has many advantages for EMR. First of all, us ing naturally colonizing propagules reduces the requirement for planting. This may be more cost-effective over the long-term (Lewis et al. 2005), as it does not require- costs for nurseries, planting manpower etc.

Secondly, utilizing natural propagule dispersal may make an EMR project more sustainable over the long-term. A regular supply of propagules from outside the site brings in new recruits to replace seedlings lost by waves, disease or insect damage.

How to Test This in the Field?

1. Observe the natural mangrove stands surrounding your rehabilitation site. Are they healthy and producing propagules? Note that fecundity (the ability to reproduce) is often seasonal in many mangrove species, even close to the equator, so observations will be affected by the time of year that they are taken. For this reason, it is essential to understand the autecology of the species of interest (Lewis (2005) Rule 1). High fecundity is an ecological trait typical of pioneer mangrove species such as *Avicennia* spp., as well as pioneer terrestrial forest species.
2. Observe where propagules wash up on the shore. Do you see propagules naturally collecting near your rehabilitation site, e.g. near the strand line (Figure 2.3)? This is an indication that the water currents are bringing in propagules from nearby mangroves
3. Google Earth can be used to observe the number and size of mangrove patches in close proximity to your restoration site. Google Earth can be used to calculate inter-patch distance. See appendix - using Google Earth for EMR.

Question 2 - What is the elevation of your rehabilitation site?

This question is related to Steps 2 and 4 of the EMR criteria. The frequency and duration of tidal flooding is the most important determinant of mangrove restoration success in many settings (Lewis and Streever 2000). Different species can tolerate different durations of tidal flooding and other hydrodynamic forces such as waves. Figure 4 shows a transect through a typical natural mangrove in Southeast Asia.

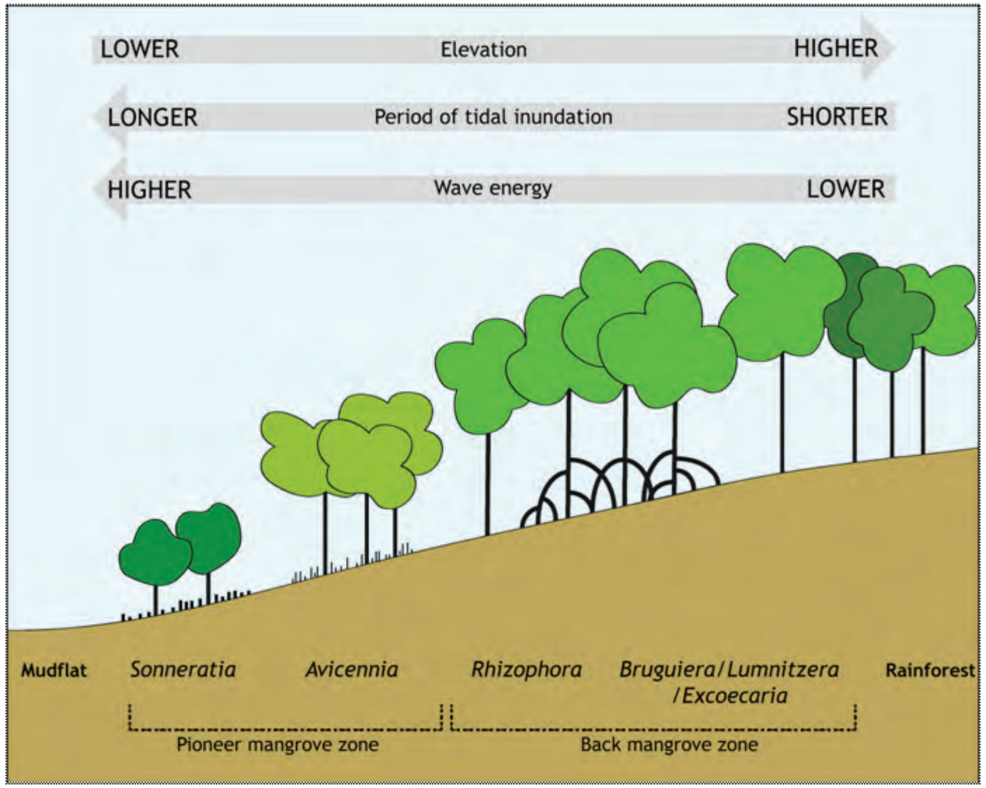


Figure 2.4 A typical cross section of a natural Southeast Asian mangrove along an elevation gradient. Tidal inundation and wave energy both change as elevation increases towards the back of the mangrove. Adapted from Friess & Oliver 2014. See also Lewis 2005

The mudflat is found most seaward and is very low in elevation; the hydroperiod here is too long and frequent for any mangrove vegetation to grow. As we begin to move landward, the elevation increases, and the hydroperiod decreases. First, pioneer mangrove species such as *Sonneratia alba* and *Avicennia alba* colonize, as they are some of the few species best adapted to tolerate the hydroperiod found here. As we move further landward, the hydroperiod decreases further. A greater range of species are found at the more landward extent (the back mangrove) as they are only able to tolerate these lower-hydroperiod conditions.

The influence of flooding on species distribution is not a new idea, but was first noted by Watson (1928). Watson mapped the distribution of different mangrove species against elevation in a mangrove near Benut, in southern Peninsular Malaysia, and was able to calculate the Watson Inundation Classes. These classes divided a mangrove area by the frequency of tidal inundation per month. Watson observed

broad patterns between the inundation class, and the type of vegetation that could be expected to be found there. We have to be careful about apply Watson's Inundation Classes directly to other sites, as this can be site-specific. A particular problem with this classification is that some mangrove species can actually colonize a range of different elevations (and hydroperiods). However, these inundation classes at least give us a general idea of species distribution in order to guide restoration. Understanding some of the hydrological factors that control mangrove seedling establishment and distribution is a key step in the EMR process (Lewis 2005).

Tolerance to flooding is species-specific

Flooding causes a rapid drop in oxygen levels in the mangrove soil, and can be anoxic (oxygen-depleted) even at shallow depths. Anoxic soil conditions can lead to a reduction in photosynthesis rate (Krauss et al. 2008), so mangroves have evolved a numberof adaptations to cope with these stressful conditions. Aerial roots and pneumatophores above the soil are an obvious and clearly visible adaptation to anoxic soil conditions. Mangroves can also maintain high oxygen concentrations in their roots, and aerate a thin layer of soil around the root (Krauss et al. 2008).Similar to the range of different flotation periods of different mangrove species, there are a range of tolerances to tidal inundation between different species, that contribute to the species "zonation" we find in natural mangroves along an elevation gradient. Different species have different tolerances to tidal inundation because they have a range of different adaptations to flooding.

Fig 2.5 The Watson Inundation Classes for a mangrove in Benut, southern Peninsular Malaysia.

Inundation Class	Flooded by:	Times flooded per month	Mangrove tree species that may be found here
1	All high tides	56-62	*Sonneratia alba, Avicennia alba*
2	Medium high tides	45-59	*Rhizophora* spp., *Bruguiera* spp
3	Normal high tides	20-45	*Xylocarpus* spp., *many species*
4	Spring high tides	2-20	*Lumnitzera littorea,* many species
5	Rare tides	<2	Many species

Adapted from Tomlinson 1986.

Why is this important for rehabilitation?
Surface elevation is important for EMR because it controls the areas where new mangrove seedlings can colonize. Understanding this information – the flooding tolerance of different species, at what elevations they may be found in a natural mangrove – can inform aspects of rehabilitation site design. This knowledge allows us to manipulate the environmental conditions at the site to be below the key tolerance thresholds to allow a natural propagule to successfully establish on a newly rehabilitated surface.

How to test this in the field?
The key step in the field is to compare the elevation of your rehabilitation site with a natural mangrove site. Since colonization has already occurred at the natural mangrove site, it suggests that the elevation, and other environmental factors are suitable. There are many ways to compare elevations between rehabilitation and natural sites:

1) We can use the **natural distribution of mangrove** trees as a "biological benchmark". Installing a marker at the lowest elevation of the natural mangrove zone (e.g. the bole of the tree that is furthest seaward) and at the highest elevation of the natural mangrove zone gives you an idea of the elevation that is flooded between low and high tides. Installing markers in the restoration site at the same time gives an easy comparison. E.g., if the lowest marker in the natural mangrove zone is dry, but the restoration site is inundated, it suggests that the elevation of the restoration site is too low.

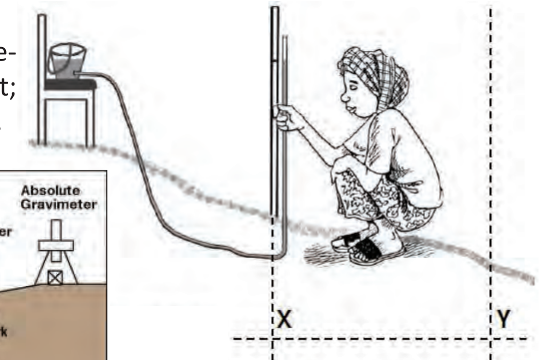
2) The hose water level is a quick and cheap way to calculate relative differences in elevation. The following information is adapted from this website:

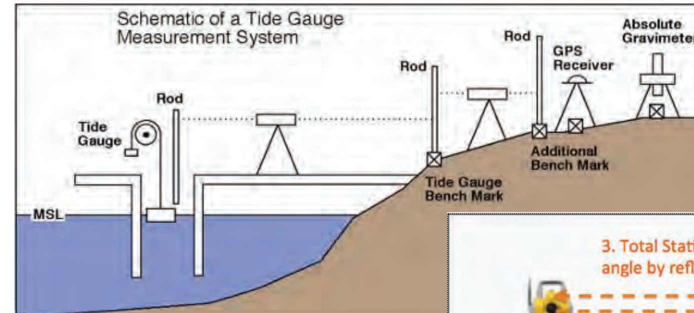
http://www.buildeazy.com/fp_waterlevel.html

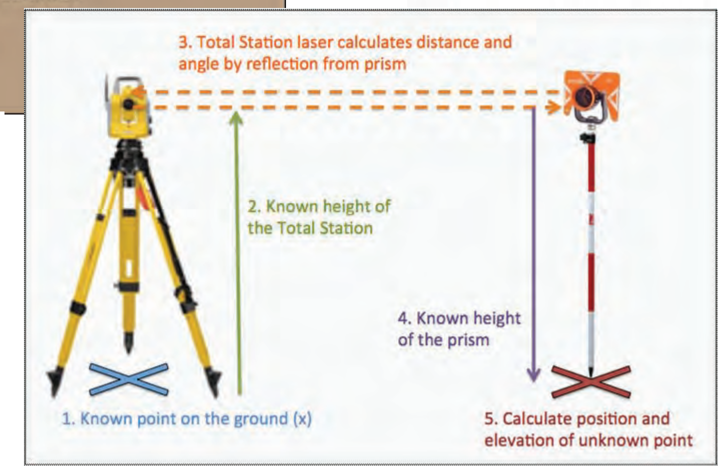
This technique is useful because it is cheap, and it allows you to rapidly determine the difference in elevation between two points. You would then adjust the elevation of the 2nd point (rehab site) to match the first point (natural mangrove). However, you can only cover short distances, limited by the length of the hose.

3) Total Station surveying is often used in the construction industry, and can be applied to mangroves too. The principle is similar to the water hose technique (Figure 6), and can be used to collect elevation information from natural mangroves and potential rehabilitation sites. Starting with a known point, you know the height of the instrument. The instrument has a laser, which is fired at a reflective prism. The Total Station uses the timing and angle of reflectance to calculate the position of the prism. Since we know the height of the prism also, we can calculate the elevation of the point below the prism.

Fig 2.6 Determining Substrate Elevations
A trio of methods to compare tidal elevations between a rehabilitation site and a reference forest; 1) a water level, 2) tide gauge and 3) total station.







The Total Station is very accurate (a few millimetres – actually more accurate than is required for a rehabilitation elevation survey) and relatively easy to use after some training. Another advantage is the ability to create 3-dimensional maps, that are useful for visualizing and communicating elevation data (Figure 7). The biggest advantage is to be able to map over longer distances than the water hose method – many hundreds of metres. However, the Total Station does require training, the laser can be blocked by trees (it needs "line of sight"), and can be expensive. A Total Station + operator can be rented for a relatively cheap daily rate.

4) If a **tide gauge** is available, elevations may be referred to the relevant Watson class. The Watson classes are useful for approximately delineating areas of a natural mangrove or rehabilitation site by elevation and tidal inundation, though the classes were only derived from a single site in Malaysia, so may not be applicable to all sites or species.

Question 3 – Is your rehabilitation site protected from waves and currents?

This question relates to steps 1, 2 and 4 of the EMR criteria. Mangroves are generally found in sheltered, low-energy environments such as estuaries, sheltered coasts or behind barrier islands and beaches. These environments do not generally experience large waves or strong currents, except during extreme events. Together, waves and currents can be defined as hydrodynamics. Hydrodynamics are linked to tidal inundation (Question 2 above).

Hydrodynamics are an important control on mangrove establishment and distribution, and understanding the role of hydrodynamics is key to successful restoration (Lewis (2005) Steps 1 and 2). To resist being dislodged by currents and waves, a mangrove seedling must grow roots to anchor sufficiently into the soil.

Rapid rooting is a key trait of pioneer species in terrestrial and mangrove forest environments. This adaptation allows pioneer species to take advantage of calm hydrodynamic conditions, or periods when there is no flooding (such as during a neap tide cycle or calm weather). We can define the "window of opportunity" required by different mangrove species in order to anchor sufficiently to resist dislodgement by large waves.

The "window of opportunity has been calculated for *Avicennia alba* (the following is described by Balke et al. 2011). This species requires 2-4 days after stranding to begin rooting. Because the *A. alba* propagule is buoyant, it requires roots 2 cm in length to not float up during inundation, which requires approximately 5-6 days. If the seedling has a root length of 4 cm it is able to resist dislodgement by normal hydrodynamics. The seedling requires an average of 8 days to achieve this, thus the "window of opportunity" required by *A. alba* is 8 days. More research is needed to define the window of opportunity required for other mangrove species.

Why is this important for rehabilitation?

Knowledge of the hydrodynamics at a potential rehabilitation site is important in order to assess whether the site is suitable for restoration. In particular, if we can estimate the "window of opportunity" required by different species to root and establish, then propagule releases can be planned for times of the month or year when the tidal regime is most suitable (e.g. a neap tide period, that may allow parts of a rehabilitation site to remain inundation-free, depending on elevation).

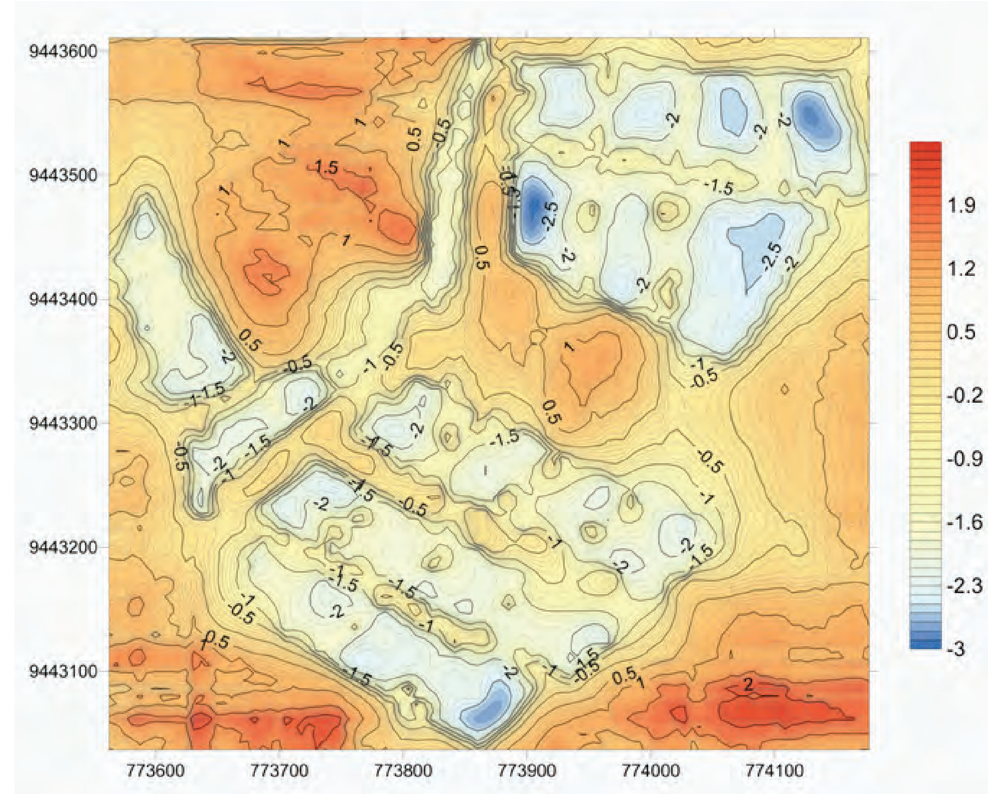


Figure 2.7 A Total Station survey of several abandoned *tambak* in Makassar, Sulawesi. Red areas are high in elevation, blue areas (inside the ponds) are lower in elevation. Data collected by Rachel Oh (National University of Singapore) and Mangrove Action Project, September 2013.

How to test this in the field?

A suitable hydrodynamic environment for colonization can be estimated by comparing the hydrodynamics in the rehabilitation site with the hydrodynamics in a natural mangrove as a baseline. While seedlings in a rehabilitation site have different resistance to hydrodynamics compared to full trees in a natural mangrove, it provides a useful approximate comparison to suggest an area with a suitable approximate hydrodynamic environment.

Boizard and DeWreede (2006) in a freely available online publication describe a number of low-tech methods in order to monitor hydrodynamics, using items that are placed in the area of water flow.

1. Clod cards or blocks (made of gypsum or plaster of paris), glued to a plexiglass surface
2. Sucrose candy

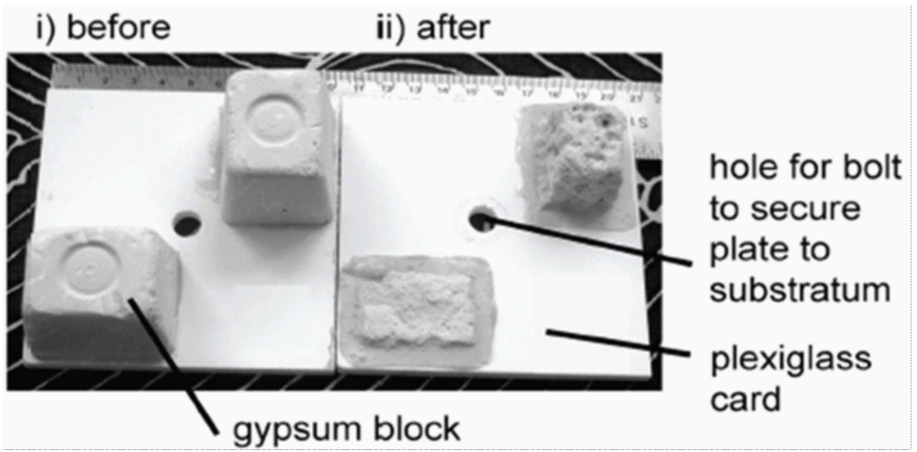


Figure 2.8. Dissolution of a gypsum block clod card to estimate relative hydrodynamic stresses. Source: Boizard and DeWreede, 2006

These techniques depend on the principle of dissolution – if you deploy one of these materials of a fixed weight into the field, the water motion will erode the material and it will dissolve in the water (Figure 8). Faster water motion equals faster rates of dissolution. The original weight minus the final weight tells us how much material has been lost. Areas of the site where more material was lost suggests hydrodynamic "hotspots", and measurements of loss can be compared to a standard calibration curve to estimate water velocities (Boizard and DeWreede 2006).

We can also use the "window of opportunity" concept to guide restoration. This factor can be estimated by collecting and growing mangrove propagules and taking regular measurements of their root growth. Simple experiments can then be conducted to calculate the force required to dislodge a seedling in the field by pulling (Balke et al. 2011). Once we know the "window of opportunity" for different species, we can tide tables, tide gauges and/or elevation measurements (from Question 2 above) to estimate periods of the year when the "window of opportunity" may be available.

2.3 Conclusions

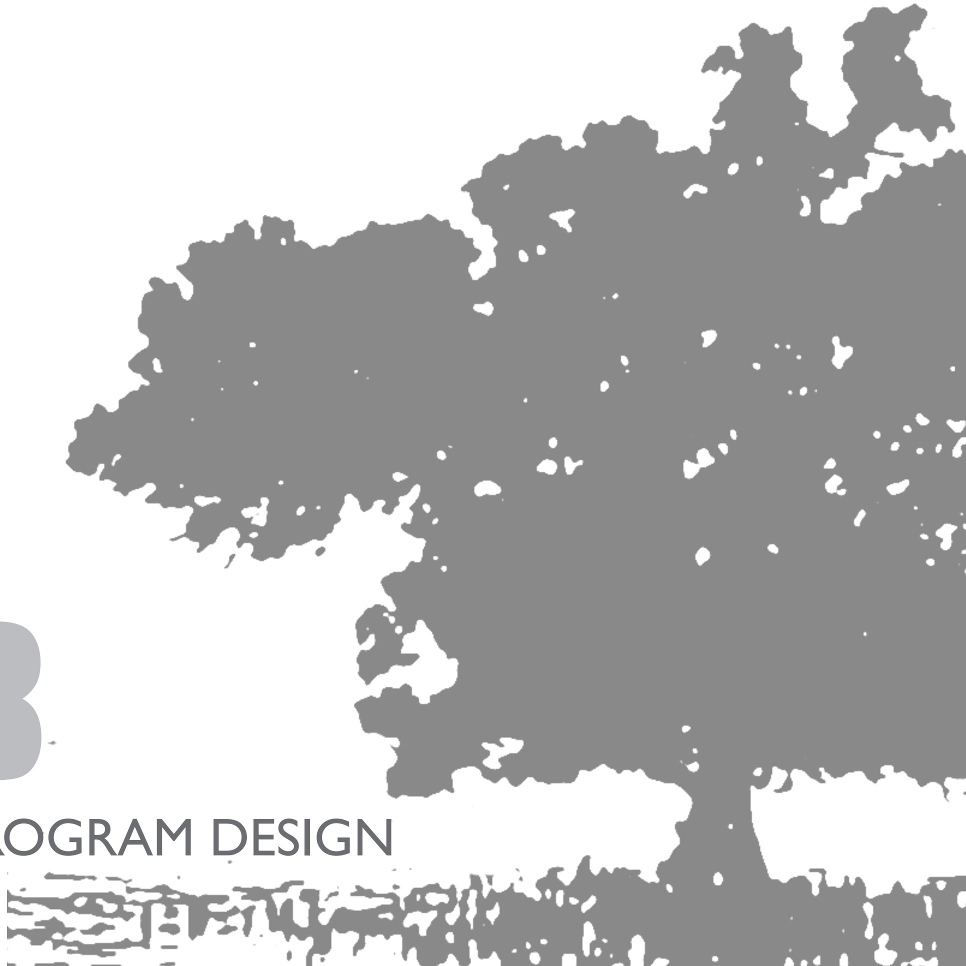
Decades of failed mangrove plantings around the world have shown the importance of understanding the planting environment and the biophysical factors that act as a stress on an establishing seedling. The intertidal zone is a stressful environment, with many biophysical factors fluctuating greatly over the short time period of the tidal cycle, and greatly influencing the establishment and subsequent distribution of mangrove vegetation. Three important biophysical factors – 1.distance from other mangrove patches, 2. tidal inundation, and 3. hydrodynamics – have been discussed here. However, other factors may also influence seedling establishment to varying degrees. Such factors may include waterlogging and drainage, salinity (see Krauss et al. 2010 for a fuller description of these processes).

In conclusion, working with the biophysical environmentand understanding the key physical processes affecting colonization and establishment is an important aspect of EMR. It is particularly important in the context of Step 4 of the EMR criteria, which describes how important it is to "do your homework" on these biophysical parameters, so that we can select the most appropriate restoration site that will have the greatest chance of success. This means that instead of selecting the most convenient site (e.g. an open mudflat), we instead select sites with the right biophysical conditions, such as (1) distance from nearest mangrove patch with available propagules, (2) the right elevation and tidal flooding levels, and (3) sufficiently low waves and currents so that (naturally colonizing) seedlings are not dislodged.The tolerance of mangroves to these physical processes is species-specific, but understanding these tolerances during the initial planning phase of a rehabilitation project will go some way to improving its ultimate success.

Acknowledgements
Some of the work presented in this chapter (e.g. Figure 7) has been conducted by Rachel Oh (National University of Singapore), Rio Ahmad, and other colleagues from Mangrove Action Project Indonesia. This work was funded by the National University of Singapore (R-109-000-141-133).Thanks to Robin Lewis and Ben Brown for helpful comments and suggestions on this chapter.

3

PROGRAM DESIGN



3.1 Introduction

The measurements and observations described in this manual taken together span the physical, biological and to some extent chemical elements that define the ecological integrity of any given mangrove system. This includes degraded mangrove systems that are being considered for rehabilitation, as well as analogue mangrove forests which act as references used in the design of rehabilitation in a degraded system. These reference systems may also serve to provide estimates for future performance of a mangrove rehabilitation effort; in terms of total production, carbon sequestration and storage, biodiversity, fisheries value or other desired metrics.

A program to assess a degraded mangrove area usually is begun in response to community or government concern over the state of the mangrove and a desire to restore it. A thorough assessment phase is always recommended before engaging in any mangrove rehabilitation effort, to clearly demonstrate both the ecological feasibility of mangrove rehabilitation as well as genuine stakeholder interest and involvement. Although effective assessment programs follow similar paths in their development, each is unique and reflects both the physical nature of the mangrove area and surrounding watershed, as well as the people involved.

Mangroves of the world vary in many ways including size, hydrology, productivity, biodiversity, surrounding land use, degree of disturbance and human utilization. Readers of this manual, and participants in the Mangrove Action Project network also vary in terms of resources available, degree of affiliation with established coastal resource management programs, the needs and concerns that drive rehabilitation efforts, understanding of the mangrove and surrounding watershed, and level of stakeholder skill, knowledge and experience (Lewis, 2009).

The purpose of this chapter is:

- To describe a measurement and observation path that builds from an aesthetic (qualitative) understanding of the mangrove and surrounding area to more quantitative measures taken in the mangrove forest itself.
- To describe the factors that shape the design of a mangrove rehabilitation assessment in order to inform an appraisal stage which will either recommend that mangrove rehabilitation is not feasible, or that stakeholders should move to the design phase for actual mangrove rehabilitation.
-

3.1.1 Assessment of the Mangrove Forest and its Surrounding Watershed

The path described here follows a general pattern beginning with the use of physical indicators (remote sensing and mangrove forest surveys) which will inform the **3.1.1 Assessment of the Mangrove Forest and its Surrounding Watershed** mangrove rehabilitation design, biological indicators which will form the baseline for future monitoring, and socio-economic information which will inform stakeholder involvement. Moving along this path, one develops a "big picture" view of water the mangrove forest in its many dimensions, but also a deeper understanding of the potential for mangrove rehabilitation at a site specific level. Those groups and individuals who are developing a mangrove rehabilitation program can choose appropriate initial assessment activities depending upon the factors described later in this chapter. We make recommendations for assessment activities which we consider essential as well as those which can be considered optional.

3.2 Designing an Assessment Program

Designing an effective mangrove rehabilitation assessment program requires understanding of two aspects; the physical nature of the mangrove forest and surrounding watershed, and the human dimensions of the program participants and local community. From this understanding, one can develop and assessment program that not only meets human needs, but that is also viable and likely to result in biophysical success.

Assessment in this process is broken down into two phases. The initial phase is called a ***preliminary assessment***. The preliminary assessment is performed in a rapid manner, with only a small amount of stakeholder involvement, to try and determine rapidly both the physical as well as social viability of continuing with mangrove rehabilitation. This is especially important nowadays, as eagerness to plant (not "replant" which refers to a second or third planting effort often after failure of the first) mangroves has resulted in numerous failures, most often due to planting inappropriate areas (most often intertidal mudflats below Mean Sea Level) or due to lack of local community interest and involvement.

After a preliminary assessment is performed, a more in-depth or ***comprehensive assessment*** may be recommended or required. The results of both preliminary and full assessment then need to be appraised, before continuing with mangrove rehabilitation design and implementation.

This is depicted below in the project cycle which has been adapted specifically for mangrove rehabilitation projects.

Mangrove rehabilitation assessment are based upon the following main questions;

1. Who is interested in this mangrove system? What is their concern?
2. What do we want to assess? What indicators need to be measured or observed?
3. How will we make those assessments? What approaches and methods are required? What measurements are optional?

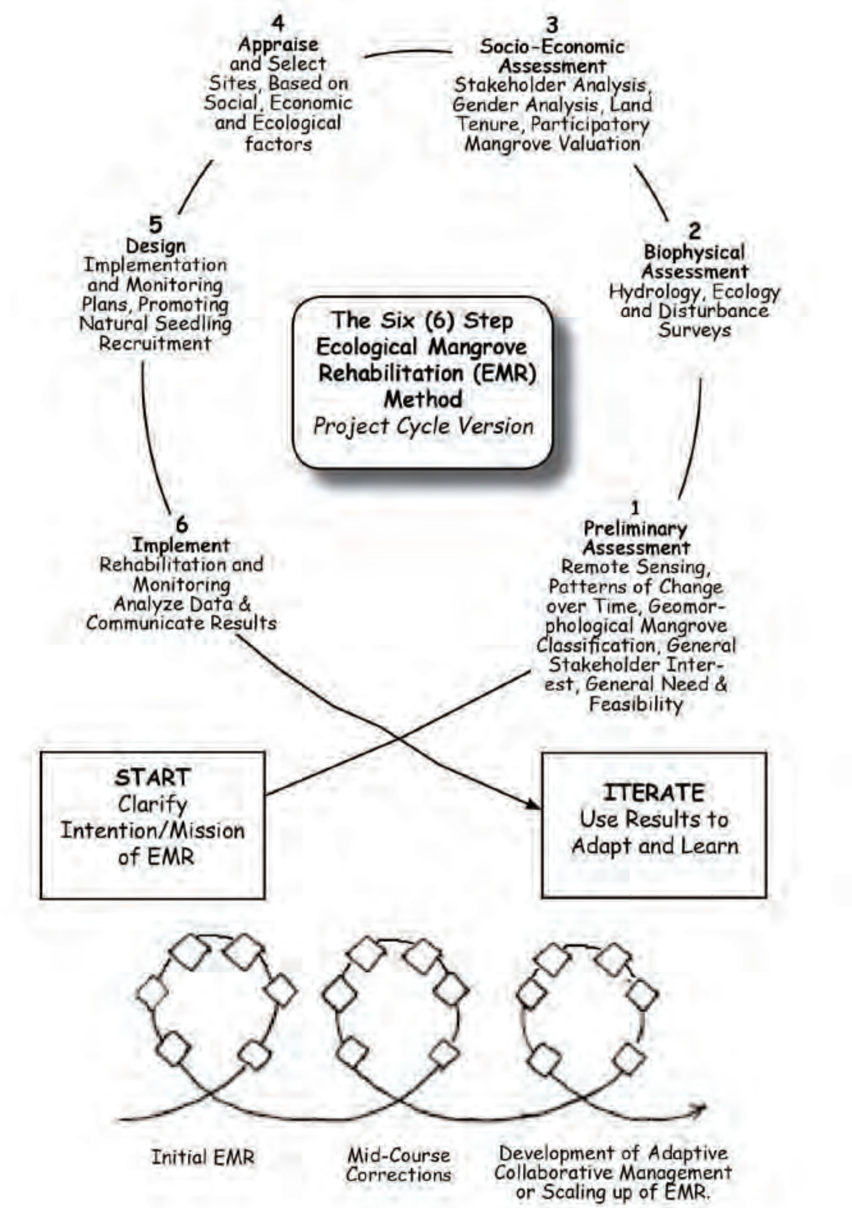


Figure 3.1 - The project cycle. Each step is built upon the previous step, the answers and questions generated by one step, inform and shape the next level. (note – use the EMR specific project cycle).

4. Where do we want to make our measurements and observations? Is there an adequate reference forest available? Do we need to re-create a model of the mangrove forest in the past?
5. When do we want to make our measurements and observations?

3.3 Preliminary Assessment

A preliminary assessment often includes looking at one or a series of remote sensing imagery such as aerial photos or satellite images, to begin to understand the extent of mangrove degradation, change over time, the proximity to a natural source of seedlings and or reference forest. Looking both upriver and out to sea will also reveal local land uses, which should provide a focus for the development of questions that need answers.

- ✓ Is there obvious disturbance to the mangrove forest?
- ✓ Was the area in question indeed a previous mangrove forest? Or has an afforestation (planting mangroves where there were never mangroves before) project been suggested by some stakeholder?
- ✓ Are there any obvious disturbances to the ways in which water flow in and out of the mangrove area?
- ✓ Where are nearby communities located, are there any clear community impacts on the forest?
- ✓ What are major nearby landuses?"
- ✓ Is there any large industry nearby or agricultural/aquaculture lands?
- ✓ Are they these landuses encroaching on the mangrove forest?
- ✓ Are there any clear patterns of sedimentation or erosion evident?

Once potential assessment sites have been identified, a mangrove walk may be the next step. This can initially be undertaken in a rapid and qualitative manner, still falling under the category of preliminary assessment or as part of a more comprehensive assessment.

This preliminary assessment method will be covered in Chapter 4.

3.4 Comprehensive Assessments - Biophysical and Socio-Economic

This step in the program is often a more organized and focused approach that builds from the questions addressed in the preliminary assessment. The purpose of assessment is to determine, through measurements, observations, interviews and discussions

- whether there is a mangrove degradation problem,
- the sources of the problem,
- interest in resolving the problem,
- and the overall viability of mangrove rehabilitation.

In this manual, Chapter 5 will cover comprehensive biophysical assessments, while Chapter 6 will cover comprehensive socio-economic assessments, both of which will inform rehabilitation design and implementation.

3.4.1 Biophysical Assessments

Activities in Chapter 5 describe various approaches to measuring and observing biological and physical characteristics of both the rehabilitation site in question as well as nearby reference mangrove forests. This includes studies of ***ecology*** (vegetation, habitat, fauna, edaphic conditions), ***hydrology*** (size and shape of tidal channels, erosion/sedimentation patterns influencing tidal inundation and frequency, substrate height), and ***disturbances*** which inhibit mangrove establishment and healthy growth. From these activities, more specific questions will emerge. These questions will help determine which indicators to measure to both inform restoration, and also to provide a baseline from which to compare future development of the rehabilitated system.

We also include biological and productivity assessments, which may not be necessary to inform rehabilitation design, but can be useful to the practitioner to prove the value of rehabilitation activities to government or other stakeholders.

3.4.2 Social-Economic Dimensions of Assessment

Chapter 6 will take us through the process of assessing socio-economic factors of the local community and other relevant stakeholders. The following questions address the other important aspect, alongside the biophysical nature of the mangrove forest, that helps determine the direction a mangrove rehabilitation program will take; the social dimension.

- Who cares about the state of the mangroves?
- Who currently has access to and control over the mangrove/intertidal area? Is this in the form of ownership or customary use rights?
- Who are the marginalized and powerless members of the community?
- Who should be involved in rapid surveys? Longer term assessments?
- What government policies exist, at all levels, that impact on the mangroves?
- Are there conflicting policies? Overlap in government jurisdiction?
- Where does the power currently lie in the community?

- Who will use the survey/assessment measurements? What type of quality needs do they have for the data?
- Do community groups exists? To what extent is community organizing required?
- What are the resources available to the group?
- What is the general skill level in terms of taking measurements and interpreting observations? To what extent is training or capacity building required?
- What is the community's level of experience with mangrove resources?
- What is the value of the mangrove resource to the local community?
- What is the value of in-tact mangrove resources?
- What are the levels of economic welfare in the local community?
- What are economic priorities of the community? Other stakeholders?

The information uncovered in both Biophysical and Socio-economic assessments will provide the foundation for planning a rehabilitation program that is at an appropriate scale and that seeks to answer the right questions.

The assessment activities and approaches chosen will be based upon the physical character of the mangrove, the skill level of the group, others who might use the data or observations and the resources available to the group.

"Where" to make measurements and observations is based primarily upon the area defined in the preliminary assessment. "When" to make measurements and observations is influenced by the time schedule of interested stakeholders, seasons (wet and dry), tide schedules and other factors.

Given an understanding of the existence of problems which impede natural mangrove growth, the sources of these problems, the level of community interest and the viability of rehabilitation, it is then possible to plan for and take effective action, described in Chapters 7 (project design) and 8 (implementation).

3.5 From Assessment to Action

An assessment program often generates another set of questions that generate another round of measurements and observations that lead ever closer to defining the sources of the problem or issues to resolve. The questions under the action-taking step include: What are the root causes of mangrove degradation (definition of the problem)? Who is affected by the problem? (people, animals) Who is responsible for the problem?

The transition from observations and measurements to interpretation of the data and definition of the problem is critical. Only then is it possible to create an informed design to address the roots causes of mangrove degradation. Rehabilitation may cer tainly be one outcome of this process. But it is equally likely that rehabilitation will not be recommended. There will almost certainly be additional actions required to address the root causes of destruction.

Some of these include;

- Short to medium term livelihoods support to relieve community pressure off of mangroves.
- Policy amendment to offer a greater degree of protection to mangroves.
- Focused community awareness building, oftentimes requiring a specific gendered approach.
- Environmental education for youth to ensure long-term understanding of mangrove resources and develop an ethic of appreciation, protection and sustainable utilization.

Chapters 7 and 8 are dedicated to moving from assessment to mangrove rehabilitation implementation and other forms of action taking, by going through a planning process and then discussing implementation.

3.6 Model Programs

Several case studies are provided in Chapters 8 on Implementation and Chapter 10 to show how different stakeholders have approached the issue of mangrove degradation. EMR was originally laid out as a 5 step process, the first three of which were of an assessment nature (Ecological Assessment, Hydrological Assessment and Assessment of Disturbances). In the model program from Tanakeke Island, South Sulawesi, MAP - Indonesia found that between 18 – 22 distinct steps were required in undertaking EMR alone, without considering additional programs such as livelihoods, community based coastal resource management or environmental education. What is clear in all approaches, is that a significant amount of time and resources dedicated to assessments (social and ecological), greatly improves the quality of the program and the likelihood of success of the future action.

The moral of the story is that you need to do your homework, in the form of assessments, before taking action.

3.7 Costs of Restoration

The actual cost of mangrove restoration are rarely reported or documented. Lewis (2005) summarizes most of what we know about costs, but these are largely costs within the USA. Costs of projects outside of the USA are usually lump sums for a project which may include significant overhead (office costs, travel, accounting) costs. Where they are reported, they need to be broken down into various categories such as institutional overhead, planning, permitting, land acquisition, planted mangrove costs if used, labor, machinery costs if used, surveys, engineering, monitoring and reporting.

For example typical constructed mangroves in Florida cost USD $125,000 per ha, and even simple hydrologic restoration is about USD $25,000 per successful ha due to high design, permitting and monitoring costs. These costs can be reduced significantly (to say USD$100-1,000 per successful ha) where extensive mechanical excavation is not needed and extended permitting time frames and requirements do not exist or can be reduced.

Why worry about costs? There is only a limited amount of money for mangrove restoration, and wasting it on projects that do not work, or paying more than is needed to achieve successful mangrove cover over time just wastes those limited funds. All mangrove restoration projects should have as one of their goals to achieve "cost effective and successful restoration." Too often, project funds are made available and spent without proper accounting for what was achieved at what cost. Each project provides the opportunity to learn where funds are best spent, and where expenditures are not needed. Construction and operating a nursery for mangroves is a common initial expenditure without determining in advance if volunteer mangroves might come into a project site and eliminate the need for a nursery.

If growing and planting nursery grown mangroves is defined not necessarily as an essential part of the successful restoration of an area, it may be identified as an important educational tool, or as an essential part of a community based effort where local fisher

Figure 3.2 - Demarcating Mean Sea Level as part of an EMR training.

folk wish to help a project along. That is fine as long as the costs to build a nursery and grow mangroves for these purposes does not take essential funding away from efforts like careful site selection, hydrologic restoration, or monitoring and reporting.

How should costs be reported? It should never be a cost per seedling, as that implies planting. It should be cost per ha of successfully restored mangroves over five years, which likely produces only about 1000-2000 viable trees per ha in the long term (20-40 yrs) (but that can be as low as 500). USD $1,000 per ha is reasonable if some design of an EMR project ***has already taken place***, or the people in charge are well trained in EMR. The larger the project, the lower the per hectare costs (down to USD $100 per ha for projects over approximately 1,000 ha). All these numbers are ballpark estimates, and every project has individual circumstances, like resolution of land ownership and use issues which can increase the time and costs. Monitoring costs are not included here, just actual restoration costs.

Remember it is mostly hydrologic restoration that is needed with plantings only for education or to encourage community based involvement, which is fine.

4

PRELIMINARY ASSESSMENT

4.1 Introduction

A mangrove ecosystem is an area where fresh water meets sea water in a semi-protected coastal environment. The dominant vegetation of this ecosystem are mangrove trees which are specially adapted to live in this specific environment of variable salinity, tidal inundation and water-logged soils. It is useful to begin a mangrove action project by studying the interactions of land and sea, and the patterns of water flow in and out of a mangrove area (part of the area's hydrology) as a whole, before examining parts of the system. To understand how human activities impact the mangrove ecosystem, it is best to observe first the physical characteristics of the mangrove area. By taking a bird's eye view of the mangrove forest through topographic maps and satellite images, it is possible to grasp the physical complexities of the mangrove ecosystem before visiting the actual forest.

Remote sensing is the acquisition of information about objects by way of sensory devices which are remotely situated, such as in airplanes and satellites. Remote sensing has proven to be a powerful and valuable tool for analyzing mangrove forests and land-use practices within and adjacent to mangrove areas. Aerial photographs and satellite images are useful in the detection and analysis of threats to the mangrove forest. The relationship between adjacent land use and mangrove forests as well as information on floods, droughts, deforestation, green-belt width for storm protection, wave patterns and agricultural/aquacultural development and practices are increasingly monitored through remote sensing.

The two major forms of remotely sensed data are aerial photography and satellite images. Both have benefits and drawbacks, and the preferred system depends on what information is needed. There are some universal strengths and weaknesses associated with both methods of remote sensing. Remote sensing allows large scale monitoring of the environment. A single image can cover an entire mangrove forest, allowing the user to see the "big picture" and to monitor a large area instead of small individual areas. Of course, the larger the area imaged, the lower the resolution, or detail will be. The spatial resolution of satellite images is measured in units called pixels, which are the smallest pieces of information that can be detected. The resolution and common scales of some common satellites are as follows:

Satellite	**Resolution**	**Preferred Scales**
LandSat ETM	28 meters	1/50,000
Spot 5 Colour	2.5	1/30,000
French Spot 2, 4	10 meters	1/25,000
IRS ID Pan	5	1/15,000
IKONOS	?	1/5000
Quickbird	?	1/10,000
Google Earth	?	

IKONOS and Quickbird are two types of satellite images which are usually good for specific site management plans, for instance for planning hydrological/ecological mangrove rehabilitation. The recent liberation of satellite images by Google Earth has democratized the use of remote sensing. A specific guide outlining some of the more basic uses of Google Earth for EMR is provided in this manual as an appendix.

Another major advantage of remote sensing is that it can detect a much wider range of the electromagnetic spectrum than the human eye can see. Various sensory devices can detect information about objects in the ultraviolet, visible and infrared wavelengths. For example, IKONOS satellite images with a very high spatial resolution of 1 meter are being used to distinguish between mangrove species in Sri Lanka Not only is this an advancement for the monitoring of forests, it is even more important considering their patchy nature in Sri Lankan mangroves (in contrast to classically zoned forests). The presence of species such as *Acrostichum aureum* can also be detected from IKONOS imagery, which is important in the early warning for cryptic ecological changes (Dahdouh-Guebas et al. 2005) that may affect mangrove species composition. The highest resolutions (as in pan-sharpened multi-spectral composites) remain invaluable for visual ecological investigations. Advancements such as this may serve many management purposes, not the least in prioritizing and planning for mangrove rehabilitation if needed.

Another limitation is the cost of purchasing the imagery. Government offices, planning bodies, international NGO's, and universities often have aerial photographs or satellite images than may be available for class use (especially slightly older imagery). After the Indian Ocean tsunami, many international agencies have made satellite imagery available for greenbelt rehabilitation works. A list of contacts for provision of free satellite imagery has been attached as an appendix. Moderate resolution imagery is available for free from Goggle Earth, but the higher resolution imagery (Google Earth Pro) is available only by paid subscription at about $USD400 per year.

Activities 4.2 - 4.5 ahead focus on the implications of changing land-use practices on the health of the mangrove system. Activities 4.6 and 4.7 seek to answer the questions: How large is the functional mangrove area? Where are the boundaries of the mangrove? Who own the mangroves? Who has jurisdiction over the mangrove forest? How has the mangrove and surrounding area changed over time?

Activities for this section are listed below:

Activity 4.2 A Bird's Eye View of the Mangrove Forest
Activity 4.3 Mangrove Greenbelts
Activity 4.4 Changing Land Uses Over Time
Activity 4.5 Community Mapping of Mangrove Forest
Activity 4.6 Mangroves and People
Activity 4.7 Perimeter, Land Ownership and Management Status Mapping

Additional Section
- Appendix X - Using Google Earth for EMR (end of manual)

Activity 4.2 A Bird's Eye View Of The Mangrove Forest

Objectives
- ✓ Learn to interpret aerial photographs and satellite imagery.
- ✓ Develop a basic understanding of the structure of mangrove forests.
- ✓ View the mangrove forest holistically.
- ✓ Gain comprehension of mangrove forests, inflows/drainage/discharge, tidal creeks, rivers and estuaries.
- ✓ Gain basic comprehension of mangrove hydrology.

Materials
Digital remote sensing imagery, LCD projector and/or copies of satellite images or aerial photographs, topographic maps of coast (if available), markers or crayons, and pencils.

***Time*:** Approximately 45 minutes.

Background Information
This activity is designed to provide students/workshop participants with a foundation of knowledge of mangrove forests and hydrology. It is important to understand the basic structure of a mangrove forest to fully understand the processes and factors that control the mangrove ecosystem. Aerial photographs and satellite imagery offer an opportunity to view the mangrove forest as a whole entity. Through looking at images of the whole mangrove forest, participants will gain comprehension of mangrove forests, inflows/drainage/discharge, tidal creeks, rivers and estuaries.

Procedures
1. Use an LCD projector or provide multiple copies of an aerial photo/satellite image of a local mangrove forest so that everyone can follow along with the activity. Also hand out topographic maps of the coastal area so that students can write in characteristics of the forest as the activity progresses.

2. A mangrove begins at its terrestrial edge and continues down to the river-bank, estuary, lagoon or coast. Mangrove forests rely on a mix of fresh water coming from land and salt water from the sea. Fresh water sources include streams and rivers, ground water and rain water. The resulting water is brackish and is heavily influenced by the tides.
3. On the satellite image, see if you can locate sources of freshwater and salt water.
4. Tidal creeks assist the flow of water in and out of a mangrove area. Tidal creeks begin at the landward edge and widen as they meander toward the sea. Note the position and shape of tidal creeks on the satellite imagery. Are they straight like ditches or curved like natural rivers?

Activity 4.3 Mangrove Greenbelts

Objectives
- ✓ Learn about the functions of a greenbelt.
- ✓ Learn about local legislation affecting the width of the greenbelt.
- ✓ Measure greenbelt widths using remote images and compare with legal minimum greenbelt widths.

Materials
National laws, local ordinances on greenbelt sizes. Copies of satellite images or aerial photographs with scales. Markers or crayons, and pencils. Calculator.

Time Approximately 30 minutes.

Background Information
Much has been made of the importance of greenbelts since the Dec 2004 tsunami which devastated coastal areas around the Indian ocean basin. Although empirical evidence is lacking that an intact mangrove greenbelt can confound a tsunami, there is no doubt that a vigorous greenbelt helps to remediate potential damage from both wave and storm.

Each country has its own set of laws to determine the extent of obligatory mangrove greenbelt in natural mangrove areas. Common figures in the region are similar to Indonesian law which stipulates a 200 meter greenbelt depth along the coast and 50 meters along major rivers. In some cases a formula is used to determine the breadth of the greenbelt. An ecological formula has been calculated in Indonesia calling for a greenbelt 130 times the difference between the average annual high tide and average annual low tide.

Ex: Where the average difference between the high and low tide is 1.7 meters the prescribed greenbelt depth is: 130 x 1.7m = 221 meters.

In this activity, participants will measure greenbelts both along the coastline and rivers and compare their findings with national laws or local ordinances.

Procedures
1. Work in small groups with images of your mangrove area.
2. Determine what local and national laws state regarding mangrove buffers along the coast and major rivers.
3. Determine the scale of the remote image. For this example we will use a 1/5000 scale.
4. Using a 1:5000 scale, means that every cm on the image equals 500 meters.
5. This means a 200 meter greenbelt will be greater than 0.4 cm (4 millimeters)

$$\frac{200}{500} : \frac{x}{1} = 0.4 \text{ cm}$$

and a 50 meter greenbelt will be greater than 0.1 cm (or 1 millimeter)

$$\frac{50}{500} : \frac{x}{1} = 0.1 \text{ cm}$$

6. Begin to measure mangrove buffers along the coastline and river banks if possible. Locate areas on the map where buffer sizes are in conflict with local/national laws.
7. Areas where the greenbelt seems inadequate can be ground-truthed. Bring a GPS unit, measuring tape and a digital camera to the field site, and begin to collect evidence of inadequate coastal buffers.

Discussion Questions
1. What functions do coastal greenbelts serve?
2. Are the majority of coastlines and rivers in your area adequately protected by a greenbelt?
3. Why are some greenbelt areas not intact?
4. Do you have the political approval to rehabilitate the coastal greenbelt?
5. Do you have the technical capability to rehabilitate the coastal greenbelt?

Activity 4.4 Changing Land Uses Over Time

Objectives
- ✓ Study different land uses in the mangrove area
- ✓ Develop an understanding of how land use affects the mangrove forest
- ✓ Gain awareness of human impacts on the mangrove forest and associated fisheries.

Materials
Laminated copies of an aerial photograph or satellite image depicting a local mangrove forest. Transparencies, clear tape, pens.

Time Approximately 30 minutes.

Background Information
Most people think of mangrove forests as coastal ecosystems, and this is true, but since mangrove forests rely on a consistent fresh water influx, land based activities which im- pact fresh water sources also have a large impact on the mangrove. Farming activities, road or even footpath construction, housing development, aquaculture development and other land uses can alter the regular flow of freshwater into the mangrove. Deforestation in the highlands behind a mangrove forest may have a deleterious effect as well on mangrove health, as deforested uplands show an increase in run-off and decrease in infiltration to the aquifer, mangroves which once received a steady flow of fresh water will experience fresh water floods after rain events and longer dry periods due to empty aquifers.

More directly affecting mangrove forests are land-use decisions which lead to the con- version of mangrove forests to other ecosystems. Due to short term thinking, man- grove forests are converted to industrial shrimp farms, oil palm plantations, or are clear cut for charcoal making. Mangroves are also often converted for development projects such as housing, airports, harbors, hotels etc. These conversions largely ignore the multiple long-term economic benefits and environmental services that mangrove provide such as fisheries production, non-timber forest products, waste water treat- ment, storm and wave protection and erosion control. The following exercise has been developed to examine what land-uses are taking place in and around your local man- grove area. Identification of various land-uses is the first step in making informed future land-use decisions.

Procedures
1. Work in pairs or larger groups, depending on the availability of images.
2. Place a transparency over the part of the image that includes your mangrove area and tape it down.
3. Once you have the transparency properly placed, outline your mangrove forest.
4. All around the mangrove forest label the different land-uses that you can detect from the photo.
5. Locate your community on the map if visible. How close is it to the mangrove?
6. Denote any land-uses occurring within the mangrove forest such as aquaculture pond, or charcoal production area.
7. How might the different land uses in and adjacent to the mangroves affect the mangrove forest? Look especially at the vegetation, development and blockages of water flow.

Discussion Questions
1. Discuss the effects on the mangrove forest of noted land use changes in and behind the mangrove. Which changes would be most detrimental to the health of the mangrove forest?
2. How have land use practices changed in and around your mangrove in the last 10 years? 20 years? 30 years?
3. What has been the effect of these land use practices on the health of your mangrove? On the fisheries of the mangrove?

Activity 4.5 Community Mapping of Mangrove Forest

Objectives
- ✓ Map the boundaries of a local mangrove forest
- ✓ Show the locations of the tidal creeks, and water inflows/outflows that enter your mangrove.
- ✓ Locate significant natural features in and around your mangrove
- ✓ Illustrate major land uses in and around your mangrove forest.
- ✓ Determine access, land ownership and land use permissions in for the mangrove area.

Materials
Geographic survey maps, road maps, topographic maps, land-ownership data, transparencies, pencils, crayons or colored pencils, paper (preferably tracing paper), Activity 1.4 data sheet from Appendix A. (The map should include the entire mangrove forest to be studied).

Time Approximately 80 minutes.

Background Information
The first step in a mangrove action project or rehabilitation project is to define the boundaries of the mangrove forest. The health of the mangrove forest is also directly linked to the land and use of the land that surrounds the mangrove forest and resultantly affects the flow of water in and out of the mangrove system. This expands the concept of a mangrove forest to that of the actual area where mangroves are growing, plus the surrounding land area that affects the health of the mangrove forest. Extending this paradigm, we see the mangrove forest as part of the larger watershed which flows from mountains to sea. There is increasing attention given to this whole watershed approach.

Due to global warming and resultant sea-level rise, there is also much talk of mangrove migration inland. As coastal mangroves become inundated with sea water, mangroves are migrating inland in cases where there is room for landward movement. In this exercise, we will draw the boundaries of the actual mangrove forest as a management unit, but also draw in the areas that affect the future of the mangrove. This will allow us to contact the appropriate agencies with jurisdiction and land owners of the areas that need to be managed in the present as well as the future ensure the long-term survival of the mangrove forest.

Procedures

1. Locate your local mangrove on a survey map or road map and find the corresponding area on your satellite photo.
2. On the satellite photo, differentiate between mangrove trees and terrestrial vegetation if possible. If this proves difficult look for roads on the satellite map or if roads are not visible, look at the survey or road map and note the position of roads or other landmarks.
3. Try and draw a line around the entire mangrove area which will separate the mangrove forest from terrestrial areas.
4. Calculate the area of your mangrove from the map: Make a grid on a transparency with boxes 1 cm x 1 cm. Place the grid transparency over the mangrove forest area. Count the number of boxes covering the mangrove area. Determine measurement of distance on the map by using the map and its scale. To find the area, multiply the centimeter scale by the number of boxes (#1 on Activity 1.4 data sheet in Appendix A).
5. Trace the visible tidal creeks running through the mangrove area. Count these and record on the data sheet.
6. Record the names of any major rivers.
7. Record any other place names that can be determined.
8. Use your own and other people's knowledge of your region to identify on the map the major land uses within and surrounding the mangrove forest. (General Development Maps and Zoning Maps, available from county and township governments are helpful in identifying land use. For this activity you may want a larger view of the mangrove area including parts of the mid or upper watershed.
9. Record on the data sheet the area percentage of the land uses. You can use the tracing paper with various colors representing the various land uses. Major land uses may include aquaculture, agriculture, urban/suburban, industrial, mining, logging, forested, reserve, etc.

Use the grid transparency to help calculate percentages of land use. Calculate the total mapped area, then count the boxes under a specific land use. To determine a percent land use, divide the total mapped area by the specific land use.

Ex. Total mapped area = 600 $cm^{2.}$
Area under aquaculture = 85 cm^2 (85 boxes)

85/600 = 0.1416666 = 14 %

10. Determining ownership of the mangrove and surrounding land area is an activity which may potentially cause conflict. The situation will differ in each region. Oftentimes, a user or developer of the mangrove will not have official permission or will have permission from a government agency that does not actually have jurisdiction over the area in question. Resolving land use and ownership issues needs to be done carefully, but is important to providing long term security to a mangrove rehabilitation or management initiative and also in providing benefit to a larger swath of society, namely local fisherfolk communities.

    Determining and mapping land ownership/land use may be a separate activity. Participatory, community mapping is a common strategy to expose and resolve land ownership issues/conflicts.

11. Locate or draw on the map significant features (including forests, salt pans, mudflats, rivers)
12. Locate or draw on the map additional hydrologic features such as weirs, trenches, canals, dike walls, drainage pipes etc.
13. The finished map will be useful as a start to any mangrove action or restoration project.

Discussion Questions

1. Where does the water for your mangrove forest come from? Do streams and rivers flowing into the mangrove flow all year? Are there historical creeks that no longer flow into the mangrove forest due to blockage? Are there other alterations to the natural flow of water into the mangrove area?
2. What are some of the major land uses in and around your mangrove forest? How might these different land uses affect the mangrove.
3. What are the percentages of land use types in the and around the mangrove forest? Do land use changes occur as you move from the upper watershed to the mangrove?
4. Which government agency or agencies have jurisdiction over your mangrove forest? What do you know about these agencies? Are they actively managing the mangrove forest? Is there an opportunity for community involvement in mangrove management?
5. Which government agency or agencies have jurisdiction over the areas surrounding your mangrove forest? Are they in coordination with the agency/agencies in charge of the mangrove forest?
6. Are there any private land-owners with claims inside of the mangrove forest? If so, are these claims legal?
7. Who owns the land immediately behind the mangrove forest on the landward edge? Are their activities disturbing the health of the mangrove forest?
8. How would human activities in one part of the mangrove or adjacent to the mangrove affect the health of the mangrove? For example, how does land based agriculture affect the mangrove forest?

Activity 4.6 Mangroves and People

Objectives
- Develop interviewing skills
- Design a questionnaire
- Compile the results of interviews and piece together the history of the mangrove forest.

Materials
Pencil, paper, tape recorder (optional).

Time
Approximately 80 minutes class time; 40 minutes to design questionnaire and 40 minutes to discuss results (Participants should do the actual interviews outside of class).

Background Information
Mangrove forests are the focal points of human activity around the world. People who live close to mangrove forests come to know them intimately. Fisherfolk communities especially have watched and interacted with the mangrove forest and its inhabitants for their entire lives. Fisherfolk have knowledge about the mangrove and local community just waiting to be tapped.

In this activity. Students will interview fisherfolk to learn more about the mangroves. History comes alive through interviews. Discussions with real people about their impressions and experiences with the mangrove forest is often much more meaningful than reading a book, article or viewing a video or film. It will be useful to have the data sheets from Activity 1.4 on hand when performing the interviews.

Procedures
1. Have students work alone or in groups to develop a series of questions they would like to ask someone about the mangrove forest. Below are some sample questions.
    - How long have you lived in this area?
    - What do you remember the mangrove forest being like when you were a teenager?
    - Did you use the mangrove forest in different ways than it is used now?
    - What are your hopes for the mangrove forest in the next 50 years.
2. Have students interview several people about the mangrove forest (they can do this as a homework assignment over a weekend or overnight in the case of a workshop). The following suggestions will help students to conduct an effective interview.
    - Try to interview older people, who may have a lot of knowledge about local history. Family members and neighbors may be a good place to start in recruiting people to interview.
    - Inform the person you are planning to interview of the purpose of the interview, how long it will last, and how the interview results will be used.
    - Give the interviewee an idea of the types of questions you will be asking.
    - Try to draw out specific examples from people who make general statements. For example, if someone were to tell you that they used to catch fish in the mangrove ask them where, during what tides, what kinds of fish, how much, what equipment they used, etc.
    - Role-play interviewing other students/participants before conducting the real interviews.

Discussion Questions
1. Discuss your interview findings as a whole group. How do the student's view of the mangrove differ from the people they interviewed
2. In what ways is the mangrove of today like the mangrove of the past (10, 20, 30, 40 years ago)? How is it different?
3. Were there any common experiences with the mangrove? How did the experiences differ?
4. How did it feel to learn about the mangrove forest from other people?

Activity 4.7 Perimeter, Land Ownership and Management Status Mapping (Required)

Objectives
- Identify and accurately mark the perimeter of the potential rehabilitation site.
- Determine and confirm ownership/use rights of the rehabilitation site.
- Confirm the use status of each area of potential rehabilitation site and confirm areas for rehabilitation.
- Confirm owner willingness to allow rehabilitation.

Output A complete map of area, ownership and status, confirming areas for rehabilitation, with size of each area marked.

Materials
- GPS
- Current aerial photographs of potential rehabilitation site, both laminated and un-laminated.
- Government maps (Dept Forestry, Fisheries, Land Planning)
- Any additional previously created maps of potential rehabilitation site.
- White board markers (different colours).
- Pens
- Notebook

Time 3 days
- 1 day for perimeter, ownership and status interviews
- 1 day to ground truth
- 1 day for map creation

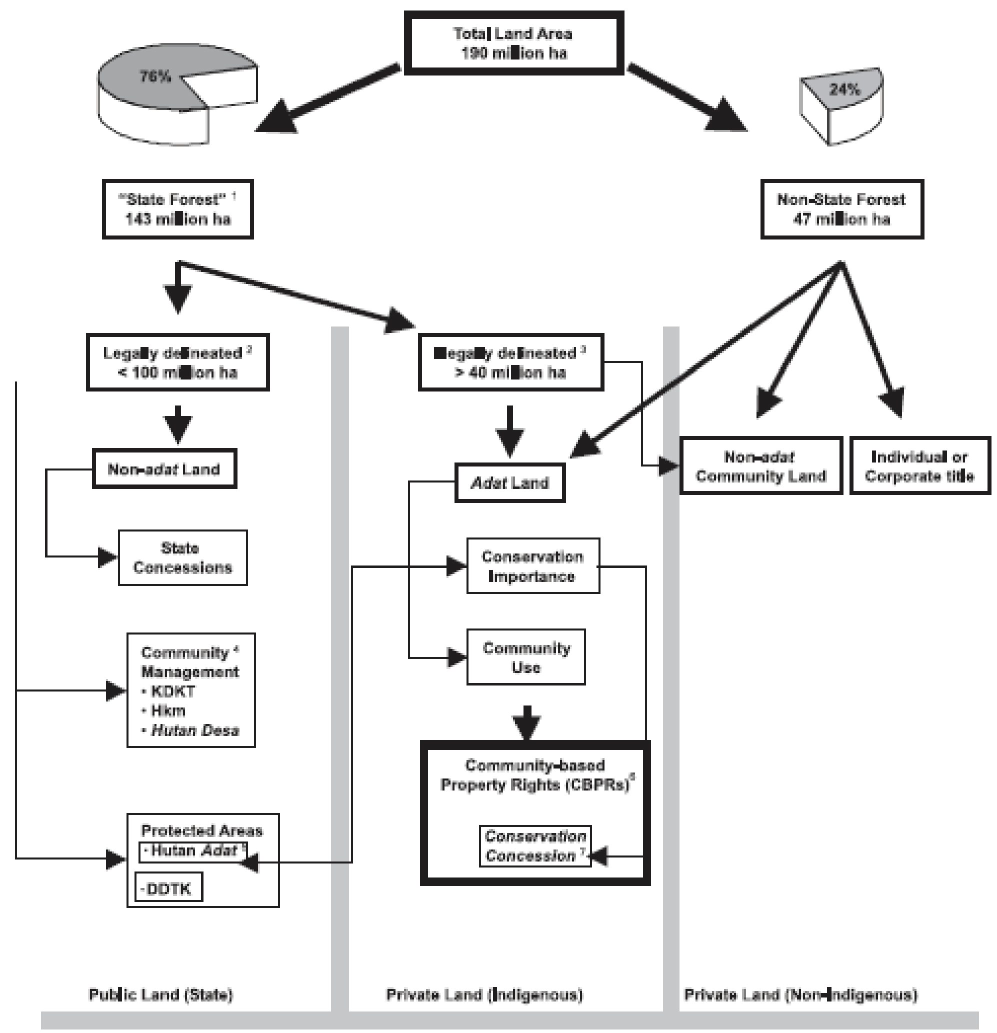
Background Information
With regards to land use and ownership, mangroves are placed in a precarious position between land and sea. They fall in the jurisdiction of various agencies, from technical agencies such as forestry and fisheries departments, to various levels of governments from village, municipal, district, provincial or national levels. To add to the confusion, some mangroves are individually owned, by numerous small-holders or conglomerated into the hands of one or very few wealthy landowners.

Lack of clear policy on mangrove jurisdiction in no small part has resulted in large-scale degradation. It also makes it extremely important to resolve land ownership and use issues, to the extent possible, before attempting rehabilitation. As this manual has a pro-community bent, we strongly encourage a

mangrove rehabilitation practitioner to consider how to promote improved access to, and control over, mangrove resources by first hand natural resource users (fishers, farmers, community foresters, women, marginalized individuals, the poor) as a major priority.

Figure x, below, depicts various land use and ownership possibilities in Indonesia, as an example of tenure arrangements that need to be considered from the onset of a mangrove rehabilitation program.

Figure x: Possible Forest Tenure Arrangements ex: Indonesia (CIEL, 2002)



Procedures
On laminated aerial photograph identify potential area for rehabilitation. The potential rehabilitation area includes ALL areas owned or managed by the community at hand. Consult with community representatives, village heads, and technical government agencies, to outline borders of community owned/managed land. Mark on photograph.

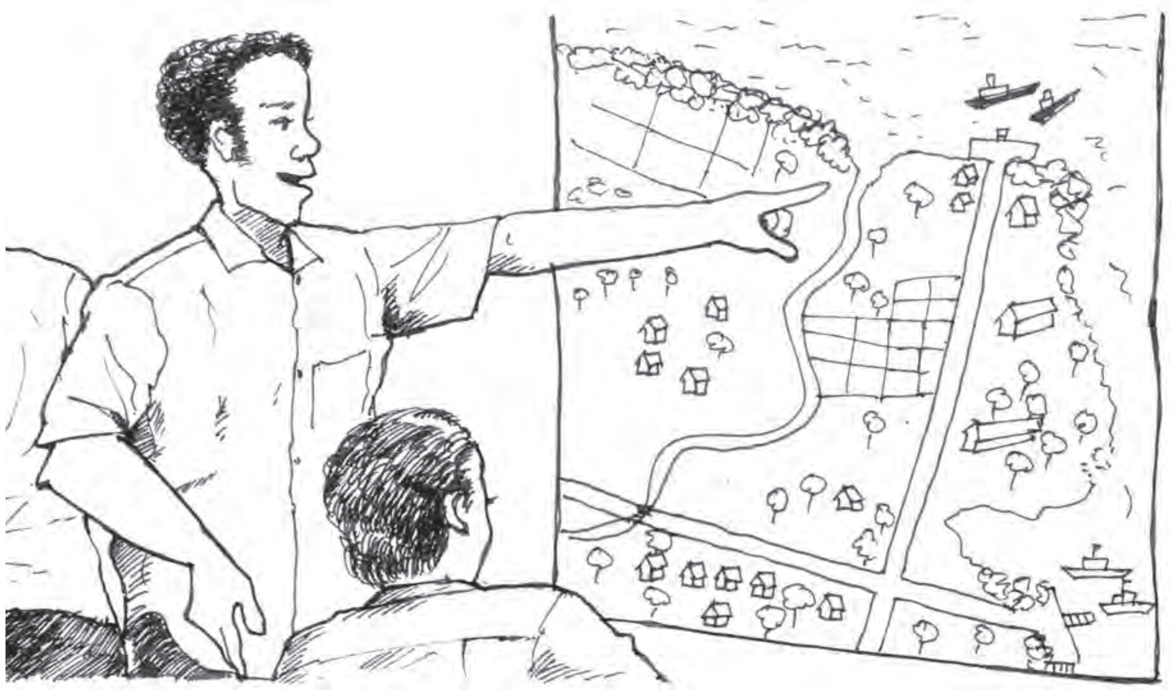
1. Review individual ownership of areas within the community boarder. Mark on photograph.

Currently operated	(red)
Disused but plans to operate	(yellow)
Disused and willing to rehabilitate	(green)

2. Find owners identified in 2., confirm border of individual ownership areas and mark status of each area using the following colour codes:

   After every interview recorded details on a map to avoid any loss of information.

3. Record any issues of ownership/additional information arising from these inter



views in your notebook.

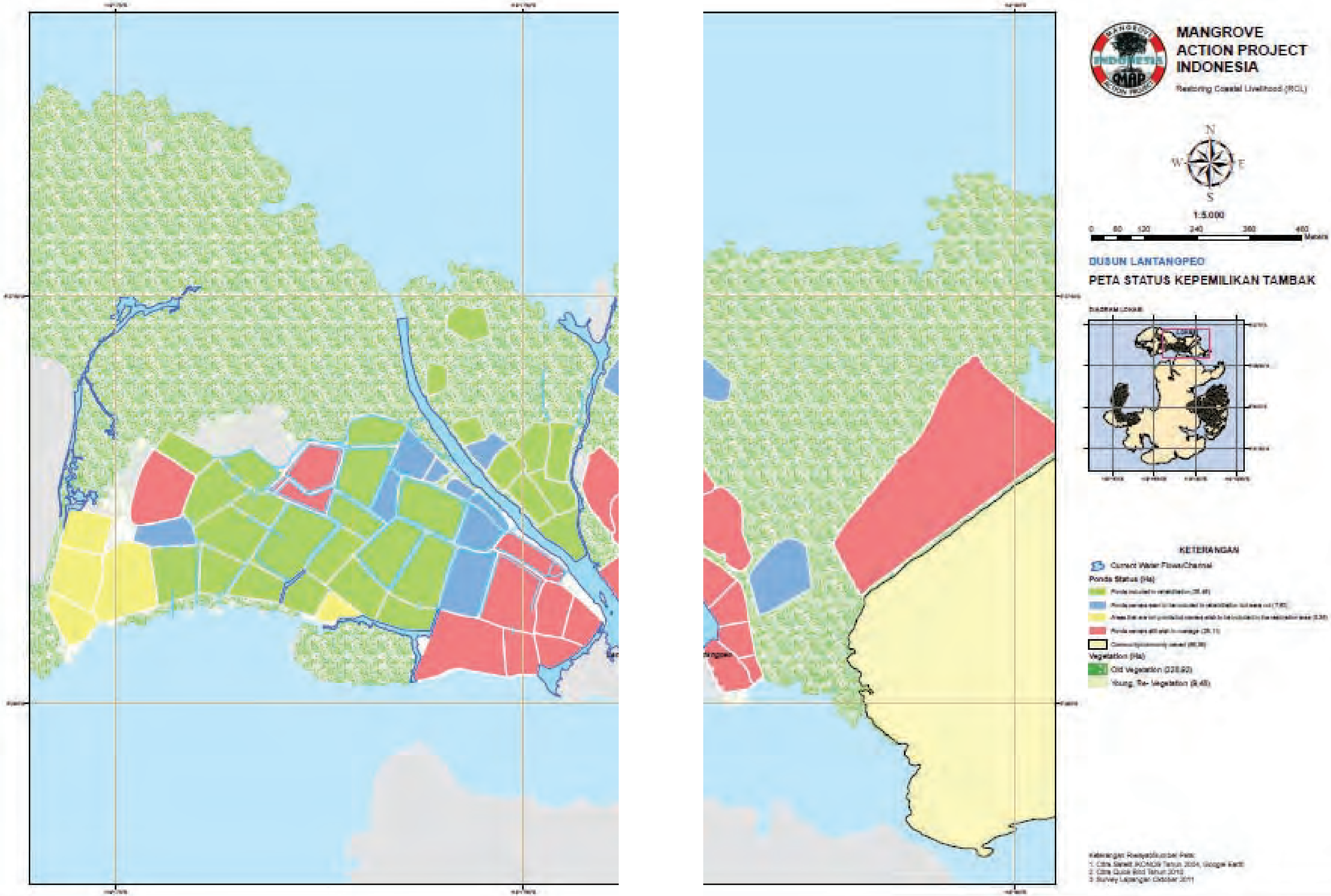
4. If areas within the border are not individually owned (eg. owned by the whole community) mark with the following code:
5. Areas adjacent to areas available to rehabilitation (the green areas) where natural re-vegetation has occurred and the majority of vegetation is still in the seedling and sapling stage, overlay status colours with the following code:
6. Using a GPS, ground truth the perimeter of ponds discussed above, as well as adjacent natural re-vegetated areas.
7. Calculate areas potentially available for rehabilitation in km^2 and mark on map.

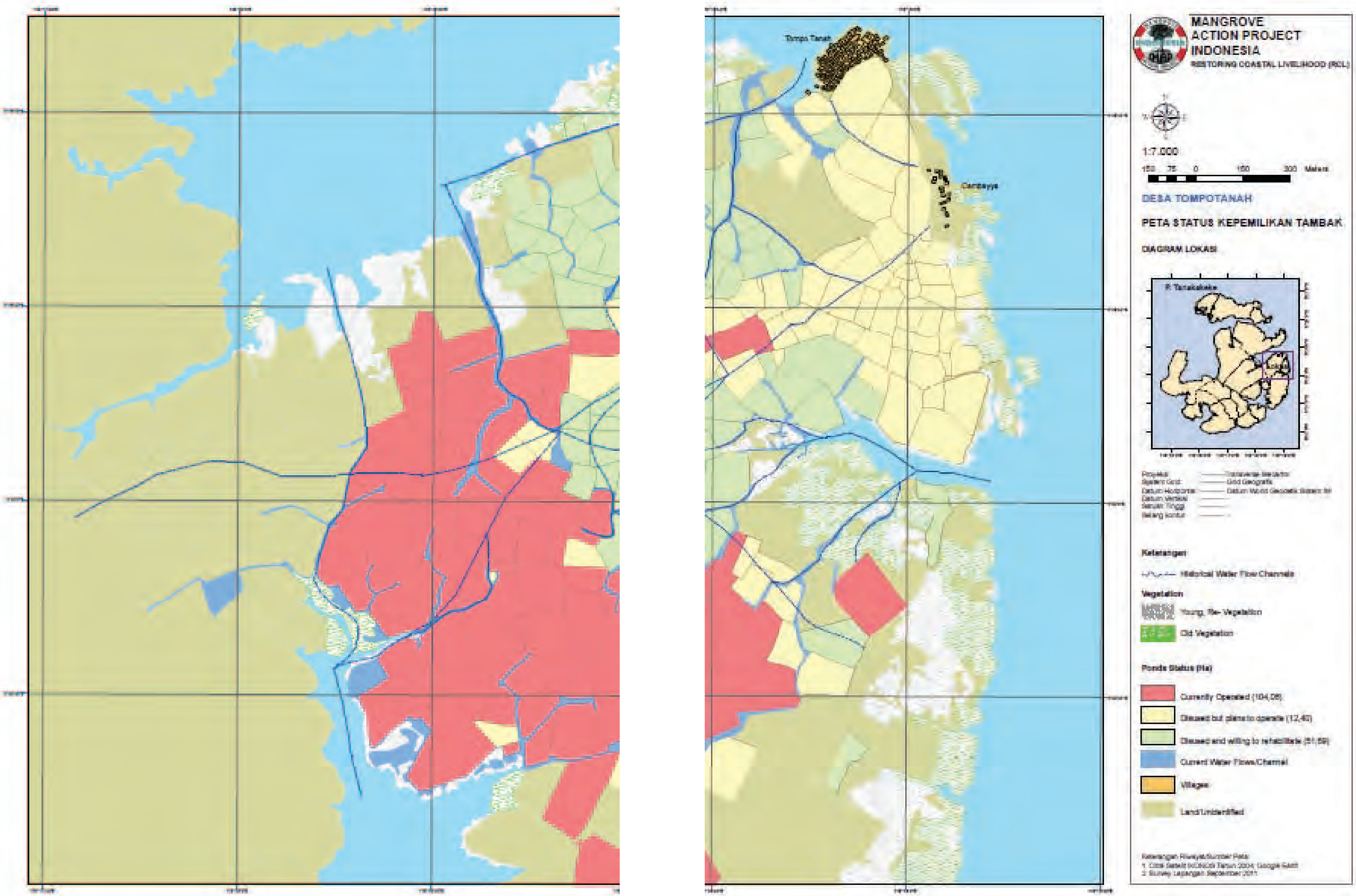
> Make sure the map includes areas surrounding the area to be rehabilitated in faint outline, so land and water channel continuations are visible.

A pair of actual land ownership and status maps are included on the next pages for reference

Discussion Questions

1. What are the difficulties in talking with landowners about relinquishing their ponds for mangrove rehabilitation? What surprised you about this activity?
2. If land use or ownership is unclear, what steps can you take to help bring about clarity? Who else needs to be involved?


MANGROVE
ACTION PROJECT
INDONESIA
Restoring Coastal Livelihood (RCL)
N
W
E
S
1:5.000
DUSUN LANTANGPEO
PETA STATUS KEPEMILIKAN TAMBAK
KETERANGAN
Current Water Flows/Channel
Ponds Status (Ha)
Vegetation (Ha)
Old Vegetation (228,92)
Young, Re- Vegetation (8,45)



Tompo Tanah
Cambayya
MANGROVE
ACTION PROJECT
INDONESIA
RESTORING COASTAL LIVELIHOOD (RCL)
1:7.000
150 75 0 150 300 Meters
DESA TOMPOTANAH
PETA STATUS KEPEMILIKAN TAMBAK
DIAGRAM LOKASI
P. Tanakeke
Keterangan
Historical Water Flow Channels
Vegetation
Young, Re- Vegetation
Old Vegetation
Ponds Status (Ha)
Currently Operated (104,08)
Disused but plans to operate (12,40)
Disused and willing to rehabilitate (51,59)
Current Water Flows/Channel
Villages
Land/Unidentified
Keterangan Riwayat/Sumber Peta:
1. Citra Satelit IKONOS Tahun 2004, Google Earth
2. Survey Lapangan September 2011

5

BIOPHYSICAL EMR ASSESSMENTS

1. **Hydrological Assessments**
2. **Ecological Assessments**
3. **Disturbance Analysis**
4. **Biological Surveys**

5.0 Overview

This chapter provides activities to guide learners in a biophysical analysis of their mangrove area. The chapter is divided into four sections; on hydrology, ecology, disturbances inhibiting natural mangrove growth/regrowth, and finally biological and productivity indicators. Not all of the activities in this section are necessary in order to develop an Ecological Mangrove Rehabilitation plan or design. We have labeled some activities as required, while others are optional.

When undertaking these activities, you may be doing so to inform your EMR design, or also to establish a baseline for future monitoring after the rehabilitation project. Before undertaking the surveys, it will be important to clearly establish your project's goals. If the project is simply one to rehabilitate mangroves, you might not need as many replicates during your surveys. If the project is also intended for academic purposes, or to demonstrate the change in quality or value of parts of the mangrove system, your survey methods will need to be more rigorous, with an adequate number of replicates. Consulting a statistician before designing the surveys will be important.

As it stands, we present basic methods for a variety of surveys, with the caveat that they should be adapted to suit an individual project's needs.

Factors Influencing Mangrove Establishment and Early Growth

Key ecological principles influencing mangrove establishment and early growth were discussed in Chapter 2. To reiterate, of the environmental requirements for mangrove recruitment, growth and healthy long-term functioning, there are eight – major determining factors (Chapman, 1977, Brown, 2007 and Lewis, personal communications and Friess, 2012).

1) temperature, 2) protected coastlines, 3) currents, 4) edaphic conditions, 5) sedimentation patterns, 6) salt water and 7) tidal inundation and frequency and 8) presence and functioning of tidal creeks.

Not all, however, of these factors need to be measured as part of Ecological Mangrove Rehabilitation surveys or monitoring. Activities in section 5.1 focus is on biophysical metrics related to hydrology. The first activity relates substrate elevation to tidal inundations and frequency. The second looks more closely at patterns of sedimentation and erosion. The third looks at tidal creeks, which are essential attributes of a healthy mangrove forest which functions over the long term.

Ecological metrics will be covered in section 5.2. This begins with a study of vegetation; both individual mangrove ecology (autecology) as well as community associations. We also offer a study of edaphic conditions (properties of soil/substrate) in this section. Activities in section 5.3 take a look at disturbance, assessing modifications of the original mangrove environment that currently prevent natural secondary succession.

Section 5.4 contains biological and productivity assessments, which, although not essential to inform mangrove rehabilitation design, are used for creating a baseline for quantifying the success of a rehabilitation effort. Especially useful are measurements of invertebrate and fish populations helps create a baseline by which to monitor ecosystem functioning. Birds and mammals could be added, which also indicate ecosystem functioning, but are not discussed explicitly in this manual. A participatory biodiversity survey is also discussed here – as a way for local communities to increase their appreciation of the richness of their mangrove resource. Tracking changes in productivity, biomass and carbon sequestration and storage are helpful to managers, to demonstrate the economic value of the system.

Section 5.1:	Hydrology Assessments (Sedimentation/Erosion Patterns, Substrate Elevation, Tidal Inundations and Frequency, Tidal Creeks and Channels)
Section 5.2:	Ecology Assessments (Autecology, Community Associations, Edaphic Conditions)
Section 5.3:	Disturbance Analysis
Section 5.4:	Biological Surveys (biodiversity, benthic macro-invertebrates, nekton survey).

Many of the activities relate to one another, building knowledge step by step; however, the activities are also designed to stand alone.

Each activity is written in curriculum style – in order to be useful in a training setting, such as an EMR training or field school. Use the descriptions in the background section to decide which activities to perform, keeping in mind what you hope to accomplish, the skills and needs of the group, how you are going to use the information and available resources such as time, money and equipment. Again, each activity is labeled as recommended or optional. This status was determined by significance to designing and EMR plan, as well as cost and difficulty.

Many of the activities include data sheets, which are found at the end of the Chapter. These sheets provide an easy, organized manner of collecting data, and are meant to be copied and used in the field.

Finally, the findings from the various assessments can be rated on a scale of 1 – 3, and entered into a table of resilience indicators at the end of Chapter 6. To rate an indicator, the condition of the indicator in the rehabilitation site can be roughly compared to the condition of the same indicator in a nearby reference forest. In this way, a practitioner or manager can quickly estimate the progress of the rehabilitation, in order to make changes known as mid-course corrections.

As an example, a tidal creek in a rehabilitation area which is experiencing blockage, or filling up with sediment a year or two after hydrological rehabilitation might be rated a “1” when compared to a normal functioning tidal creek from a reference forest. A manager will understand that the tidal creek might requiring re-excavating as part of mid-course corrections.

As another example, assessments may reveal that after 3 years, all naturally existing mangrove species have colonized an area. This metric would be given a value of “3” and no new work would be required to reintroduce a certain species of mangrove into that area.

Section 5.1 Hydrology Assessments

(Mapping historical and current channels (in rehab site and reference forest), dike walls/breaches and instance of sedimentation, MSL, placement of tidal datums, sedimentation/erosion Patterns)

Overview of Tidal Flows
Towards the beginning of Mazda et al. (2007) describing their exhaustive study of hydraulics in mangroves in their Part I “Outline of the Physical Processes Within Mangrove Systems,” the authors state;

> “Among the various types of water movement within mangrove areas, tidally driven currents are crucially important.”

Mazda et al. (2007) go on to describe in excellent detail, how mangroves are filled and drained with tidal waters differentially (due to friction during the draining process (ebb tide) with roots, trees, etc. It is an excellent and important read to anyone who wishes to delve deeply into the physical mechanics of mangrove forests. What we provide below are practitioners’ observations of tidal flows that can help a practitioner survey a mangrove area in order to design a rehabilitation project.

Healthy mangrove systems owe their functioning to a network of tidal creeks, that flood and drain the mangrove floor regularly. They are an essential natural feature, in particular for ingress and egress of mobile fauna, particularly fish and larger invertebrates (crabs, shrimp). The extent of regular in and out flows of tidal waters, as well as fresh water entering the system from inland (rivers, rainfall and groundwater) and flowing out to sea, is measured as the tidal prism. The tidal prism as it flows through a defined channel indicates the amount of scouring that will take place to keep tidal creeks open, free of debris and siltation based upon the velocity of the water flows.

When the tidal prism is small, the creek may close due to silting and eventual overgrowth by mangroves. This further reduces the tidal prism and thus tidal exchange, and eventually leads to the large die-off of mangroves from either hypersalinity, or excessive flooding by heavy rains or spring or storm tides that cannot drain from the system.

Blockage of tidal creeks through lack of bridges or culvers, inadequate design of culverts or closure of culverts due to fouling are one of the most common causes of mangrove die-offs worldwide. One indicator that a tidal creek is experiencing blockage is build up of sediment in part of the channel. This sediment may be deposited during flood tides, or dur- ing ebbing tides, which will be indicated by the direction in which the sediment is oriented.

Which comes first - the mangrove or the creek? Look at a tidal delta mudflat. First the creeks, then further deposition, then mangroves colonize, but only on higher ground, which limits tidal cover and flows and channelizes the creeks further until a functioning network of tidal creeks is formed. These changes can be tracked over time during a mangrove rehabilitation program.

Some researchers have noted that tidal creeks in New World mangroves tend to form sinuous, braided networks, while mangroves in the Old World exhibit dendritic creek systems; larger channels with smaller branches near to perpendicular to the larger channel, and again smaller perpendicular channels. (Lovelock, Personal Communication)

Fig 5.1 Perpindular tidal creek morphology in Old World Mangroves (left) vs. Sinuous tidal creeks of New World Mangroves (right).

This general morphology of tidal creeks should be kept in mind during a rehabilitation project.

Two activities will be presented related to tidal creeks which will be useful to a mangrove rehabilitation practitioner;

1. Delineating the extent and general morphology or shape of a tidal creek network in a reference forest,
2. Measuring physical characteristics of tidal channels (at rehab site and in reference forest) such as cross-sections, flow/ and total discharge. These measurements are useful for re-creation of tidal channels at the rehabilitation site.

5.1.1 Mapping Extent of Tidal Channels (recommended)

Objectives

- To calculate the extent of a tidal creek network in the study site (historical and present day) and in a reference forest (present day).
- To gain an idea of the morphology of the tidal creek network.

Materials – Mapping Historical Flows

- Large current aerial photograph of potential rehabilitation site, and a local undisturbed reference site, both laminated and un-laminated.
- White board marker.
- Pens
- Notebook
- Bamboo stakes – for estimating tidal path in the field
- Tea & Snacks for community

Time 1 day and 1 evening

Background Information

This activity will look at the extent of a tidal creek network at both the rehabilitation site and a nearby reference forest. As the rehabilitation may have undergone significant alteration, it may be necessary to refer extensively to historical remote sensing images and maps, and also undertake community interviews with community elders. Tidal creeks usually widen as they approach the coast, and may or may not have connections to terrestrial sources of fresh water. The main tidal creek (or river) generally runs perpendicular to the coast, with branches running perpendicular to the main creek. Tertiary creeks may again run perpendicular to the secondary creeks, forming a dendritic network, which floods and drains the mangrove flats. Mazda et al. (2007) discuss the hydraulics of this system in great detail.

A mangrove rehabilitation practitioner may end up creating or restoring a natural looking tidal creek system in the rehabilitation site as part of hydrological repair, thus it is essential to determine where historical tidal creeks used to flow, and also the general extent of and shape of a tidal creek system from a nearby functioning reference forest.

Procedure – Mapping Historical Flows

1. If possible obtain a historical, high resolution map that outlines historical vegetation cover and tidal creeks and evaluate where historical water channels previously existed at the proposed rehabilitation site. Mark as best as possible on the laminated map with white board marker. If it is not possible to obtain a historical/ high resolution map, continue with the below methods.

2. Organize a meeting time in the evening which is best for elders to meet.
3. Identify elders of the village with the community organizers and head of village government. Invite them to a meeting that evening, along with elders already invited during the ownership and use status interviews. Provide tea, coffee and cakes.
4. Begin by identifying major features on an aerial photograph that elders will identify with (eg., the village location, the place where the meeting is held, a big tree that might be known to everyone, ownership of ponds etc., and include any features that might have been identified in interviews of activity 1). It is a good idea to start from the place building where the meeting is held and work your way out from here to the perimeter of the rehabilitation area. Make sure all participants understand the positioning of the photograph before proceeding further.
5. Gain accounts of what this area looked like before disturbance. E.g. Did mangroves grow further out towards the ocean before the disturbance? Was the shape of the area different before disturbance? If so, how?
6. Ask participants to remember where old tidal creeks used to flow prior to disturbance.
7. Record on the map with white board pen. Does everyone agree?
8. Refer back to the historical photograph if available.
9. Invite a group of community elders to go into the rehabilitation area the following morning.
10. Agree on a time for departure.
11. In the field point out landmarks and positioning on maps discussed the evening before. Go to areas of historical tidal creeks identified the previous evening. Mark any changes.
12. Record the historical tidal creeks on a the perimeter, ownership and use status map created in activity 1 using the below symbol:

Historical tidal creek

Materials – Mapping Present Day Flows

- Large current aerial photograph of potential rehabilitation site, laminated.
- Markers.
- GPS

Time: one or two tides from high to low per forest

Procedure – Mapping Present-day Flows

1. A major water flow is classified as any flow of water that is relatively large and its channel is self maintaining i.e. the flow of water on the flowing and ebbing of the tide does not allow for sedimentation to infill the channel.
2. In an ex-aquaculture area, watch the ebbing tide to gain the best view of major water flows. Mark each point the channel passes through a dike wall breach and estimate its course between each breach. Be sure to record major water flows directly outside of the perimeter also.
3. Record on map with the key below:
4. While watching the tide ebb to record major waterways/channels, qualitatively note the relative water runoff and drainage of the area using the following categories:

Major water flow

5. Run off of tidal water: High, low, negligible (evidence of standing water).
6. Soil drainage: good (fast), poor (slow), water-logging prolonged feature
7. If the site has a combination of each category, note the most prominent category.

Analysis

1. Mark a piece of string using the scale on the map (250m, 500m, 1000m)
2. Using the string, calculate the total linear meters of the mapped tidal creek network in the reference forest and the historical flows.
3. Divide this total by 1000 to get linear kilometers.
4. Calculate the total area of the forest in hectares.
5. Divide the linear km by the total number of hectares of the site to arrive at linear km per hectare
6. Calculate the current network of tidal creeks at the rehabilitation site and determine linear km per hectare
7. Compare linear km per hectare of tidal creeks in the reference forest, historical forest and current mangrove rehabilitation area.

Discussion Questions

- What were the difficulties encountered in determining historical flows?
- Were there any difficulties encountered in determining current tidal creek extent in the rehabilitation site? In the reference forest?
- How do the linear km compare between the sites? Explain.

- What were other interesting features or observations of the tidal creek system, in terms of morphology? Flood and ebb?
- What further studies, observations, do you think are required of tidal creek systems to help inform your rehabilitation plans?

5.1.2 Channel Cross Section, Flow and Total Discharge – Reference Forest and Rehab Area (Optional)

Objectives

- Measure the physical characteristics of tidal creeks/channels
- Understand the relevance and impact of physical characteristics.

Materials

Pencils, tape measure, string, several oranges (or similar floating objects), thermometer, stop watch.

Time 2 hours

Background Information

Water flow in tidal creeks fringed by mangroves (i.e., R-type systems) is very different from that in rivers without mangroves (Mazda et al., 2007). The flow in a tidal creek in a mangrove system can be very high, facilitating the inundation of the mangrove forest floor during flood tide, and the drainage of the mangrove forest during ebb tide, which may be much delayed due to the presence of mangrove vegetation causing friction.

There are various ways to calculate this exchange in water, including flow rate, total discharge and calculation of the tidal prism. More important than measurements, are understanding the concept of how a healthy tidal creek system facilitates the long-term functioning of a mangrove forest, by allowing for healthy flooding and drainage, which has effects on the substrate (size of particles, texture, aeration), as well as floral and faunal communities.

Tidal creek flow is also, of course, influenced by water emanating from the mainland, in the form of freshwater from rivers and groundwater. The dynamics of tidal creeks are numerous and can be studied at depth. For the purposes of a mangrove rehabilitation practitioner, it is important to understand the physical nature of individual tidal channels, and the tidal creek system as a whole, when it comes time to repair dysfunctional hydrology (improper flooding and draining). Re-establishment and maintenance of an adequate tidal prism is a general goal of hydrological rehabilitation, to ensure long-term growth and functioning of the mangrove ecosystem.

Procedures

Divide into groups. As there are many tasks in this section, tasks can be divided amongst the groups, with a sharing session at the end. Measurements should be taken during rising and ebbing tides. Times and dates should be noted, and correlated to tide predictions.

1. Record on the data sheet the location of your observation site. Use maps created in previous activities.
2. ***Channel type***: At your observation site is the channel straight, meandering, braided, human made, natural? Check the appropriate box on the data sheet.
3. ***Weather***: Record the weather over the last 24 hour period. Clear, sunny, overcast, rain, showers, storm, etc.) Recent rainfall can affect flow and amount of water in the tidal channel.
   Some helpful definitions;
   - ***Rain*** < .75 cm over 24 hours
   - ***Showers*** 0.76 – 2.5 cm over 24 hours
   - ***Storm*** > 2.5 cm over 24 hours
4. ***Last Precipitation***: record date, amount (cm) and duration (hours)
5. ***Recent Weather***: Record recent weather that may have some effect on the water conditions, especially major storms. Be sure to record the date of this weather condition. Ask fishers and farmers, or consult news reports for aid.
6. ***Air Temperature***: Using a thermometer, measure the temperature of the air in degrees Centigrade.
7. ***Water Temperature***:
   - Lower the thermometer 10 cm below the surface of the water
   - Keep the thermometer in the water until a constant reading is obtained (about 2 minutes)
   - Record your measurement in degrees Centigrade.
   - Take 5 measurements and average them on the data sheet.
8. ***Average Channel Width***: Measure the stream's width from bank to bank at 5 locations along the observation site. Record each measurement on the data sheet. Compute the average (immediately or later).

   Note: If tidal channel is too deep to cross (or there are crocodiles around), you may estimate the channel width using the following width classes; < 2m, 2-5m, 5.1-10m, >10m

9. *Average Channel Depth*: (For shallow channels only) Wade into the channel. Do not go deeper than waist deep. Using a meter stick, measure the depth of the water in 5 locations and record your measurements on the data sheet. You can average this measurement immediately or later.
10. *Surface Velocity*:
    a. Use a tape measure along the channel or streambank to mark a section at least 20m in length.
    b. Position someone at the upstream (depending on direction of tidal flow) and someone at the downstream ends of the marked section.
    c. Release an orange to travel with the direction of the flow along the main current.
    d. Use a stop watch to time the passage of the orange from the beginning to the end of the marked length.
    e. The downstream person should yell when the orange floats by the end point to inform the time recorder.
    f. Repeat this test 3-5 times and average the results.
    g. Save, peal and eat the orange to maintain vitamin c levels.
    h. Calculate the velocity in meters/second and record on the data sheet.

    Velocity = Distance/Time

    Note: An orange works well because it floats more or less in the zone of maximum velocity (just below the surface). However, a similar object may be used.

9. *Bank-full Width*: Most tidal creek surveys are conducted during rising and falling tide, but not at peak high tide. The width of the tidal creek will be reliant on your estimate of where the bank occurs. Some judgment will be required to predict the bank-full stage – which is the point where the tidal creek spills over into the general floodplain of the mangrove forest floor.
10. *Channel Cross Section*: Is your channel rectangular, U-shaped, V-shaped, or other? Please check the box on the data sheet which matches the shape of the tidal creek channel. If you are unable to see the shape of the bottom and banks, please estimate with your best guess. You can base your estimate on the flow of water. The slower the water in the middle of the stream, the flatter the bottom.
11. *Channel Bottom*: What is the predominant inorganic and organic substrate of your tidal creek? Check the appropriate boxes on the data sheet. (see Fig 5.2)
12. *Channel Alteration*: At your site, or nearby, have there been any major channel amendments, such as dredging, straightening, hard-scaping? Are there dams or weirs present? Check the appropriate boxes on the data sheets.

Fig 5.2 Channel Bottom Types

Inorganic	
Bedrock	
Boulder	(> 25cm diameter)
Cobble	(6.5 - 25.5 cm diameter)
Gravel	(2mm – 6.5 cm diameter)
Sand	(0.005 – 0.20 cm diameter)
Silt	(soft, fine sand)
Clay	(fine sand with a sticky texture)
Dead Coral	(whole or fragmented)
Organic	
Muck-mud	(black, very fine)
Pulpy Peat	(unrecognizable plant parts)
Fibrous Peat	(partially decomposed plant material)
Detritus	(sticks, wood chips, coarse plant material)
Logs, Limbs	(large woody debris)
Seagrass	(live beds)
Live Coral	(attached)
Sponges	(attached)

Discussion Questions

- Channel bottoms, cross-sections, and surface water velocity are interrelated. How are these observations and measurements related at your sampling site?
- Could you predict, govern the shape of the channel cross-section and the water-course bottom, what the water velocity might be like?
- Is there evidence of human-causes change in the channel or water-course bottom?
- How do tidal channels at the reference site differ from channels at the rehabilitation site?

SPECIAL TOPIC: DETERMINING THE TIDAL PRISM

The tidal prism is defined as the amount of water necessary to fill up the basin between ebb tidal water level and flood tidal water level and is calculated by multiplying the tidal range times the basin area and subtracting the volume of sandy shoals.

This is related to the tidal volume, which is defined as the amount of water flowing through the inlet during ebb and flood and can be calculated by multiplying the measured velocities in the inlet with the cross-section area of the inlet.

Theoretically the tidal prism should be half of the tidal volume.

Degradation of the upper watershed changes the tidal prism. A denuded catchment or watershed, will have larger fluctuations of water contributed to the mangroves. High and intense flows will be common in the rainy season, as runoff is increased due to lack of absorption of rainwater into the ground water. These high flows will deliver large loads of sediment to the mangroves, due to increased erosion.

Lack of absorption of rainwater into the ground causes low flows during the dry season, as aquifer recharge is lower. This means that aquifers have less water to contribute downstream over time. These long periods of low flow, and hence reduced tidal prism, can be problematic for mangroves, as sediments delivered in the rainy season are can clog up tidal creeks,.

Clogged tidal creeks cause stress in mangroves, due to lack of water exchange. They can cause mortality as well, especially during times of flooding, as drainage of water out of the mangrove forest is hampered, and mangroves can "drown" due to prolonged inundation in anoxic conditions.

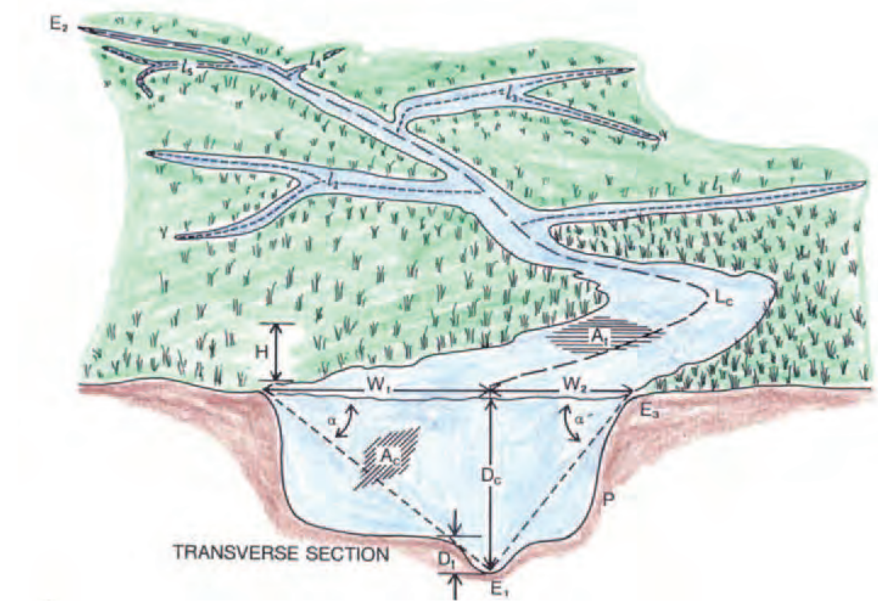
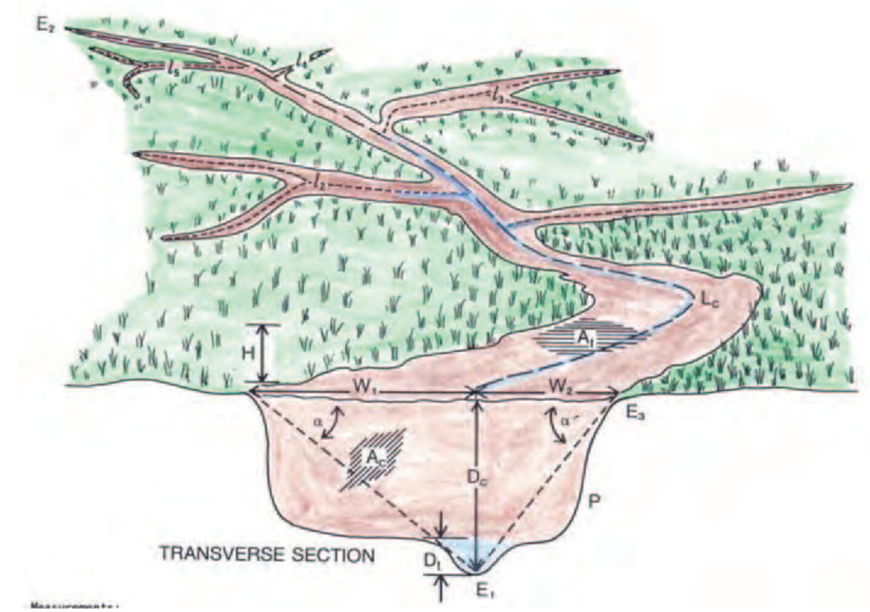


Fig 5.3 Catchment Health and Tidal Prisms. The tidal prism above, under conditions of a healthy upper watershed, is high and consistent, due to absorption of water into the aquifer, and slow release throughout the year. Below, a degraded upper watershed will have highly fluctuating tidal prism, high volumes during rain events, and low volumes, leading to tidal creek siltation, during the dry season.



5.1.3 Mapping dike walls/breaches and instance of sedimentation (recommended when working in disused aquaculture ponds)

Objectives

- To determine the relative condition of all dike walls in the area to be rehabilitated.
- Establish where current breaches in dike walls are located
- Establish if any sedimentation is occurring in current breaches and water ways

Materials

- Current aerial photograph with current marked breaches and waterways.
- Pen
- GPS
- Laminated aerial photograph
- Categorisation key (this can be different than the map key to be used, eg. use different colours in the field, or have abbreviations)
- Markers (different colours)

Time One day for field work (up to 25 ha) and half day for data entry on map

Background Information
The development of dike walls and artificial drainage channels in an aquaculture complex severely disturbs the natural flood and ebb of tidal waters through an inter-tidal area. Understanding the current status of dike walls, including their breaches, and the flow of tidal waters through drainage channels is essential for planning hydrological restoration.

In the case where a restoration of a former aquaculture area will include levelling of dike walls, filling of channels, and regrading of the substrate, the pre-restoration condition of dike walls and tidal channels is not critical, although it is good to depict on a map in order to track change over time.

In the case where a restoration of a former aquaculture area will largely rely on the cost-effective practice of strategic dike walls breaching, filling of artificial channels and creation of "natural" meandering channels, mapping the pre-restoration condition of dike walls, breaches and tidal channels is essential.

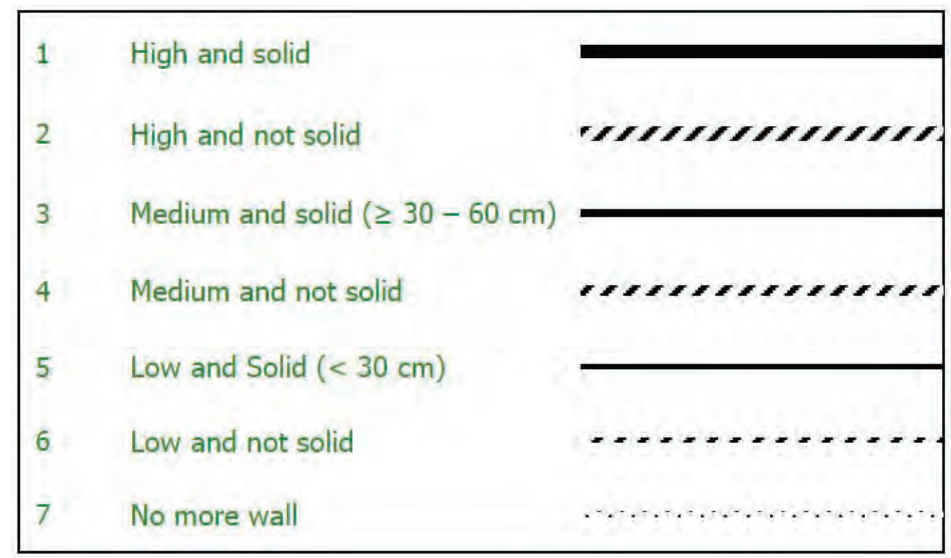
Several case studies from chapter 8 (Implementation) and chapter 10 (EMR case studies) will highlight the strategic breaching approach to mangrove rehabilitation in greater detail.

Procedures

The relative condition of all dike walls within and on the perimeter of area to be rehabilitated must be marked using the following categories and keys:

Note: Any wall that is slightly raised is still considered a dike wall as it acts as an interference to flows.

1. Locate all walls to be categorized on the aerial photograph.
2. In the field, allocate each wall within and surrounding rehabilitation areas a category and associated number.
3. Mark dike walls on map with the following key.



4. Record all ***major*** breaches in the perimeter and internal dike walls on the laminated photograph using the following classifications:

5. Evidence of sedimentation adjacent to major breaches (micro-delta formation) or in tidal channels must be recorded. There are two types of micro-delta formations:

   a. Ebb tide micro-deltas form on the seaward side of a breach.
   b. Flood tide micro delta form on the landward side of a breach.

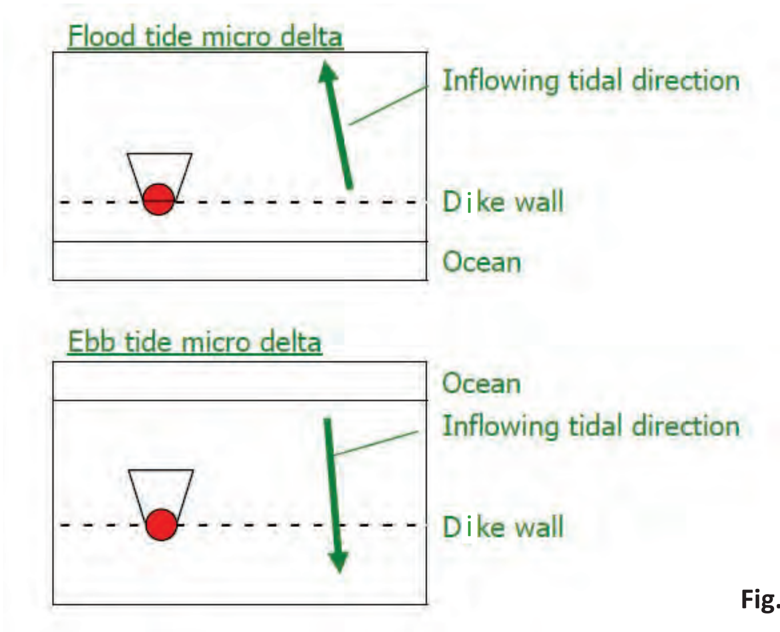


Fig. 5.4

Use the following symbol to indicate sedimentation adjacent to major breaches or in tidal channels.

Discussion Questions

- After mapping dike walls, what are your concerns about the condition of dike walls at the restoration site?
- Do tidal channels at the site appear to be natural or very unnatural? How can you tell?
- Do some tidal channels seem to have heavier flows than others? How does this influence flooding and drainage at the site?

5.1.4 LOCALLY DETERMINING MEAN SEA LEVEL (MSL) - RECOMMENDED

Objective

- To calculate a relative MSL height in rehabilitation area, when real measures or tidal gauges are not available.

Materials

- Current tide chart for closest area to rehabilitation site
- Measuring stick
- Data sheet
- Pencil
- GPS

Time 14 days – one complete cycle from full to new moon.

Background Information

Determining current Mean Sea Level helps to set boundaries on the rehabilitation project. Mean Sea Level seems to be the lowest substrate elevation where mangroves will grow, and the total zone of optimum planting for mangroves or natural colonization will range from MSL to above Mean High Water (MHW). Many planting projects fail, because they attempt to plant mangroves below mean sea level, under the false assumption that mangroves can grow anywhere in the intertidal zone. Low tides, which expose sub-MSL mudflats, seem attractive to mangrove planting projects, because there are seldom land-use conflicts this far out along the coast. However, these plantings will nearly always fail, except during the occurrence where sedimentation brings sub-MSL mudflats up to the level of MSL or higher. Rapid sedimentation, then, becomes a separate issues to measure and analyze (see activity 5.1.5).

Procedure

1. Locate a stable place for measurement close to housing, and on the seaward edge of a mangrove area.
2. Place a stick where measurements will take place. GPS this point and record on data sheet.
3. Measurements begin on the first high or low tide on the full or new moon.
4. Every high and low tide for the following 14 days must be measured.
5. In areas where tides are semi-diurnal, 2 highs and 2 lows per day must be recorded.
6. Record all measurements on data sheet

7. After all data has been collected, add all high tides together, and all low tides together and divide by number of tides recorded.
8. If tides are semi-diurnal, add all of the highest tides together, all of the lower high tides together, Average each.
9. Record relative MSL

Discussion Questions

- Were you able to calculate Mean Sea Level?
- How might you demarcate mean sea level in the field?
- Do you have any observations regarding the distribution of mangroves and mean sea level at your site?
- Do you have any observations regarding the mangrove colonization and mean sea level at your site?

5.1.5 Observing Patterns of Sedimentation & Erosion (optional)

Objectives

- Recognize evidence of bank erosion coastally and along tidal channels/rivers.
- Recognize evidence of sedimentation/accretion coastally, in micro-deltas and along rivers.

Materials

- Time-series remote sensing imagery (10 to 30+ years)
- Pencils
- Activity 2.3 data sheets

Time – half day for 25 hectares

Background Information
The critical factors of the duration and frequency of tidal inundation, which are the main drivers of successful mangrove recruitment and growth, are closely linked to surface elevation. From the simple tidal profile in Fig. 5.5, we can see that the higher up the intertidal zone we go, the less frequent tidal inundation occurs throughout the year. This dictates species distribution and the overall range of mangroves in any given area.

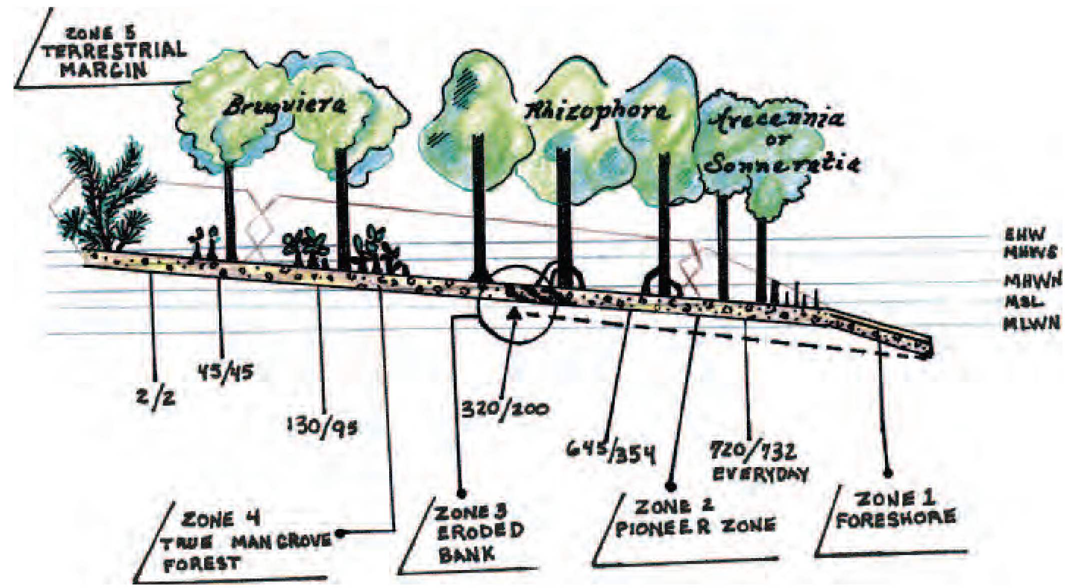
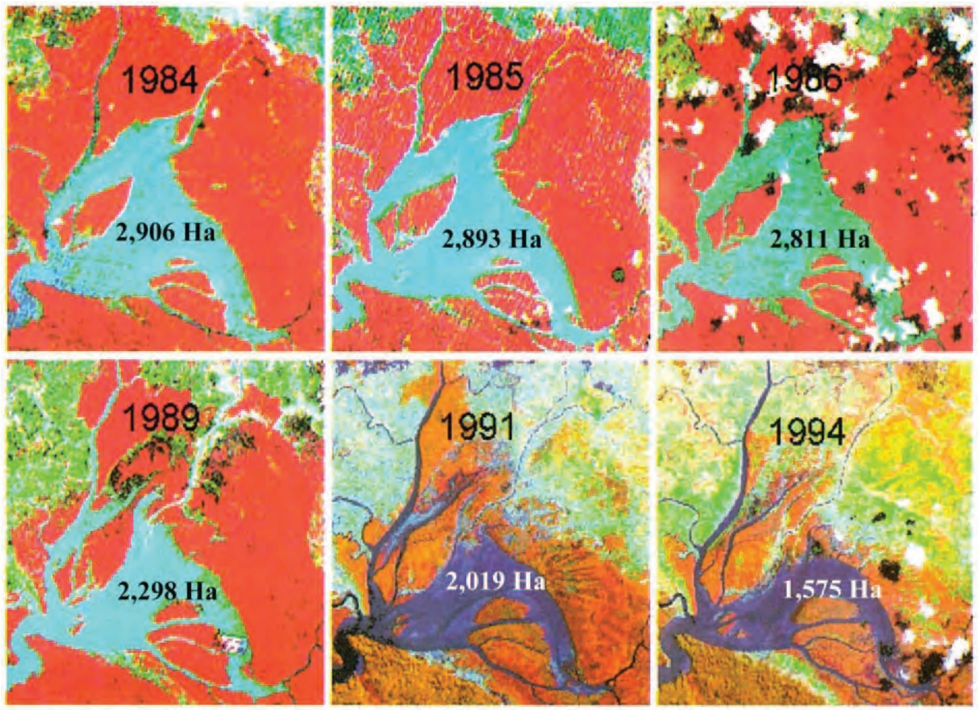


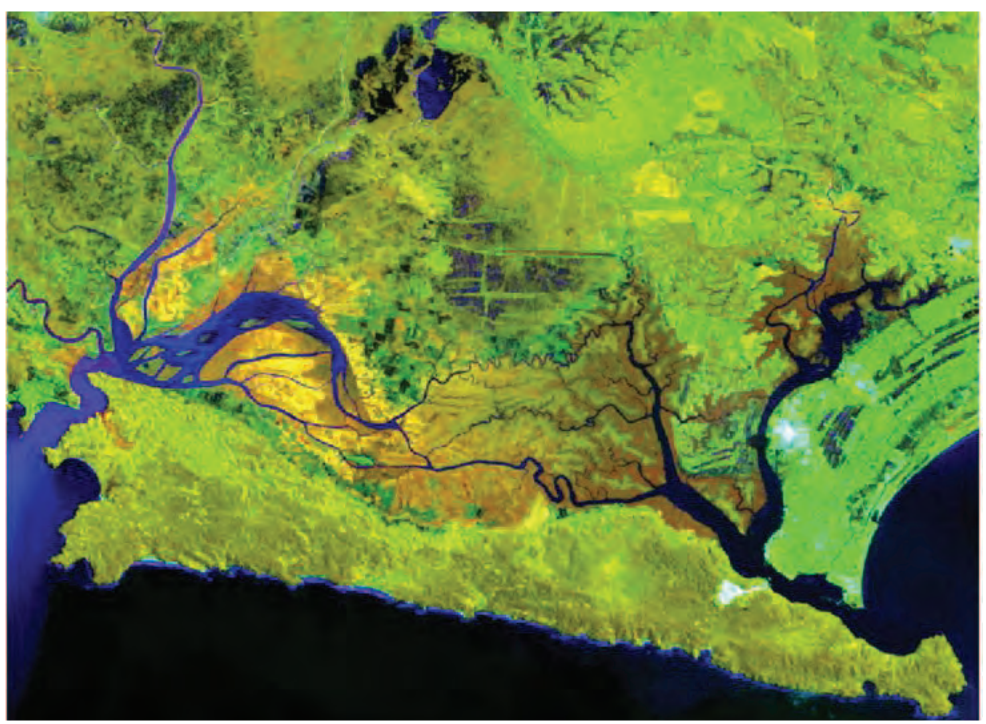
Fig. 5.5 Duration of tidal inundation and frequency - assuming two daily high tides over the course of an entire year. (Lewis, 2005)

Substrate heights, however, are not constant over time. Some areas experience sedimentation, while other areas erode. Rates of sedimentation and erosion will vary as well. An area which supports mangroves today, yet is experiencing a high degree of sedimentation, will not support mangroves in the future (see Fig. 5.6). Rather this system will turn into some type of terrestrial system, such as a beach forest, saltmarsh, freshwater wetland or terrestrial forest. Likewise, where rates of erosion are high, (Fig. 5.6) even adult mangroves fall into the sea, and there is no chance of establishing young mangroves of the same species, without remediating the effects of erosion, which may require an engineering intervention, or may not be possible at all.

What about the effects of future sea level rise? Even where sedimentation is occurring, it may not be able to keep up with the pace of sea-level rise.

There are numerous methods for calculating rates of sedimentation and erosion which require long study and/or expensive equipment, is thus. What is provided below are qualitative methods for observing patterns of erosion and sedimentation, which should help guide rehabilitation and other management options.





86

Fig. 5.6 The area of surface water in Segara Anakan Lagoon, Central Java reduced from nearly 3000 ha to 400 ha over a 25 year period due to upland erosion, reducing mangrove habitat as well (opposite page). Mature coastal mangroves in Mimika, Papua (above) and Bengkalis, Riau (below) have succumb to severe abrasion, part of the dynamic nature of coastal geomorphological processes.

Procedures
Take measurements both on rivers/major tidal channels, as well as along the coastal. Combine both sides of the river for riparian measurements, Record observations on Activity 5.15 data sheet in Appendix B.

Estimating extent of erosion (qualitative)

1. ***Bare Soil/Substrate***: estimate the percentage of the area along river banks and the cost, which is bare soil, not bound by plants and their root structures or covered in concrete or rocks. These bare areas could be due to people access, roads or crossings, boat traffic, clearing, erosion from strong, changing currents…Record your estimate on the data sheet.
2. ***Bank Slope:*** note the steepness of the bank slope. Is it steep, moderate or slight? Check the appropriate box on the data sheet.
3. ***Bank Stability***: estimate the amount of erosion that is present on the banks. Rate the bank erosion using the qualitative rating system in the conclusions/indicators section below. Record the rating you have selected on the data sheet.
4. ***Slumping or Bank Movement:*** rate the slumping and movement of the bank using the quantitative rating system in the conclusions/indicators section below. In some areas the removal of vegetation leads to slumping and movement of the banks. Record you selection on the data sheet.
5. Observe and record evidence of adult mangrove or other trees fallen due to erosion.
6. Observe and record presence or absence of mangrove seedlings underneath adult mangrove trees.

Estimating extent of sedimentation (qualitative)

1. Normative Sedimentation: estimate the percentage of the area along river banks and the cost, which is bare soil, not bound by plants and their root structures or covered in concrete or rocks. These bare areas could be due to people access, roads or crossings, boat traffic, clearing, erosion from strong, changing currents…Record your estimate on the data sheet.
2. Colonization: by Mangrove seedlings and/or halophytic grass.
3. Colonization: initially by mangrove vegetation quickly turning to terrestrial or beach vegetation., - indicates Rapid Sedimentation.

For a quantitative measurement of sedimentation - refer to Fig 5.7 on RSET's.

Discussion Questions
- Are there areas of sloughing or obvious erosion along the river and or coast? What are the causes of erosion?
- Is there evidence of sedimentation? Is it gradual or rapid?
- What are management or rehabilitation options in areas undergoing gradual erosion?
- What are management or rehabilitation options in areas undergoing extreme erosion?
- What are management or rehabilitation options in areas undergoing gradual sedimentation?
- What are management or rehabilitation options in areas undergoing rapid sedimentation?

Fig. 5.7 Rod Surface-Elevation Table–Marker Horizons (RSET-MH)
The use of Rod Surface-Elevation Table–Marker Horizons (RSET-MH) are gaining popularity due to concerns about patterns of coastal erosion and sedimentation in the background of sea-level rise. This low-cost, simple, highly precise method can be paired with spatial data sets and used to create models useful for spatial planning and mangrove restoration design. Use of RSET's for monitoring of substrate elevations, in a coordinated manner between nations, is important to inform climate change policy at local, national and regional scales.

Driving an RSET rod through a mangrove soil profile (left). Measuring salt-marsh surface elevation with an RSET (right).

Section 5.2 Ecological Assessments

(Autecology, Community Associations, Edaphic Conditions)

Overview

This section starts with a rapid vegetation survey, to quickly understand what the remnant mangrove community looks like. The rapid survey can also be undertaken in a reference forest. At the end of this survey – you will have an idea of natural sources of propagules available for restoration, and their proximity to the restoration site. If close – natural revegetation is highly likely. If propagules are limited, rehabilitation may require human assisted propgule distribution. This means harvesting ripe mangrove fruits and seeds, and releasing them periodically in the rehabilitation area.

After rapid vegetation survey, a more thorough survey needs to take place. Detailed surveys can take place both in a restoration site as well as a reference forest. The first step in a restoration site is to roughly divide the site into mangrove zones (seaward, mesozone and landward). Next, survey plots are established which may involve a mixture of permanent or temporary transects and quadrats.

Finally you will be ready to undertake vegetation surveys, gathering information on autecology (individual species ecology) and community associations (associations of different mangrove species commonly found growing together).

This section closes with optional edpahic studies, which investigates the qualities of the substrate which are important to facilitate mangrove establishment and early growth.

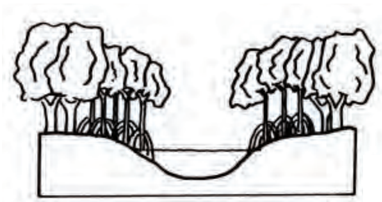


Fig. 5.8 Examples of Mangrove Community Associations

5.2.1 Rapid Vegetation Survey (optional)

Objective:

- To classify rehabilitation area and/or reference forest by mangrove species and maturity class with rapid survey methods.

Output

- Completed map of rehabilitation area with rapid survey mangroves species and maturity classes.

Materials:

- Current aerial photograph of rehabilitation site
- Map of rehabilitation area
- Markers

Time: 3 hours or more depending on size of rehabilitation site.

Procedure

1. Analyze a current remote sensing image of the rehabilitation site. Determine which areas of the rehabilitation site have abundant vegetation, a moderate amount of vegetation, or little to no vegetation. Mark these zones on the map, for easy reference in the field.
2. Walk each zone in the field, rapidly classifying them for species and relative maturity, and estimates of percent dominance.
   - Species: use a different color to represent each species
   - Relative maturity: represented by tinted shades of each species color
     - o 25% - seedlings
     - o 50% - saplings
     - o 75% - young trees
     - o 100% – old trees
   - Estimate percent dominance using a rough percentage (25%, 50%, 75%, 100%)

     Areas with no vegetation are left blank.
3. Record data on a baseline map (see Fig 5.9)

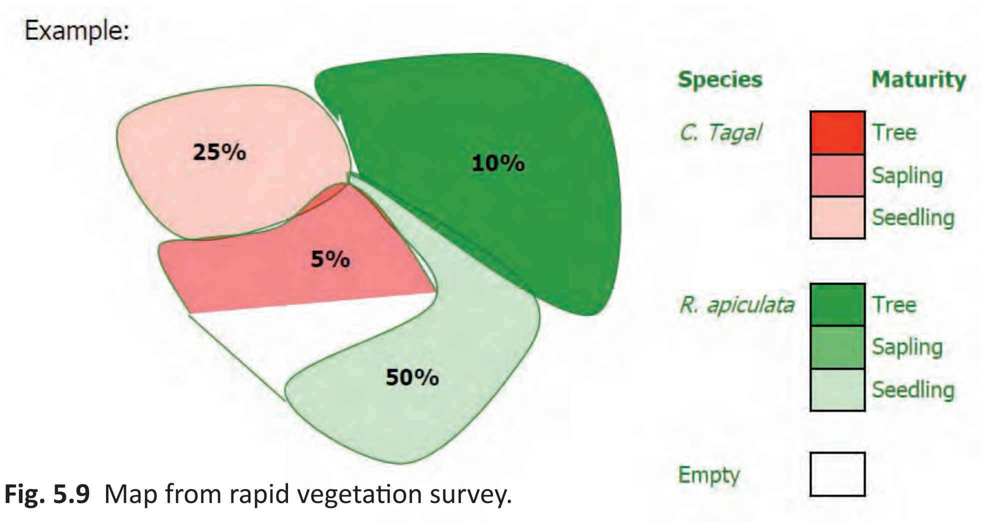


Fig. 5.9 Map from rapid vegetation survey.

Discussion Questions

- What are the dominant adult trees in or adjacent to the rehab area?
- Do you consider the area to still maintain a high level of mangrove biodiversity?
- Are pioneer mangrove species (*Avicennia* spp., *Sonneratia* spp., etc.) present?
- Is there evidence of natural regeneration in the rehabilitation site? Adjacent to the site?
- Would you consider the rehabilitation site to be propagule limited? (sensu Lewis 2005)

5.2.2 Delineation of Mangrove Zones (optional)

Objective

To create stratifications within the rehabilitation area that are an arbitrary representation of mangrove zones. These stratification will be used for the random placement of 3 sampling plots in each zone.

Background Information

Mangroves traditionally occur between Mean Sea Level and Highest Gravitational Tide. Mangroves may be split into three zones based on relative position in the intertidal system (see Fig. 5.10). This activity involves demarcating stratified zones (seaward, mesozone and landward), before determining placement of random plots, in order to ensure that all potential mangrove zones are represented before detailed vegetation surveys. . If tidal inundation levels are known, use these as the guide for stratifying the rehabilitation area into 3 zones. If inundation levels are not known, use the following method.

Materials

- Map created in activity 5.2.1, current remote sensing images of rehab site and surrounding area, pen, ruler

Time 1 hour

Procedure

1. Analyse the remote sensing image and map from activity 5.2.1. On the map, indicate a trio of zones.

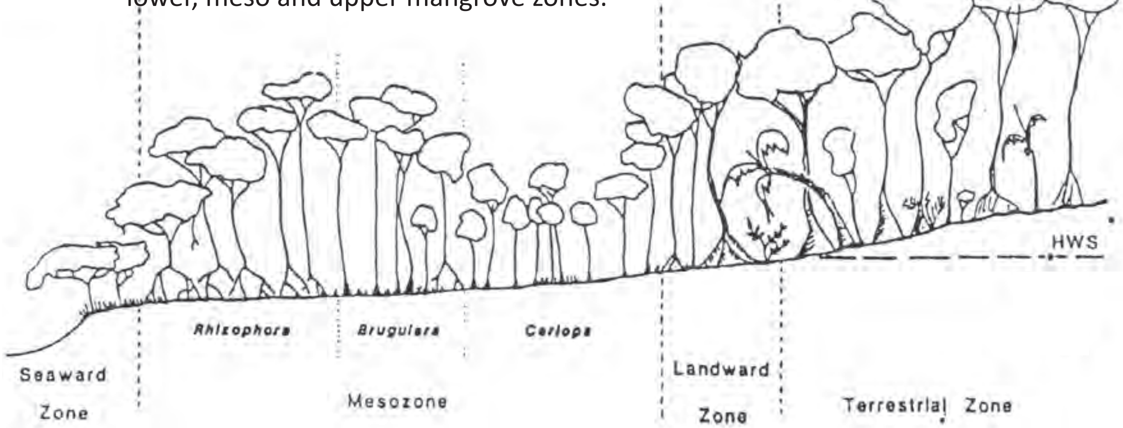
   Zone 1: Seaward zone
   Zone 2: Mesozone
   Zone 3: Landward zone

2. Demarcate zone 3, the landward zone creating a contour line. Measure the widest point from the terrestrial edge to the edge of zone three. Record.
3. Continue to demarcate the mesozone and seaward zone, also creating contour lines. The lines should run relatively parallel to the coast, but take care around tidal creeks, which will alter the shape of the contour.
4. Try and give names to these zones based on dominant species or community associations.

Discussion Questions

- Are all three mangrove zones represented at your site?
- What are the major, noticeable distinctions between zones in terms of vegetation?
- What are the major, noticeable distinctions between zones in terms of substrate type?
- How do tidal creeks influence your mangrove zonation?

Fig. 5.10 Typical cross-section divided into lower, meso and upper mangrove zones.



5.2.3 Establishing Permanent Transects (recommended)

Objective:

- Establishment of permanent transect lines that run through all representative zones of the rehabilitation area (seaward, mesozone, landward)

Output

- GPS coordinates for start and end point transect line and the compass direction of transect from start point.

Materials

- Map of perimeter, ownership and status created in activity 1.
- Ruler
- Marker
- Notebook
- 2 pre-made permanent transect markers.
- Bamboo stakes every 20 m of permanent line – number required depends on length of
- Transect line
- Spade
- Crowbar
- Nylon string (the length of transect)
- Compass
- Long measuring tape (the one you can wind up)
- GPS

Time 2 hours

Procedure

1. On the map from activity 5.2.2 identify a single path for a transect line which extends through all three mangrove zones, running from the coastline, landward.
2. Determine the GPS points of both the start and end points of the transect. Record.
3. Determine compass direction of transect line from the start point. Record.
4. Determine length of transect. Record.
5. The permanent transect will be used for both measuring substrate elevations (Activity 5.2.4) and vegetation (Activity 5.2.5)

6. In the field, locate the start point GPS coordinate in the field. If this point is located on a dike wall, move just in front of the wall.
7. Install one permanent transect marker at the GPS point by digging a hole large enough to fit the base of the pre-made marker so it is flush with the soil surface. Infill around the base, compact soil until marker is sturdy.
8. Attach transect line.
9. Walk in the compass direction already identified.
10. Using a 20m measuring tape, place bamboo stakes every 20 meters stretching a rope between them, until the end point GPS coordinate has been reached.
11. Number each of the stakes (A1, A2, A3....) and mark with GPS.
12. Install the remaining permanent transect marker at the GPS endpoint and attach the transect line.
13. Repeat for the total number of transect lines required.

Discussion Questions

- Do your transect lines run through all representative mangrove zones (seaward, meso, windward)?
- How do you know if you have enough transect lines? Too many?
- How can modern technologies help you in laying out appropriate transect lines?

Fig. 5.11 Running a transect line through a recently logged area in South Sulawesi

5.2.4 Substrate Elevation Survey (recommended)

Background Information
Mangrove establishment, growth and zonation are inextricably linked to substrate elevation. Mangroves normally grow between Mean Sea Level and Highest Gravitational tide, with pioneers colonizing lowest elevations, and the greatest variety of biodiversity at higher elevations near the mangrove – hinterland interface.

Substrate elevation directly affects the duration and frequency of tidal inundation, which may be the most important factor in determining mangrove distribution. This survey is carried out in the rehabilitation site and a reference forest, and is linked directly to the following activity, creating a vegetation profile.

These activities are required. They are excellent activities to run in a group setting, to illuminate to stakeholders where mangroves should be expected to grow and why. Creating large murals depicting substrate elevation and vegetation profiles is a common practice over the first two days of an EMR training.

Objective:
- Obtain height of substrate every 20 meters along the permanent transect as well as start and end points.

Output
- A completed cross section profile of combined substrate height and associate vegetation data.

Materials
- Bamboo stakes (pre-placed during permanent transect placement)
- Meter rulers or equivalent
- Data sheets
- Tide Chart (adjusted to local MSL calculated in activity 5.1.4)
- Timers
- People (1 person per every 3 stakes minimum)
- 30 m clear plastic hose
- Water

Time One hour (during high tide)

Note: this is a low-cost, but labor intensive activity. Substrate elevation is more easily measured with a theodolite or total station the use of which requires trained operators.

Procedure

1. Determine the time of the peak high tide for the day of the activity. It is a good to choose a day near the full or new moon, to ensure a very high tide.
2. The day before the activity, during high tide, check all measuring stations to see if they are inundated by the tide. Mark those stations not reached by the high tide.
3. Organise your team, give each a ruler or equivalent measuring tool and a data sheet with required measuring time marked on the top.
4. Allocate measuring stations to be reached by high tide to team members, ensure everyone knows where to go in the field and which stations they are responsible for. Circle each station the team member is responsible for on data sheets.
5. Ensure watches/cell-phones are synchronised and all recorders are sure of the time of highest high tide before leaving for the field.
6. Ensure there is enough time for each team to get to the most remote measuring stations.
7. At the appointed time, each member of the team will place their measuring device on the surface of the substrate and measure how many centimetres up the stake the water reaches.
8. Substrate elevation is then calculated by subtracting the distance between the water surface and the substrate, from the known elevation of the water surface (read from the tide chart).

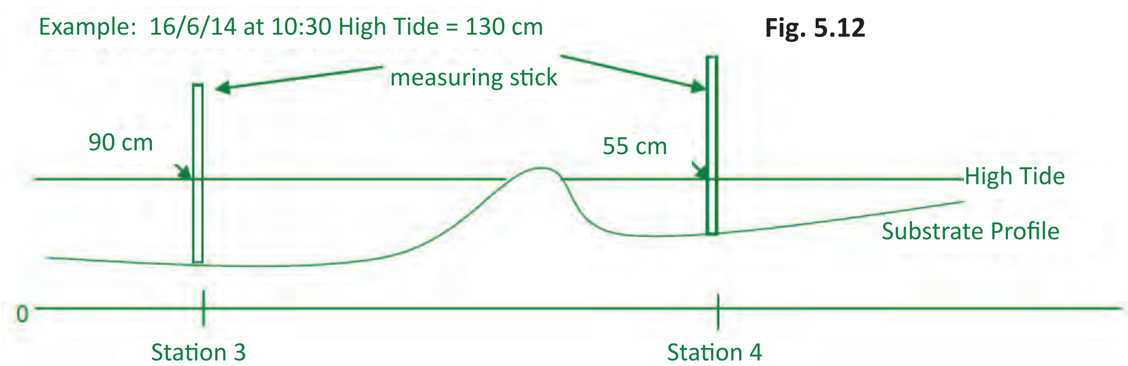


Fig. 5.12

Substrate elevation at station 3	=	130 cm - 90 cm
	=	40 cm above 0 (lowest gravitational tide)
Substrate elevation at station 4	=	130 m - 55 cm
	=	75 cm above 0

9. If the water level of the high tide does not finish at a measuring station, place an additional bamboo stake where the water and the substrate meet (the high tide mark). The substrate elevation at this point will be the exact height of the tide above 0. (see Fig 5.13)
10. For remaining measuring stations that high tide did not reach, use a water level to determine the height and record on data sheets. (see Fig 5.13)

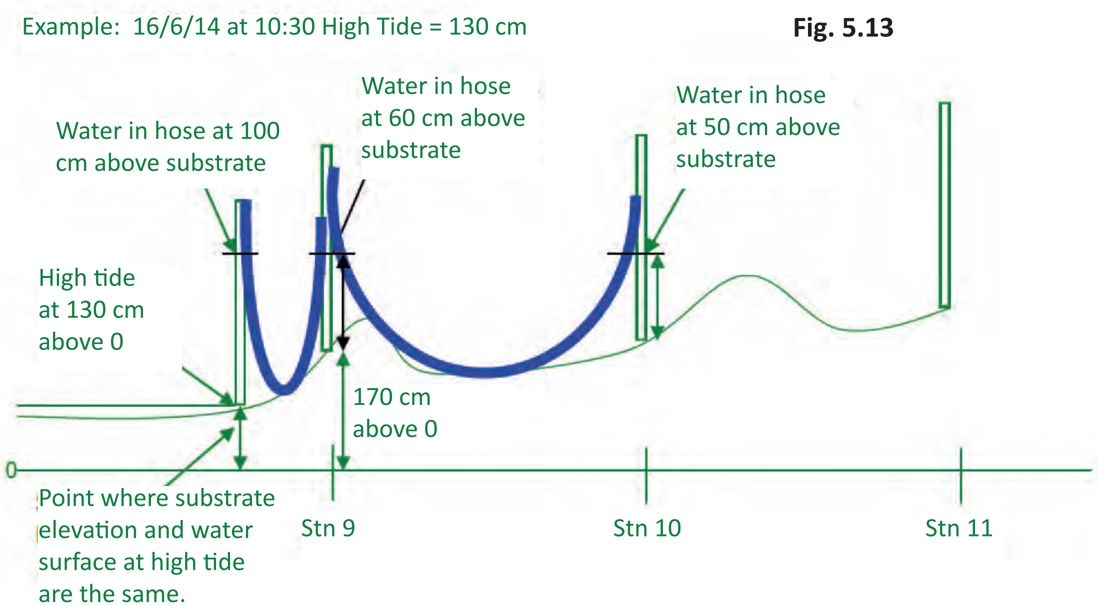


Fig. 5.13

11. To calculate the ***substrate elevation*** at station 9:
    - We know the high tide level is 130 cm (from the tide chart). Therefore we know the substrate height where the water surface intersects with the substrate is also 130 cm above 0.
    - The water in the water level is positioned at 100 cm above this point. Therefore the point at which the water is held is 230 cm above 0.
    - The water at station 9 is level with the water at 230 cm above 0. It reads 60 cm on the measuring stick. It is therefore 60 cm above substrate.
    - Therefore the substrate elevation is 230 cm - 60cm = 170 cm above 0.
12. To calculate the substrate elevation for station 10, take the substrate elevation of station 9 (170 cm) and subtract the water level height measurement at station 10 (50 cm). The substrate elevation at station 10 is therefore 170 cm - 50 cm = 120 cm above 0.
13. Once all data sheets have been received, compile data onto one sheet. DO NOT throw away any data sheets.
14. Make all required substrate elevation calculations and an rough sketch of the substrate profile in a grid at the bottom of the data sheet.

Discussion Questions

- What is the total range between lowest tide and highest tide?
- What tidal information do you still find confusing?
- Do you have any initial observations relating vegetation to substrate elevation?

Fig. 5.14 Using a water level to measure substrate elevations towards the landward edge of the mangrove which is rarely inundated by high tide.

5.2.5 Vegetation profile linked to substrate heights (recommended)

Background Information

This exercise builds from the previous activity, relating vegetation to substrate elevations. This activity is carried out in the rehabilitation site (in the event that some natural regeneration or planted material is growing in the rehabilitation site) as well as the reference forest. This information will be crucial in the design of the rehabilitation initiative, informing the practitioner in terms of what species can be expected to grow in the various intertidal zones of the rehabilitation site, and also clearly defining the current boundaries of the rehabilitation area (not yet taking into consideration patterns of short or long term sedimentation and erosion).

Objective:

- Record species, size class and height of all vegetation as well as percentage of halophytes (salt-water tolerant grasses) one meter left and right of a transect line.

Output

- Cross-section profile relating substrate elevation to vegetation type.

Materials

- 2m PVC pipe (2" diameter)
- measuring tape (dress-makers tape)
- telescoping tree height measuring stick
- mangrove id field guide
- data sheet

Time 1 or 2 days – 1-2 low tides depending on length of transect.

Procedure

1. Measurements are to be taken along the permanent transect, at every 20 meters pre-place bamboo stake and at the start and end permanent markers.
2. Start at the seaward transect marker at low tide.
3. Lay the 2m PVC pipe perpendicular to the transect line, with the center of the pipe intersecting the transect line.
4. Record all species touching the PVC pipe both right and left of the transect line.
5. Record size class of each species (see Fig 5.14) on data sheet.
6. Record height of each species, including seedlings, on data sheet.
7. Only record DBH for trees, not seedlings or saplings.
8. Record % coverage of halophytic grasses. Do this by measuring the range (in centimeters) along the measuring stick these plants occupy, and calculate the following equation to obtain percent cover:

   Species % cover = Sum of cm occupied/2

9. Carry out steps 3. to 8 along the entire transect at 20 m intervals.
10. Back at lab input data into spread sheet and calculate for each measuring station:
    - Total # individuals for each species
    - Total # individuals for each size class
    - Average height of each size class

Tree:
Height > 1.3 m
Dbh ≥ 2.5 cm

Sapling:
Height > 1m < 4m
Dbh < 2.5 cm

Seedling:
Height < 1m
Dbh N/A

Fig 5.14 - Key
Mangrove size class.

Discussion Questions

- What was difficult about this activity? Do you have recommendations to change the activity?
- What patterns do you notice which relate mangrove species to substrate elevation?
- How do you expect the pattern of distribution of mangrove species to look after the rehabilitation effort? Explain.

5.2.6 Establishment of Sample Plots – Quadrats (recommended)

Objective:

- To randomly select and install three 5m x 20m sample plots within each zone identified in activity 8.

Output

- A total of 6 sample plots randomly selected and established with permanent markers for easy identification in future monitoring.

Materials

- 6 pre-made permanent plot markers – depending on number of zones identified in activity 8
- Crowbar
- Spade
- 3 pre-measured rope 20m long + additional length for attaching to stakes
- 12 bamboo stakes
- Map with marked zones and transects
- Scientific calculator
- Pen

Time 2 hours for random selection of plots, 30 minutes per plot establishment.

Procedure

1. On map with marked zones, overlay a grid of 5m x 20m squares, or use Google Earth's random sampling point generator (instructions in Appendix - Using Google Earth for EMR)
2. Allocate each grid square within the rehabilitation area a number.
3. Using the random number generator on calculator, select three numbers per zone, mark the associated squares.
4. If numbers generated fall outside of the rehabilitation zone, or in a zone that already has 3 numbers selected, discard and continue selecting until three squares have been selected in each zone.
5. With your back to the ocean, install the permanent plot marker in the bottom left hand corner of the quadrat. GPS these points and record on vegetation ecology data sheets (Appendix B)
6. In the field locate the GPS coordinate for permanent marker installation. Install by digging a whole deep enough to leave 5 - 10 cm of marker above the substrate surface. Place a bamboo stake next to marker.
7. Attach a rope to the marker and extend 20 m perpendicular to the shoreline. Place a bamboo stake and attach the rope.
8. Extend the rope 5 m 90° to first side of quadrat. Place bamboo stake and attach rope.
9. Extend rope another 20 m parallel to the first side of the quadrat, place bamboo stake and attach.
10. Extend the rope 5 m to complete the long plot.
11. Repeat steps 7 - 10 for each sample plot.
12. Ensure each plot is clearly labeled to avoid future confusion. For example, the three plots in zone one could be labelled Z1.1, Z1.2, Z1.3 - reading from left to right in facing from the shoreline.

Discussion Questions

- Was there anything difficult about laying proper quadrats?
- Do you feel that quadrat size or shape needs to be changed for your survey site? Why or why not?

5.2.7 Vegetation Survey – Quadrats (recommended)

Objective

- To obtain representative data on key factors for individuals, species and community vegetation within the rehabilitation area to use as a baseline by which future monitoring will be measured against.

Output

- Analysed data and presented in baseline monitoring report. All raw data stored on database.

Materials

- telescoping tree height measuring stick
- measuring tape (dress-makers tape)
- scientific calculator
- premade 1m x 1m gridded quadrats
- data sheets
- canopy reader
- field id guide for mangroves, associates and halophytic grasses

Time 2 hours per quadrat + time to go between sample plots and the addition 30 minutes per plot establishment.

Procedure

1. Trees and saplings will be measured within each 5m x 20m plot, to measure seedlings and grass ground cover, using three 1m x 1m nested sub-plots within the larger plot area.
2. Before entering the field, on paper divide each 5m x 20m plot into 1m x 1m squares. Allocate each square a number and randomly generate numbers on a scientific calculator until 3 plots have been selected. These squares are where the 1 m x 1m subplots will be placed. Give each bottom (seaward) left hand corner of subplots a coordinate (see Fig. 5.15). Mark each plot coordinate on the top of the data sheet.

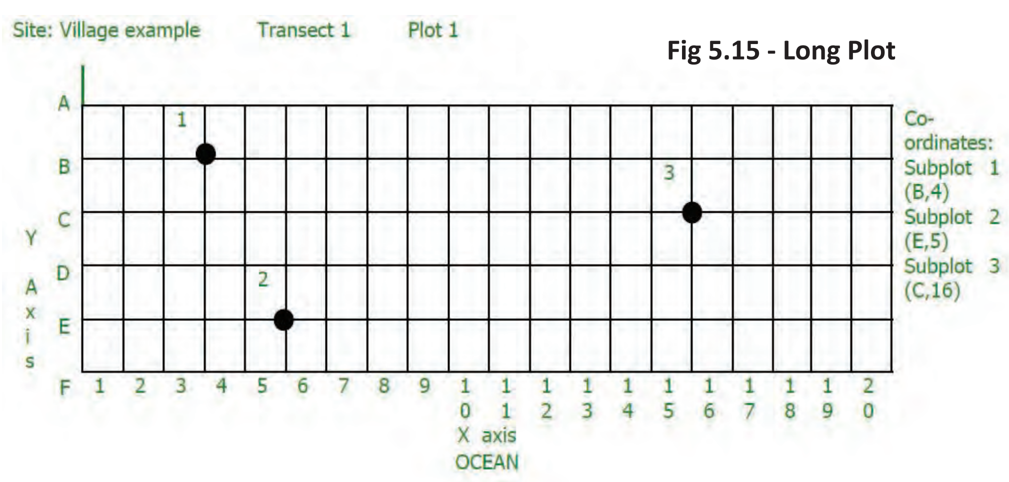


Fig 5.15 - Long Plot

For Trees & Saplings

3. In a 5m x 5m plot, for each tree present record on data sheet:

a. *Species* – use species guide book for identification, if unable to identify in field, take sample, label and bring back for future identification.

b. *Height* – use the extendable measuring stick, estimations can be made for the top 20cm of tree. Ensure the same team member measures the height of tree to minimise human variation. The team member responsible for measuring height should always hold the pole at the same height on his body eg. at their breast. The height from ground to breast must be added to measuring stick reading to gain total height of tree.

c. *Diameter at Breast Height* (dbh) – is always measured at 1.3 m above ground level. We will measure the circumference at breast height and later convert this to diameter. As trees within mangroves are often varying in growth patterns, we cannot use one standard rule for measuring. See figure on following page as a guide to determine where to measure on trunk.

4. Record all sapling species within the 5m x 5m plot.
5. For each species of sapling, record the height of the first 10 encountered, and average.

For Seedlings & Halophytic Grass

6. Locate each subplot coordinate preselected in step 2 and place premade quadrates.
7. Within each subplot record the number of seedlings of each species present.
8. For each species of seedlings, record the height of the first 10 encountered, and average.
9. If other halophytic grasses are present in subplots, count the number of squares they occupy and calculate percent cover using the following equation:

$$\frac{\text{No. of squares occupied}}{\text{Total no. of squares}} \times 100 = \text{\% ground cover of given species}$$

Analysis

Back at base, convert all tree circumference measurements to diameters using the following formula:

$$dbh = C/\Pi$$

calculate Basal Area (BA) for each species of tree present using the following formula:

$$BA = \Pi^{*} dbh^2 / 4$$

To calculate canopy cover, use the following equation:

Total number of squares with leaves present x 2

Insert data into pre-prepared excel spreadsheet and calculate standard deviation, variance, total, and mean of each plot and subplot.

Data from quadrats can also be analyzed to uncover common community associations (associations of species) in the forest.

Although it is helpful to apply statistics to uncover community associations, this can also be undertaken qualitatively.

A column has been added to the Autecology data sheet, to note species frequently growing in proximity to one another.

Discussion questions

- Was the quadrat size appropriate for your site?
- Are there clear community associations present at your reference forest? Rehabilitation site?

5.2.8 Edaphic Surveys (optional)

Objective

- To measure and track key soil conditions that influence mangrove recruitment and early growth.
- To understand which key soil conditions can be both a) easily and meaningfully measured and, b) effectively augemented during mangrove rehabilitation.

Background Information

There are numerous soil characteristics, ranging from physical to biochemical, but not all are important to measure for the rehabilitation practitioner. Particle size and soil structure, for instance, are important properties, but since they are difficult for a practitioner to change, these are not necessary measurements, but rather metrics for academic study.

Related to this may be the measurement of pore-water soil salinity. This is an important soil characteristic, which can be improved quickly by restoring a normal hydrological regime to a rehabilitation area. However, salt concentrations in soil-pore water varies greatly, not only seasonally or monthly, but hourly. Many measurements would need to be taken for proper analysis, and because of that, they are not practical for the rehabilitation practitioner. Thus, although rehabilitation efforts can influence soil-pore water salinity, the measurement of it is too variable to be of great use to a practitioner.

It is clear, however, that many edaphic conditions determine the extent of mangrove recruitment and growth. Soil attributes such as texture, nutrient availability, hydrogen ion concentration (pH), redox potential (Eh), organic content, temperature and density seem to effect recruitment and growth. What is more, these conditions can be enhanced by methods such as planting marine tolerant grasses, or mixing organic matter into the substrate in strategic patches.

So, the question remains, what edaphic measurements can be taken simply that can also inform rehabilitation design, and how to take them. Below we offer a very brief look at some of the important edaphic measures and even briefer methods on how to collect them. Resources are provided at the end of the section for further investigation. Later, in the chapter on implementation, we re-visit edaphic studies, recommending some trials that can be undertaken at the rehabilitation site to potentially enhance edaphic conditions and improved conditions for seedling establishment and growth.

Fig 5.17 Special Topic: Physico-chemical changes in the substrate

When a mature forest dies, such as occurred in *R.stylosa* forests in Darwin Harbour after Cyclone Tracey, a number of other environmental factors including physical and chemical changes in substrates can be initiated which may in turn inhibit seedling recruitment. McKee (1993) found clearing of mangrove forests can result in changes in soil redox potential, associated rapid accumulation of sulphide and subsequent acidification. Such changes have been linked with limited natural regeneration of seedlings in one hectare clearfelled lots (Hamilton and Snedaker (1984) as cited in Ellison and Farnsworth, 1996). The process has reciprocal effects however, because the root systems of adult mangrove trees modify the surrounding soil, reducing redox potential and toxic sulphide levels (McKee, 1993). It follows that if toxic soil conditions actively limits seedling establishment and survival, as suggested by recent research by Youssef and Saenger (1996; 1998), then clearings created by disturbance may remain largely devoid of vegetation until a sufficient level of forest cover alters and improves sediment structure and chemistry. Such unfavourable substrate conditions in the middle of clearings would provide additional reasons for the incremental recovery of mangrove forests outward from the edge of the forest—as is often observed in disturbed mangroves. One may speculate further, that once a critical threshold level of mangrove vegetation cover is reached and substrate conditions are suitably ameliorated, subsequent reforestation may be quite rapid. Nevertheless, this whole recovery process may require several decades after the original forest has decayed. It should be noted that during the nine years since this experiment was commenced, seaward cyclone damaged clearings have recently shown substantial and relatively rapid recovery (pers. obs.). This may indicate that substrate conditions have stabilised and altered sufficiently for this threshold to have been breached. *Sonneratia alba* has, however, effectively replaced *R. stylosa*, which is now virtually absent from these clearings. (Metcalfe, 2007)

Important Soil Parameters to Measure for the Practitioner

Redox Potential (Eh) is a quantitative measure of reducing power which provides a diagnostic index of the degree of anaerobiosis or anoxia (Patrick and DeLaune, 1972). Typical Redox potentials may range from -200mV to +300 mV, the former being completely anoxic (typical of waterlogged soils with a high concentration of anaerobic bacteria) and the latter indicative of well oxygenated soil.

Sulfides can also be measured to understand to what extent a soil may be aerobic or anaerobic. H_2S is a waste product of anaerobic bacteria, and quite toxic to plant roots. Mangroves are able to buffer the soil around their root hairs from H_2S by breathing oxygen through their roots and bark, and sending it down to the root hairs. However, each species of mangrove has different tolerance to H_2S concentrations, which also differs between newly established seedlings, saplings and mature trees. (McKee 1993)

Hydrogen Concentration (pH)
Acidity in mangrove soils influences the availability of nutrients. Most mangrove soils are well buffered, having a pH in the range of 6 to 7, but some have a pH as low as 5. (Kathiresan, 1999)

Measurement of the acidity or alkalinity of soils using pH must be done with fresh samples to avoid oxidation of iron pyrites (a common constituent of mangrove soils) to sulphuric acid, thus giving a much lower value of pH than normally occurs in situ (English et al. 1997).

Salinity
The salinity of mangrove soils has a significant effect on the growth and zona- tion of mangrove forests. The majority of mangrove species grow best in low to mod- erate salinities (25 ppt), although there appear to be marked differences in the ability of species to tolerate very high salinities. In the past, soil salinity was measured in pore water that drained into a hole made by removing a sediment core. This is not a reliable measure of soil salinity because of uncertainty about the source of water filling the core hole. The method, in which pore water is physically squeezed from the soil sample, is preferred (English et al., 1997).

Soil Particle Size
Two methods are presented for the analysis of soil particle size: a 'hydrometer method' (after Bouyoucos, 1962) and 'pipette method' (after Buchanan, 1984). All soils and sediment (unconsolidated or 'loose' deposits) are composed of particles with a wide range of sizes. These are generally divided into 3 major groups:

- gravel (greater than 2 millimeters),
- sand (0.062 - 2 millimeters)
- mud (silt and clay).

The mud fraction is further divided into coarse silt (62-15.6 µm), fine silt (15.6-3.9µm) and clay (less than 3.9 µm). A graded scheme for soils is given by the Wentworth Grade Scale (Folk, 1974). The species composition and growth of mangroves is directly affected by the physical composition of mangrove soils. The proportions of clay, silt and sand, together with the grain size, dictate the permeability (or hydraulic conductivity) of the soil to water, which influences soil salinity and water content. Nutrient status is also affected by the physical composition of the soil with clay soils, which are generally higher in nutrients than sandy soils (English et al., 1997).

Major Nutrients
Phosphate and nitrate are the major nutrients in mangroves systems. Total phosphate (PO4) and total nitrate (NO3) can be measured in situ with a soil test field kit (Lamotte, Hach), or in the lab, as can a variety of other forms of phosphorous and nitrogen, including both organic and mineral and rates of mineralization.

Nitrogen is normally a limiting factor for mangrove growth at all sites, although in some mangrove environments (with low amounts of "native" soil) phosphates have been shown to be the limiting factor (Boto, 1983, Chen and Twilley, 1999). As fertilization of a mangrove rehabilitation site presents significant challenges, this measurement in not normally taken strictly to inform practitioners, but rather for academic studies.

General Method

1. Soil samples can be taken with a corer/auger. A variety of augers are needed for different substrates, form soft to hard. A typical auger has a 5cm diameter and measures anywhere from 50 cm – 200 cm long depending on data requirements. Soil samples are usually taken from 10 cm sections of the auger, and quickly saved in labeled plastic bags for analysis in the lab.
2. Special care needs to be given to samples for metrics like Redox potential – which can not be exposed to oxygen, and requires saving in a glass test tube with a stopper.
3. Temperature is normally taken at two depths, 10 cm and 40 cm.
4. Both pH and Redox potential are also taken at two depths, 10 cm and 40 cm using a pH/millivoltmeter with platinum electrode.
5. Soil can be collected at both depths and strained using a 20 ml syringe to collect pore water for analysis of salinity using a refractometer.

6. In the lab – soil samples can be analyzed for further metrics such as; wet weight, dry weight, nutrients, trace elements, microbial counts, soil organic carbon and soil composition
7. For each site, three replicates from each sampling plot are used. (English, 1997)

Soil Density - Measured as Shear Strength
In a natural forest, soil density is often higher than in a disturbed site, due to thick root growth and more consolidated clay substrates.

Soil density was shown to have a high degree of correlation to mangrove survivorship and early growth in sites damaged by bulldozer tracks in Darwin Harbor (Metcalfe, 2007)

Method
Soil shear strength (indicating soil density) of near surface soil can be measured using the 33 mm or 19 mm vane test. The shear strength is a measure of the force required to rupture the soil. Three measurements are made at random points within each disturbed site and three readings were also taken in a nearby reference forest. Soil shear strength is calculated using the formula:

$$s = \frac{10^9 \times 6}{\Pi} \times \frac{T}{D^2(3H + D)}$$

where s = vane shear strength , in kilopascals; T = torque to shear the soil, in kilo Newton metres; D= diameter of vane, in millimetres; and H = length of vane, in millimeters.

Discussion Questions

- Which edaphic parameters are you interested in measuring?
- Are any of the edaphic measures you measured useful to inform your rehabilitation plan?
- How do you expect those edaphic measures to change after rehabilitation?

Section 5.3 Disturbance Analysis

Introduction
The nature of disturbances to a site can be natural, man-made, or a mixture of the two. It is important to understand the cause of degradation in a mangrove area and ongoing barriers to natural recruitment.

Once information has been gathered in activities 5.1, 5.2 and 5.4, we need to synthesis and analyze the nature of disturbances present within the site that are inhibiting natural regeneration to inform an effective technical rehabilitation plan and anticipate future disturbances to the site. This activity poses a set of discussion questions to highlight the current hydrological and ecological state of the site (Chapter 5) and visually identify specific points of consideration during the planning process (Chapter 7).

The questions outlined here and resultant map are useful in planning workshops at both the community level as well as higher level planning sessions.

Objective Identify and analyze sources of disturbance to site inhibiting natural recruitment to inform implementation design and guide to implementation planning workshops.

Output Identified disturbances within the rehabilitation site comprehensively mapped. Synthesized information from activities in Chapter 5 Comprehensive Biophysical Assessments to link with strategy statements in Chapter 7 CBEMR Planning activity 6.

Materials

- Large aerial photograph or map of rehabilitation site and surrounding area with current tidal creeks marked.
- Large plain paper.
- Masking tape.
- Coloured markers.

Procedure
Tape the aerial photograph and plain paper to the wall during this discussion. For every question, either mark on the photograph locations of barriers and disturbances with appropriate key, or jot answers on plain paper. This map will be helpful in Chapter 7 CBEMR Planning.

Discussion Questions:

1. **Nature of the disturbance:**
   a. Is the altering disturbance to the site natural, manmade, or both?
   b. If natural, how often does this disturbance occur?
   c. How has disturbed sites naturally recovered in past disturbance events?
   d. Could the natural recovery process be sped up with human intervention? How?
   e. If manmade, are the disturbances permanent or temporary? (eg., Large factories built within the mangrove area vs. areas of clear cut mangrove forests).

2. **Disturbances to Hydrology**
   a. Is the rehabilitation site within the appropriate intertidal range of mangrove habitat – from MSL to HAT? Where is the local MSL boundary?
   b. Are there areas within the site where substrate elevations are either too high or too low to support mangrove recruitment? Where?
   c. Is the site flooding and draining completely on ebb and flood tides?
   d. Are there blockages to water entering the site from the seaward side? If yes, are these blockages permanent structures? Where?
   e. Are there blockages to water entering the site from the landward side? If yes, are these blockages permanent structures? Where
   f. Are there more or less linear meters of tidal creek networks per hectare within the rehab site compared to historical/reference forest creek networks?
   g. Are current tidal creeks following a naturally created path or manmade channels?
   h. Are there dams/weirs present along current tidal creeks hindering continuous flow of water into and out of the site? Where? Can these be removed?
   i. Are tidal creeks experiencing sedimentation or blockages?
   j. Are there water logged areas remaining in the site at low tide? Why are these areas not draining fully? Can these areas be connected to existing or planned tidal creeks?
   k. Are there areas of anoxic soils within the site? Are they close to tidal creeks?
   l. Are there areas of sloughing or obvious erosion along the tidal creeks and or coast? Where are they? What are the causes of erosion?
   m. Is there evidence of sedimentation? Where? Is it gradual or rapid?
   n. Are dike walls (if present) blocking flows to areas of standing water and/or areas of no or low natural recruitment? Which dike walls are causing the most disturbances?

3. **Disturbances to Ecology**
   a. What species were present within the rehabilitation site before disturbance?
   b. Is there evidence of natural regeneration in the rehabilitation site? Adjacent to the site?
   c. If yes, is there a pattern of natural regeneration? Eg. Small areas of high recruitment, or low, widespread recruitment.
   d. If natural regeneration is occurring in places, are the species the same as species listed in question a. of this section? Which species are missing?
   e. Are there fruiting adult trees within or adjacent to the rehabilitation site? What are the dominant species of fruiting trees?
   f. Are pioneer mangrove species (*Avicennia* spp., *Sonneratia* spp., etc.) present?
   g. Are seaward, meso and landward zone adult mangrove species present in or adjacent to the rehabilitation site?
   h. Are there physical barriers preventing fruits from entering the site? Can these barriers be removed?
   i. Do you consider the site to be propagule limited? As a whole or species specific propagule limited?

Fig 5.18 Hydrological Disturbance - Although this dike wall was levelled during initial rehabilitation, it is still high enough to block drainage of the pond (background) into the tidal creek (foreground). After identifying continued hydrological disturbance during monitoring, plans for improving drainage need to be made as part of mid-course corrections.

Section 5.4 Biological Assessments

5.4.1 PARTICIPATORY BIODIVERSITY SURVEY

Introduction
A participatory biodiversity survey was put forward in an un-published document by Claridge (2004). Aside from the obvious reason of collecting information on biodiversity, the participatory nature of the activity is stressed in order to contribute to establishing a situation whereby local people more prepared to take a meaningful role in biodiversity management. This can happen through empowering them, or through creating the cultural, policy and legal "spaces" which allow com- munities to take on such a role.

Before local people can be involved meaningfully in conservation management (whether policy formulation, implementation or monitoring) there are two basic prerequisites[1] :

- there needs to be some commonality of concepts and values between them and the "outsiders" who are traditionally responsible for management, including, particularly, scientists and professional managers; and
- the local people need to have some confidence in their own knowledge and capabilities and need to be able to demonstrate the extent of this knowledge and capability to outsiders, particularly those from the scientific and bureaucratic areas with whom they will be involved in management.[2]

Establishing Commonality of Concepts
Terms such as "biodiversity" and "conservation value" are part of the vocabulary of natural resource management. They have developed their current meanings through a long process of debate and refinement through use, and are closely bound up with scientific concepts as well as largely western values. Local communities are unlikely readily to understand these terms, but they typically have their own terms, value systems and concepts which are associated with their approaches to natural resources. These are frequently expressed in ways that, for outsiders schooled more in formal western science than in the local culture, may mask the depth of their content and usefulness.

1 There are many conditions which need to be in place before sustainable participatory natural resource management can exist - see, for example, Claridge (2004).

2This is one element of the need to enhance and strengthen the capacity of local people to participate in decision-making so as to safeguard their equity which has been emphasized by the Working Group on Traditional Knowledge under the Convention on Biological Diversity (CBD, 2001).

Truly participatory survey activities can provide a way of building bridges between "scientific" and local perspectives and establishing some common understanding of the concepts used. This can be contrasted to the "sledgehammer" approach which is more common in Indonesia (more commonly referred to as *sosialisasi*) in which local people are lectured on the contents and restrictions in natural resource management laws and (sometimes) definitions of terms such as those above.

Establishing Confidence in Local Knowledge and Management Skills
The attitude that local people have no useful knowledge and no effective natural resource management techniques is all too prevalent among scientists and bureaucrats. This is fairly widely recognized, but what seems to attract less recognition is the frequent failure of local people to recognize that their own natural resource knowledge base is quite likely not only extensive but also greater, and possibly more relevant, than that possessed by outsiders.

The idea that "we are only simple poor people, with no schooling" often does as much to hinder participation in management as does the condescending attitude of outsiders to local people. It is true that even apparently commonplace concepts such as "survey", "data compilation" and "data analysis" may not be easily understood by

Fig 5.19 Participatory Biodiversity Survey As part of a 400 ha restoration in the Restoring Coastal Livelihoods Project, MAP-Indonesia held a single day event, a Biodiversity Collection competition, to raise awareness of the richness of existing mangrove resources on Tanakeke Island. Biologists from the local university assisted with sorting the collection, but emphasis was placed on parataxonomy (local names) and moreso on local relevance to the community.

This event sparked the development of an illustrated participatory mangrove rehabilitation monitoring activity (see Chp 9), which involves communities in post rehabilitation monitoring for at least 3 years after intervention.

by local people in terms of their own experience and expertise. The lack of ability to find parallels in their own experience with terms used by scientists and managers contributes to the low self-image of local groups in relation to their ability to participate in natural resource management.

It is often only when local people start to compile their knowledge of natural resources and document their natural resource management approaches that they come to realize the full extent of their knowledge and capabilities. Such realization is the beginning of confidence in their own potential to play an official role in managing their resources.

Objectives

Gadgil (2002) lists the following 6 factors as important considerations in a participatory assessment program;

1. Motivating local people to revive and build on their traditional conservation practices;
2. Establishing a positive relationship between local communities and government agencies;
3. Identifying and establishing a system of positive incentives for local communities to adopt conservation management;
4. Enhancing elements of good governance such as efficiency, participation and transparency;
5. Incorporating local information into the formal system of scientific knowledge so as to make it richer and more immediately relevant; and
6. Ensuring that folk knowledge of conservation management and sustainable resource use is preserved and at the same time giving recognition to the validity of such knowledge.

Time half day to full day for collecting, sorting, debriefing

Materials

- collection buckets
- rafia line and bamboo posts for quadrats
- nets
- cameras (cell phone cameras)
- GPS units
- maps
- field guides (books)
- field guides (prepared, laminated, with common taxa/species – no names)
- data sheets

Procedure

1. Facilitate a discussion of the benefits gained by the community from plants and animals such as; food, spices, medicines, housing, various inputs to traditional aspects of daily life, fishing gear, clothing, water, and weapons.
2. List the key habitats where the above plants and animals (providing benefits) can be found. It needs to be noted that communities may break their environment into different habitats than those identified by ecologists. Communities might lump two habitats together if they do not perceive them as providing different benefits, or might divide a habitat into smaller units if they derive different benefits from the smaller units. This kind of information about local habitats is extremely useful local ecological knowledge and facilitators need to be sensitive to it and to avoid forcing preconceived classifications onto the community. . A facilitator can think here about ecotones (the gradual but distinct differences within an ecosystem) – rather than whole ecosystems, although neither the term ecotone or ecosystem should be used with the group at the start of the exercise.
3. Brainstorm on the characteristics of these different habitats, to reveal that each habitat contains a range of different plants and animals, and that making a complete survey of the whole habitat would be impossibly time-consuming.
4. The concept of sampling should be introduced, with the idea of quadrats (plots) and the need for randomness in order to overcome bias.
5. The need to avoid bias in the results was further discussed, and a method for randomizing the choice of sample area was explained.

   One method for selecting random sampling sites follows:
   - choose one area of the particular habitat by writing each of the locations mentioned by the community on pieces of paper and selecting one randomly from a container;
   - choose the direction to the sampling area from the middle of the habitat area by writing eight directions on pieces of paper and then drawing one randomly from a container; and
   - choose the distance to the sampling point from the mid-point of the habitat (in the direction of indicated by the previous step) by writing distances on pieces of paper and then drawing one randomly from a container.

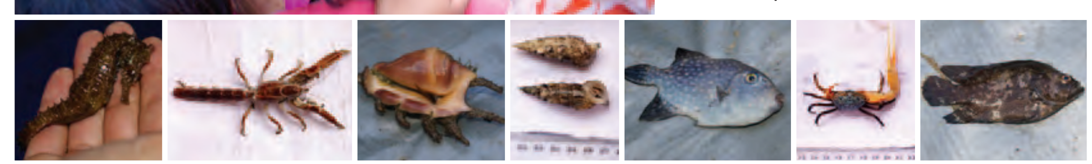
6. Develop together, instructions of how to set up plots and collect data on plants and animals.
7. Provide training in use of maps and GPS for locating the plots exactly.

8. Practice laying out a 20 m x 20 m quadrat at a randomly selected location, identified on a map using the following method;
   - Use 80 meters of raffia line. Tie knots every 10 m. Every 20 meters you will place a corner post, with the 10 m knot assisting the team in finding the mid-point of each sector of the quadrat.
   - Measure off Two 20 m lengths of line used to bisect the quadrat into four equal plots.
   - Record plant and animal information on standard forms.
9. Collect data in the field from a variety of mangrove habitats. Hopefully seaward, mesozone and landward mangroves will be represented. Tidal creeks may comprise a different habitat, as may hinterland zones. Degraded areas and references forests will hopefully be considered. Data collected may include:
   - the location of centre point of the plot (determined using GPS);
   - the name(s) of the plant or animal (local language, national language, and Latin) if known;
   - a digital photograph of each plant species ;
   - the part of the plant or animal that is used;
   - any benefits of the plant or animal to each of: people, wildlife or livestock, other plants, soil, and water.
10. Back in the village the raw data should be tabulated (see Attachment 4) by the field survey teams and summary data was extracted and tabulated. The collection can be sorted and tabulated in a central part of the village, to raise awareness/interest amongst a large portion of the population.
11. Hold a discussion to analyze the results.
12. Video footage and digital still photographs of the field activity can be viewed by the participants and other members of the community each evening, providing an opportunity for reflection.

Discussion Questions

- How did the amount of biodiversity revealed during the survey compare to your understanding of the different types of plants and animals in the mangroves before the survey?
- What were the main differences in biodiversity between the rehabilitation area and the reference forest?
- Does your community appreciate biodiversity? Why or why not?
- Is it important if an animal or plant has an economic use?
- Is it important if ALL animals and plants have economic uses?
- How might you be able to increase biodiversity in your mangrove area?

Fig 5.20 A Community Event
A briefing before the event is essential to get everyone on the same page; (*top left*) Encourage families to participate together, part of a life-long learning process; (*middle*) Sorting the samples in the center of town helps raise awareness; (*bottom left*) Contests for highest amount of biodiversity with appropriate prizes (in this case mask and snorkel) help ensure a fun time and large turn-out; (*top right*) Mangroves are highly biodiverse communities, this event collected 82 species of fauna in a single day (*bottom row*).



5.4.2 Benthic Macroinvertebrate Survey

Introduction

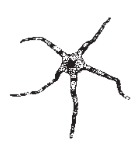
There is a pressing need for a set of criteria that can be used to identify the degree of anthropogenic impact to mangroves, as well as to identify those areas most suitable for conservation and/or restoration initiatives. Layman et al., (2010) provide a set of taxa that can be used as indicators in mangrove-dominated tidal creek ecosystems. The analysis was based on gradients of human impact measured at both local (tidal creek fragmentation) and regional (human threat indices) spatial scales. Such indicator taxa provide a simple tool for local resource managers, policy makers, and educators, and can be used for rapid assessments of human impacts on floral and faunal assemblages in tidal creeks.

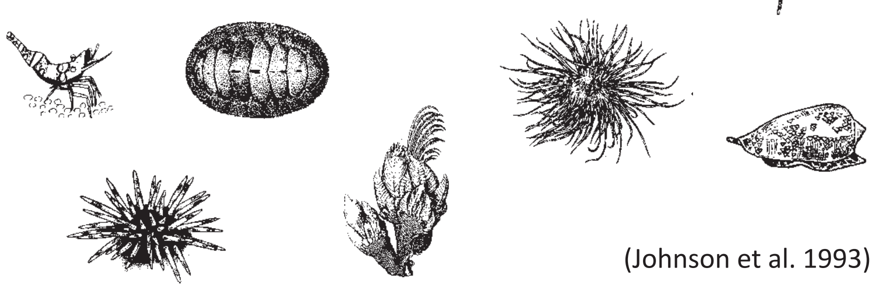
Benthic macroinvertebrates are small bottom dwelling organisms that can be seen with the naked eye. Macroinvertebrates are widely used as indicators of river water quality, which itself reflects the health of the watershed or catchment, through which a river flows. Benthic macroinvertebrates serve as good indicators because their lack of mobility means their local populations change rapidly when environmental conditions change. Most are not economically valuable, so fishing pressure does not need to be accounted for, and surveys are relatively inexpensive compared with fisheries surveys. (See Fig 5.21 for more information about what makes a good bioindicator).

Fig 5.21 Characteristics of Ideal Indicator Species

Although many organisms can be used to monitor water quality, the "ideal" characteristics that bioindicators should posses are:

- Taxonomic soundness and easy recognition
- Broad distribution to facilitate application to other regions
- Abundance to permit easy and repeatable sampling
- Large body size to facilitate sampling and sorting
- Limited mobility and relatively long life history
- Available data on organism ecology





(Johnson et al. 1993)

Indices have been developed to evaluate the health of a river or catchment, based on the types and diversity of macroinvertebrate taxa that live at the river bottom. For instance, species of juvenile water-born insects like mayfly, stonefly and caddisfly indicate a river is healthy with well oxygenated water, while an abundance of leeches, blood midges or pulmonary snails (snails with lungs) may indicate a river's water is less clean and oxygenated.

One of the most descriptive of these indices was developed by Dr James Karr and his graduate students at the University of Washington for Pacific Northwest salmon streams. This index, known as a Benthic Index of Biological Integrity was developed with both five and ten metrics, which correlated well with the health of a river especially related to anthropogenic (human-caused) degradation to the surrounding catchment. Aside from percentages of stone, caddis and mayfly nymphs in a collection, long-lived macro-invertebrates, predatory macroinvertebrates and several other metrics were used as key indicators.

Similar indices can be developed in tidal creeks which flow through mangrove systems. Craig Layman and colleagues experimented with the development of a B-IBI appropriate to mangrove dominated tidal creeks in the Caribbean and Bahamas. In selecting taxa Layman considered an IBI, (e.g., % of individuals that are members of certain feeding guilds or % of individuals with a disease), but also undertook a search for a simple set of taxa, lending itself more useful to local coastal managers, policy makers, educators and the public engaged in participatory monitoring.

They resultantly came upon a set of taxa (which included not only benthic macroinvertebrates (sponges, coral, barnacles) but flora (seagrass and *Halimeda* spp. [macroalgae]), and a host of fish species as well ,whose population dynamics could be used to gauge the degree of habitat fragmentation at a local level, and also general degradation of mangroves at broader scales.

Whether a collection of taxa should include benthic macroinvertebrates only, or a range of flora and fauna, is entirely dependent upon factors in differing biogeographic regions. As mangrove types also vary, in terms of geomorphologic classification, indicator species for at least three geomporphological types (riverine, fringing, estuary) and perhaps as many as seven (see Fig 5.22).

Below, we present a method to collect benthic macroinvertebrates from tidal creeks in mangrove systems, to prepare a Sequential Comparison Index. The SCI describes a relative degree of biodiversity of the sample, which is a rough indicator of ecosystem health. The SCI is meant to suffice, until researchers take up the challenge of developing locally appropriate B-IBI's.

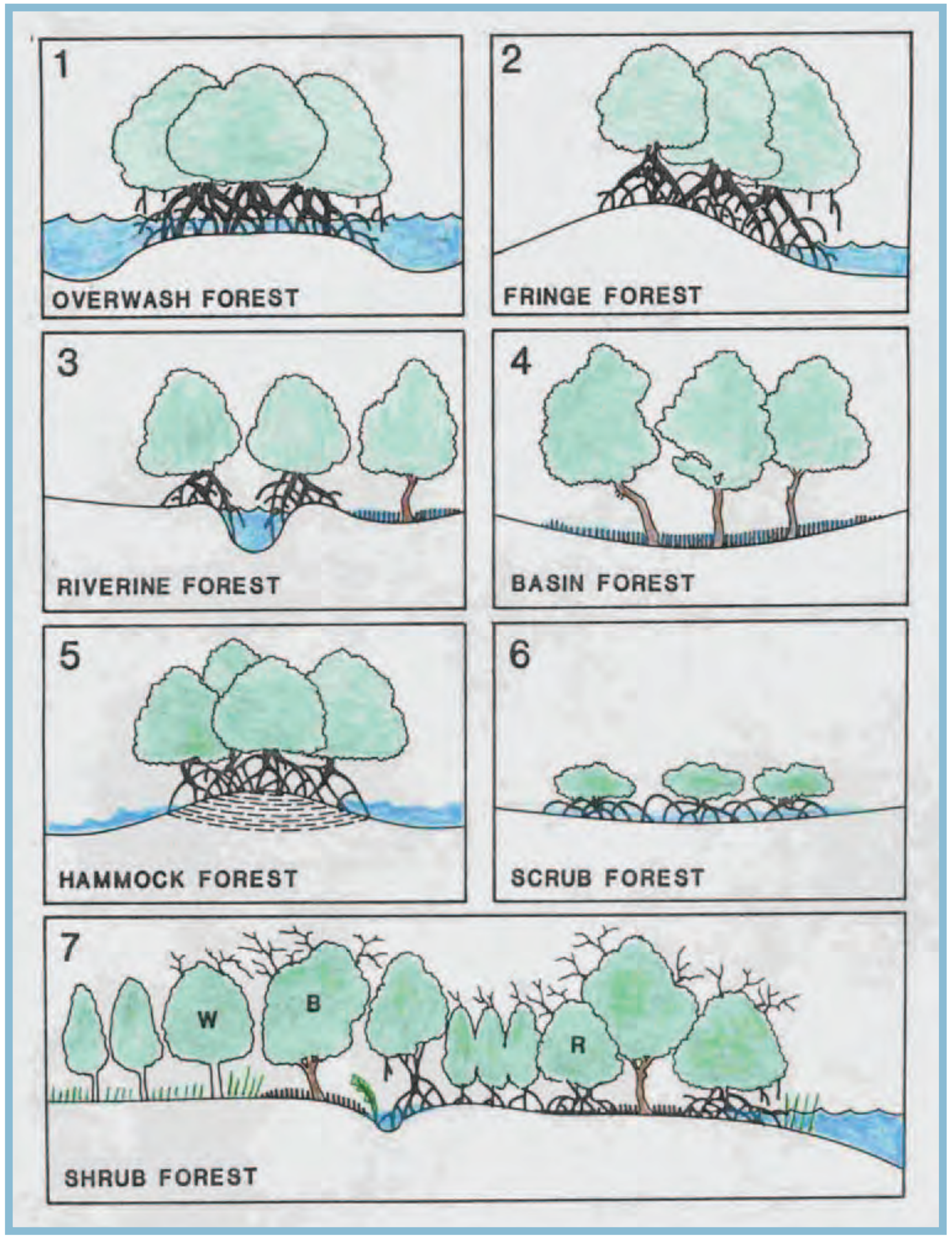


Fig 5.22 Seven geomorphological classifications of mangroves (modified from Lugo and Snedekar, 1974) which will likely each require different sets of indicator taxa for assessing the extent of human-caused disturbances.

Objectives

- Become more familiar with the range of taxa found in mangrove dominated tidal creek systems
- Measure tidal creek and mangrove ecosystem habitat quality by determining diversity or number of different kinds of benthic macroinvertebrates.

Time Approx 3 hours

Materials

- Benthic macro-invertebrate sampling gear (dip nets, kick screens, surber samplers, Hester-Dendy sampler)
- Snorkeling gear
- Waterproof paper/clipboard
- Sorting trays
- Forceps
- Guide books to local fauna
- Pickling alcohol
- Collection bottles
- Digital camera

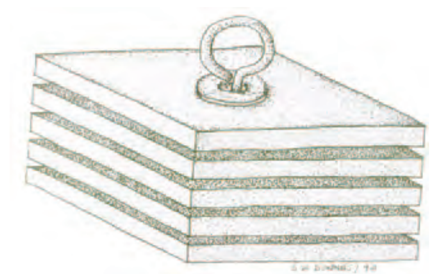


Fig 5.23 A Hester-Dendy artificial substrate sampler.

Background Information

The Sequential Comparison Index (SCI) is a measure of the distribution of individuals among grops of organisms. This index relates to the diversity and relative abundance of organisms. This measure is easily used by people unfamiliar with benthic identification. The SCI is based on the theory of runs. A new run begins each time an organism picked from a sample looks different that the one picked just before it.

SCI = # of runs/Total # of organisms picked

This index is being used in lieu of more complex indices, such as the B-IBI (benthic index of biological integrity) which require exhaustive collection and analysis of local taxa in comparison to previously understood habitat conditions, resulting in the development of reliable, measureable indicator taxa.

Procedure

1. Select sampling sites: The sites should be representative of major sections of tidal creeks typical to your mangrove forest. Sampling should be done in seaward, middle and landward sections of the tidal creek, from a pristine reference forest and degraded site such as the proposed rehabilitation site. Note the creek position, and whether it takes place in reference forest or degraded site on your data sheet.
2. Selection of substrate type: A variety of substrate types may be sampled in a variety of ways. Substrate types may include;

   Rock structure, soft bottoms, sandy bottoms, gravelly bottoms, coral bottoms, seagrass beds, halophytic grass patches, tree root structures and around large woody debris.

   Mark down the type of substrate on your data sheet. In very soft bottoms (fluid mud flats), artificial substrates such as a Hester-dendies sampler, may be placed.
3. Sample using a D-frame net or kick screen. Hold the opening end of the net into the current (direction depends on flood or ebb tide) and shuffle your feet upcurrent from the net. Benthic macroinvertebrates should be dislodged by your feet moving on the bottom and carried by the current into the net. A kick screen requires 3 people to operate, one person holding each pole, and a third person who begins upcurrent and shuffles their feet (for a standard amount of time or distance) down to the net. The third person then helps lift the bottom edge of the net out of the water so the sample can be collected and processed. Three samples, of at least 300 total organisms should be collected at each station.
4. If preparing a B-IBI collection, the sample can be preserved in 70 percent alcohol. If not, the samples should be kept alive in plastic buckets with clear tidal creek water, before processing. Keep the animals in the shade, to avoid stressing them. Following the instructions below, pick organisms from the sample to calculate the Sequential Comparison Index.
   a. Make a grid of 5-7 cm squares on the bottom of a white tray with a black wax pencil or permanent black marker. Number the squares in order.
   b. Spread the organisms evenly over the bottom of the white tray.
   c. Randomly select a starting grid from which to start picking the sample. Begin picking out organisms in a random sequence. Pick all specimens from one square before moving to the next. Continue picking until all, or 50 specimens are selected.
   d. Forceps, a pipette, or a paint-brush work well for picking smaller macroinvertebrates. Beware of potentially poisonous specimens, such as small octopus, cone shells, or spines from certain species of fish, as well as the strong claws of larger crab species.

   e. Place organisms in a dish (a white Frisbee works well) to compare each organism with the previously picked organism and record them on a work sheet using the syumbols x and o (see example below). Record an "x" for the first organism picked. If the second organism picked is similar, record another "x." In the example below, the third organism picked is dissimilar to the previous organism, and so that is recorded as an "o," indicating the start of a new run.
   f. After comparing specimens, place each in a perti dish (or Frisbee for large organisms) containing similar organisms. This provides a rough sorting of the organisms into major groups to aid in identification.
   g. To calculate the SCI, count the number of runs and dived by the total number of organisms.
   h. Calculate an SCI for each sample. Average the samples to calculate a mean SCI for the

Analysis

Determine the quantitative rating of the SCI , using the scale below.
Circle the number on the data sheet that describes what you observed.

	SCI Value
4 (excellent)	0.9 – 1.0
3 (good)	0.6 – 0.89
2 (fair)	0.3 – 0.59
1 (poor)	0.0 – 0.29

Discussion Questions

- It is thought that the tree roots have the highest level of diversity in the tidal creek. What did you find?
- How do soft bottoms compare to sandy or rocky substrates?
- How does diversity change as you move landward or seaward?
- What physical factors seem to influence diversity, and hence the SCI?

5.4.3 Nekton Diversity

The following method was provided courtesy of Severino Salmo, Philippines

Introduction

Mangroves act as nursery sites and feeding areas for a variety of juveniles of commercially important shrimp and fish species (Robertson and Duke 1987; Halliday and Young 1996). Fisheries production is linked with the extent and health of mangrove forests (Hamilton et al. 1989; Meynecke et al. 2007). The attractiveness of mangroves to fish can be explained by two hypotheses: (1) the predator refuge hypothesis (Laegdsgaard and Johnson, 1995) – where prey can avoid predators because of the structural complexity and high water turbidity in mangroves (Abrahams and Kattenfeld 1997); and (2) the feeding hypothesis – where mangroves offer foraging areas because of their high productivity and carbon outwelling.

The aim of this exercise is to document and assess tide-mobile nekton communities (fish, crustaceans and molluscs that move in and out of mangroves with changing tides). We will use a modified trap net to analyze nekton abundance, biomass and diversity index. Depending on the availability of data and sampling locations (in reference to other groups' projects), we will also assess whether there is a relationship between nekton and the state of mangrove vegetation and soil.

Objectives

- Assess diversity, biomass and abundance of nekton communities moving in and out of mangrove tidal creeks.
- Draw conclusions between nekton populations and the health of the mangrove system.

Time Approx 3 hours

Materials

- Modified triangular trap net (1.2 m height x 10 m wingspan; 3 m pocket)
- Bamboo stakes
- Ruler
- Digital balance
- Field Identification Guides for Fish and Crustaceans
- Buckets/plastic bins

Procedure

1. A modified local triangular trap net will be used. The trap net is designed to catch nekton that enter mangroves at high tide and will be potentially trapped as the tide recedes. The net will have a height of 1.2 m, with 10 m wingspan on each side (containing an area of ca. 43.3 m^2) and 3 m pocket that is connected at the cod end. Bamboo stakes will be used to secure the wings and ends of the nets to the soil. All nets will have a stretched mesh size of 2 mm. A single trap net will be deployed per site with the ends of the wings ~1 m from mangrove fringe at low tide.
2. Identify a tidal creek of less than 10 m channel width as a sampling site. Record the position of the site with a GPS.
3. Set the net during a rising tide.
4. Measure ambient water quality parameters (i.e. salinity, DO, temperature, pH)
5. Wait for the tide to peak and recede. Collect nekton from the pocket of the trap net at the next low tide. Place in buckets with brackish water for transport to the lab.
6. Take photos of the site and the trap net.
7. All collected individuals will be sorted in the laboratory. The collected samples will be measured standard length (fish), carapace width (crabs), carapace length (shrimp) using a ruler (± 1 mm), weighed using a digital balance (± 0.1 g), and identified to species level using Allen et al. (2003) and Kuiter and Debelius (2006) (use local names as well as latin names). Data on trophic category, habitat preference and juvenile size for each species will be obtained from Matthes and Kapetsky (1988) and FISHBASE (Froese and Pauly 2004).
8. Enter data and make calculations.

An example data sheet for recording nekton in mangroves:

Species Name	Local Name	Type of Nekton (fish, crab, shrimp, squid, etc.)	Length (cm)	Weight (g)	Life Stage	Habitat Preference	Trophic Structure

Discussion Questions

- What types of relationships exist between mangrove communities and nekton communities? In terms of diversity? Abundance?
- How might the results of this survey change during the month? Year?
- Do you need to make considerations for local fishing pressure? How would you need to alter the methodology to consider fishing pressure?
- How might the results of this survey be linked to mangrove value?

6

ASSESSING RESILIENCE

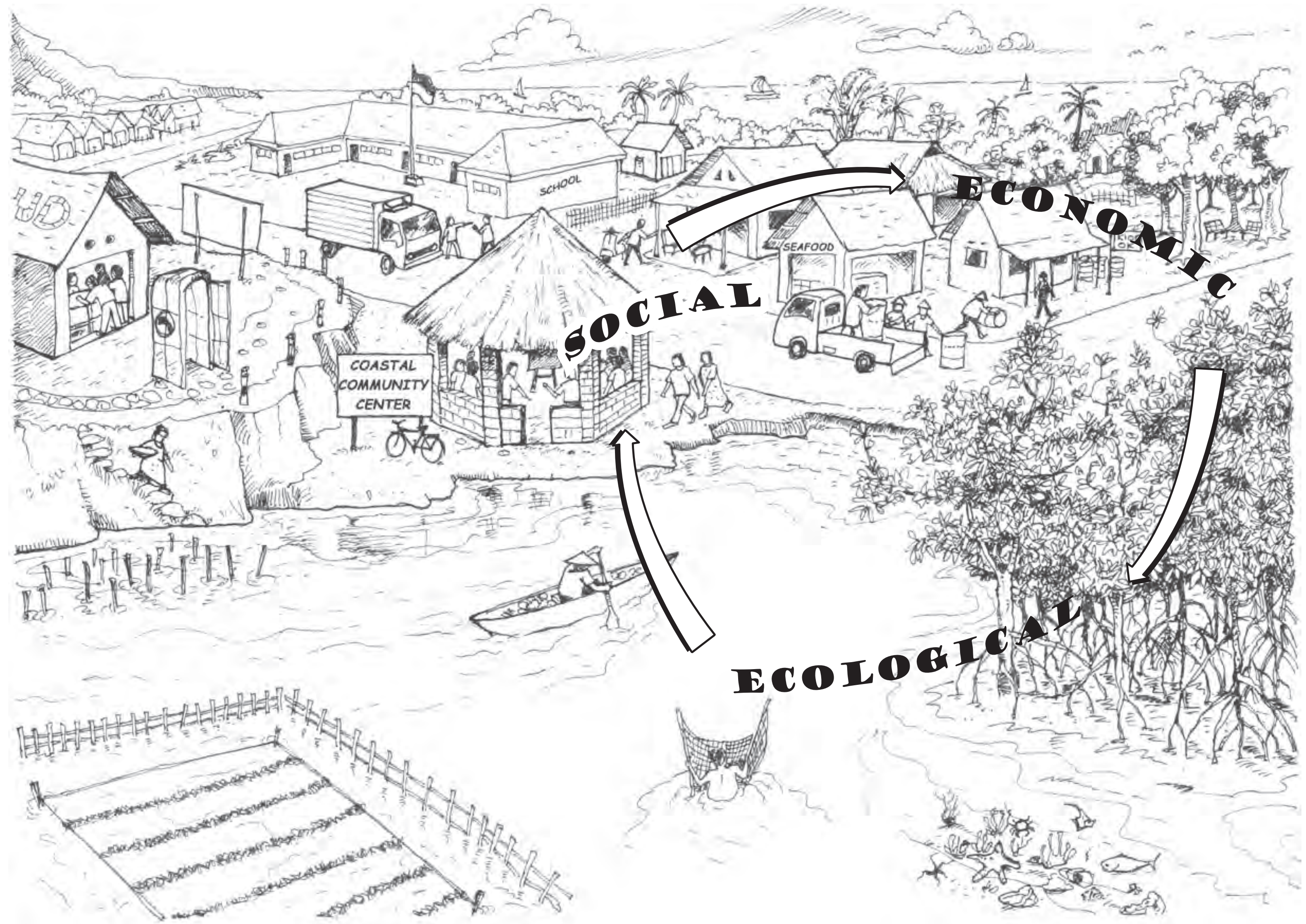
6.1 Adding Socio-economic Factors to Complete the Picture

Chapter 5 provided approaches and activities to undertake Biophysical Assessments of your rehabilitation site as well as a nearby reference forest. These measurements will be used to inform rehabilitation design, as well as to monitor changes over time. Likewise, social and economic measures will need to be taken, to help complete the picture in terms of EMR planning and design, and also to track changes which take place amongst society as a mangrove area is restored.

There are numerous resources already available to help monitor social and economic factors in a community. Many of these are part of Participatory Rural Appraisal methods, or other similar methods. At the end of this chapter we recommend several good resources, which are available for free online.

Rather than re-create the wheel, what we offer in this chapter is a brief overview of assessing social and economic factors that have clear linkage to coastal community welfare, which can be either assessed to inform a mangrove rehabilitation program design, or monitored to track socio-economic changes linked to the an EMR program. We also provide a little insight into resilience theory, which at it's heart speaks to the integration of social, economic and ecological factors into a single system.

2. ECONOMIC SYSTEM
Follows a commodity chain, from coastal resource capture and production in to end use.



1) SOCIAL SYSTEM
The community of people involved both directly and indirectly in coastal resource use and management.

This includes fishers, fish farmers, farmers, charcoal makers, etc. as well as purchasers, fisheries, agricultural and forestry extension workers and managers, other government agents, NGO workers and academia.

3) ECOLOGICAL SYSTEM
Assessment of the ecological system has three focal points, 1) the landscape level, 2) agro-ecosystem level, 3) habitat restoration. An improved ecological base drives continued social and economic development, by providing a diversity of opportunities and enhanced overall resilience.

6.2 Introducing Resilience

By tracking some key social, economic and ecological parameters around your mangrove rehabilitation project, people engaged in mangrove rehabilitation and future management can explore management options and scenarios for the mangrove system of interest, from a resilience perspective.

Resilience can be defined as the ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance (Walker, 2002). You can see how this definition is relevant to mangrove rehabilitation, in term of thinking about coping with shocks and disturbances, avoiding degradation, and regenerating after disturbance.

Resilience theory is complex, but quite worthwhile to pursue. A good place to start is at the website of the resilience alliance (www.resalliance.org). For the purposes of this book, we will only offer two additional definitions to consider, which will help ensure that your mangrove rehabilitation intervention, is not being thought of as an ecological activity alone.

Socio-Economic-Ecological System (SEES) – an integrated system of human society, businesses and livelihoods, and the mangrove ecosystem. By seeing the system from social, economic and ecological aspects, there is less risk of over-simplifying management options. Parameters in a SEES system are understood to be interdependent, with reciprocating feedback mechanisms. The concept emphasizes the 'humans-in-nature' perspective.

Adaptive capacity/Adaptability – the capacity to adapt and to shape change. In a mangrove system, one of the keys to adaptation is biodiversity. A mangrove forest with a full complement of tree species will be able to colonize newly available substrates more successfully than a monospecific stand. In the age of sea-level rise, and climate change, the ability to adapt to changes in the coastal landscape may be greater than ever.

In a social-ecological system, adaptability amounts to the capacity of humans to manage resilience. Again, diversity, and even redundance may be an important attribute. If community members, both poor and rich, as well as other external stakeholders, all care about a mangrove system, it may become harder for an individual actor to affect change, such as an investor wishing to convert an area for development.

Who Uses Information from EMR Resilience Assessments?

- Coastal Communities
- Development workers and government extension agents,
- Researchers,
- Policy makers and planners.

Why Perform a Resilience Assessment?

- To identify at an early stage, remedies to problems caused by lack of management or inappropriate management.
- To act as baseline data for evaluation of the coastal system under new management practices.
- To provide policy makers and development planners a sound basis in formulating and revising policies and programs.

Sources of Information

- District and Provincial Government Offices; forestry, fisheries, agriculture, social, planning, etc.
- Research, extension and technology institutions
- National government
- Development organizations/NGOs
- Local people (using participatory methods; see Participatory appraisal methods.)
- Field measurements (e.g., of species and associations of mangroves, substrate elevation, cross-sections of tidal channels).

Where possible, information from one source should be validated by checking with another source. For instance, the local bank's assessment of credit availability according to the local bank can be checked against local people's own assessment. This cross-checking is called "triangulation. "

Resilient resource use: The management or use of resources within their capacity to renew themselves and maintain the integrity of the system within which they exist.

Examples:

- Substrate elevation levels may be maintained due to inputs of organic matter from the forest itself, but succumb quickly to erosive forces when that source of biomass is removed.
- Harvest of *Avicennia* fruit to drive a flour making industry, with limits to percentages of harvestable fruits, to allow for natural regeneration.

6.3 Socio-Economic Indicators

Now that we have introduced the concept of resilience, not too much more will be said on the subject directly, but many sections in this book underscore the importance of the interdependence of social, economic and environmental factors. From the previous chapter, biophysical or ecological measurements were taken. In this chapter we provide a simple means of collecting social and economic information to help complete the picture from a resilience standpoint. There are numerous resources and tools specifically designed to gather socio-economic information in a coastal community. Rather than reiterate all of the good tools out there such as seasonal calenders, historical transects and gender analysis we refer the reader to a variety of useful resources in the reference section at the end of this chapter.

Towards the end of the chapter, we do provide a comprehensive scorecard, of indicators that can be measured and tracked throughout an Ecological Mangrove Rehabilitation program; social, economic and environmental. We provide a simple scoring system of 1, 2, and 3 (1 being the lowest, 3 the highest) for two purposes;

1) to inform the EMR design
2) to track changes over time.

Parameters with low scores, will require greater consideration during EMR implementation, in order to be enhanced over time.

By looking at social, economic and ecological indicators, when designing an intervention, there is greater likelihood of building the resilience of the whole system, in this case the integrated system of coastal communities and mangroves.

As an example, it may seemed far-reachng that a mangrove rehabilitation program can influence patterns of community migration (the first social indicator), but if a large mangrove area recovers, coupled perhaps with improved management of aquaculture, or development of sustainable livelihood alternatives, the need to migrate in search of richer fisheries resources, or development of new aquaculture ponds may be reduced, thus allowing fisherfolk to remain in their own communities.

Because of the holistic nature of this type of endeavour, we use the name **Resilience Assessment**, to mean the measurement of social-economic and ecological factors. The following approach and means of grossly rating various indicators was originally developed by IIRR as part of "Resource Management for Upland Areas in SE Asia," and has been adapted for use in a coastal settings.

6.4 Approach: Regard the indicators on the following pages, and use the data sheets provided to begin or continue a survey based on the following steps.

1. Identify the objectives of your assessment and select appropriate indicators. A number of potential indicators have been provided, but it is important to consider the specific needs of your own program.
2. Discuss the indicators with the local community and modify them to suit your programs specific objectives
3. Arrange for the team to go to the mangrove forest and coastal community and record information
4. Validate the information by checking against other sources.
5. Set up baseline data and identify specific indicators and parameters.
6. Rate the general state of the indicator you are measuring using the following grading system

   1 = not resilient (healthy over long term)
   2 = building toward resilience
   3 = resilient

7. Interpret rated indicators through discussions.
8. Repeat steps 3-7 each year.
9. Check for changes in the ratings from year to year. If a rating falls over time, the system is becoming less resilient.
10. Propose changes in policy and program strategies to improve resilience.

Outcomes

- Baseline data on individual coastal resources and utilization,
- Baseline data on socioeconomic status of the local community.
- Trends related to the coastal resource and local community after several years of replication and analysis.

6.5 Table of Resilience Indicators

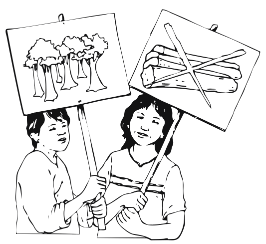
SOCIAL INDICATORS

Social Indicator	Rating	Means of Collection & Verification
A) Settlement Pattern	1) frequent migration 2) seasonal/temporary migration 3) permanent settlement	- records/reports on landlessness from public welfare department, local government - permanent migration, seasonal migration and relocation policy
B) Food, nutrition and sanitation	1) severe shortage of food 2) insufficient/permanent 3) sufficient and balanced diet, good condition of shelter	- records/statistics on health and well-being (e.g. health, food shortage, condition of shelter and other social services. - key informant interviews - field observations
C) Structure/condition	1) temporary/poor condition 2) semi-permanent 3) permanent	- statistics/spot maps/social maps from local government/NGO's - field observation
D) Peace and order	1) unsafe 2) somewhat safe 3) safe, peaceful and orderly	- records/reports on criminal events - key informant interviews - field observation
E) Exposure to toxic chemicals, pollutants and dangerous pesticides	1) frequent exposure 2) moderate exposure 3) little or no exposure at all	- surveys/records/reports on yield and production by agricultural extension officers - reports from special studies (e.g. recent fish kills) - key informant interviews - field observation
F) Access to support services (credit, extension service, inputs)	1) few or no support services 2) less than adequate support services 3) adequate support services, self-help	- research/evaluation reports from community development offices, NGO's
G) People's participation in natural resource management	1) no participation, male participation but no women's participation 2) little participation, active but few participants, few women 3) active participation, equal participation by women	- attendance sheets - evaluation reports from community and from meetings - key informant interviews
H) Local rules and regulations on the use of natural resources	1) rules or regulations inadequate 2) adequate rules and regulations, inefficient implementation or enforcement 3) good implementation and enforcement	- historical/existing information on the rules and regulations being implemented in the community over natural resources management - key information interviews - field observation

SOCIAL INDICATORS (cont'd)

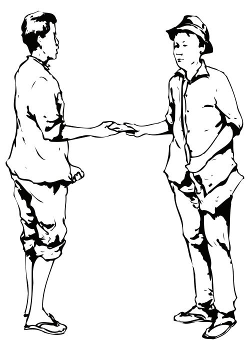
Social Indicator	Rating	Means of Collection & Verification
I) Participation by government offices in extension work and active co-management	1) no participation, no female extensionists 2) little participation, some female extensionists 3) active participation by men and women	- reports from field schools - key informant interviews - field observation
J) Integration of appropriate cultural and traditional practices into natural resource mgmt	1) no integration 2) adequate integration 3) highly integrated	- research - key informant interviews - field observation
K) Community takes long-term perspective of livelihoods and environment	1) short-term decision making dominates 2) some long-term vision 3) long term vision and action/spatial plan	- results from visioning activities - natural resource management plans - sustainable production or business practices in place
L) Community, including women aware of its rights and the legal obligations of government and other stakeholders to provide protection and services	1) lack of awareness of rights and responsibilities 2) some awareness 3) highly aware and active in ensuring rights	- pre/post tests
M) Men and women able to access to government funds and services for CBNRM and livelihood support.	1) no access, few funds and services, especially for women 2) some access, some funds and services 3) clear access and adequate funds and services for men and women	- government loan records - cooperative records - bank records
N) Local stakeholders committed to genuine partnerships (with open and shared principles of collaboration, high levels of trust).	1) low participation, no collaborative mechanisms available 2) some participation and collaboration 3) adaptive collaborative management occurs	- interviews - community sought partnerships,
O) Community and local groups have capacity to recruit, train, support and motivate community volunteers for CBNRM and Livelihoods development, and work together to do so.	1) no to low genuine volunteerism 2) volunteerism exists, but seldom for CBNRM and livelihoods 3) active volunteer base for CBNRM and livelihoods	- attendance sheets of volunteer events - reports

NRM INDICATORS



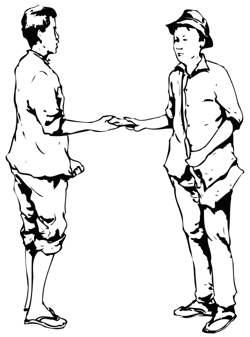
Natural Resource Management Indicator	Rating	Means of Collection & Verification
P) Community understanding of characteristics and functioning of local natural environment and ecosystems (e.g. agro-ecosystems, forests) and human interventions that affect them (e.g. large-scale monocultures, conversion of forests, erosive farming practices).	1) unaware 2) some awareness 3) aware	- Pre-post data from awareness campaign survey - Resilience assessment
Q) Adoption of sustainable environmental management practices (ecologically friendly aquaculture, maintenance of shelter belts, natural forests, etc)	1) low amount of eco-friendly practices 2) medium 3) high amount of eco-friendly practices	- Reports
R) Understanding of relevant biodiversity and preservation of biodiversity	1) no intentional biodiversity protection 2) some intentional biodiversity protection 3) biodiversity surveyed, monitored and protected	- Participatory biodiversity survey - Pre and post test - awareness
S) Preservation and application of indigenous knowledge and appropriate technologies relevant to environmental management.	1) eroding traditions 2) strong tradition – little incorporation/credibility 3) incorporation of traditional practices into modern management of resources	- Survey
T) Women and men's access to common property resources that can support coping and livelihood strategies in normal times and during crises.	1) low access 2) some access by some members 3) full access of most/all members	- Designated common property resources (e.g. hutan pangandiran) - Local legislation
U) Women and men involved in development of natural resource management plans which feed into local government development and landuse planning	1) no local plans 2) local plans but no coordination 3) local plans feeding into gov't planning	- Community CBCRM Plans - MOU's between community and government - Government management plans, land use plans
V) Habitat restoration cost	1) >$5000/ha 2) $2000 - 5000/ha 3) $500 - 2000/ha	- Project financial records, spatial data of hectarage restored
W) Forest Restoration Methods	1) planting only projects 2) experimentation of methods 3) adoption of EMR or Human Assisted Natural Reforestation	- surveys - interviews with government practitioners - interviews with communities
X) Percentage & status of conservation areas	1) poor condition (encroachment, conversion, clear-felling) 2) average condition (infrequent encroachment , conversion and clear-felling) 3) intact forest	- statistics/records/reports of local forestry office and conservation NGOs on forestry - field observations
Y) Connectivity of mangrove management to adjacent ecosystems	1) no connectivity 2) connected to other coastal environments only 3) mgmt connected to terrestrial environments	- atlas - management plans

ECONOMIC INDICATORS



Economic Indicator	Rating	Means of Collection & Verification
A) Level of local economic activity and employment (including among women and vulnerable groups);	1) low – much unemployment - especially women 2) medium – some unemployment, few local businesses - increasing oppportunities for women 3) high – numerous small businesses and cooperatives - women as major economic force	- economic surveys - business plans - cooperative records - government trade records - gendered division of labor
B) Stability in economic activity and employment levels.	1) constantly changing profession or resource base 2) adequate 3) highly stable professions – resource base	- resource surveys - household livelihood strategy surveys
C) Distribution of wealth and livelihood assets in community	1) concentrated wealth with many poor, dominant male ownership of wealth 2) some rich and poor families, large middle class, some women with assets 3) equitable	- wealth ranking - gender analysis
D) Livelihood diversification (household and community level), including on-farm (fish farm and dry-land farm) and off-farm activities in rural areas.	1) uniform 2) medium 3) highly diverse	- surveys - analysis of cooperative/business structures
E) People engaged in unsafe livelihood activities (e.g. mining, illegal logging) or hazard-vulnerable activities (e.g. rain-fed agriculture in drought-prone locations).	1) many hazardous and risk professions 2) few participants, but highly risk professions 3) non-hazardous, low-risk professions	- surveys
F) Small enterprises have business protection and continuity/recovery plans.	1) vulnerable 2) adequate 3) resilient	- study
G) Local trade and transport links with markets for products.	1) low local trade, few transport links 2) adequate 3) thriving local trade, adequate transport to outside markets	- updated commodity chain
H) Mechanisms for women to inherit property, ponds, housing.	1) no mechanisms, vulnerable women 2) adequate 3) clear mechanisms in placed and practiced	- surveys
I) Household and community asset bases (income, savings, convertible property) sufficiently large and diverse to support crisis coping strategies.	1) vulnerable 2) adequate 3) resilient	- resilience assessment

ECONOMIC INDICATORS (cont'd)



Economic Indicator	Rating	Means of Collection & Verification
J) Costs and risks of disasters shared through collective ownership of group/community assets.	1) no risk sharing, individualistic 2) risk sharing through family and non-formal structures 3) formal structures for risk sharing	- resilience assessment
K) Existence of community/group savings and credit schemes, and/or access to micro-finance services.	1) non-existent 2) non-formal structures 3) formal structures	- bank statements - cooperative book-keeping records
L) Sources of capital for livelihood activities	1) external sources 2) family, co-op 3) credit institutions, co-op, own enterprise, family	- surveys
M) Non-timber forest products use	1) unknown 2) subsistence use 3) subsistence use and marketed	- commodity/use survey - market survey

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Ecological Indicators

The results of surveys from Chapter 5 can provide the basis for scoring of ecological indicators on the following pages.

In order to score these indicators, you can compare the conditions in the mangrove rehabilitation site, with conditions in the reference forest measured (as a benchmark).

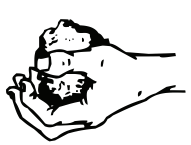
Use the same scoring system as you used above for Socio-economic indicators.

1 = not resilient (not natural/highly degraded)
2 = building toward resilience
3 = resilient (natural or in dynamic equilibrium)

ECOLOGICAL INDICATORS

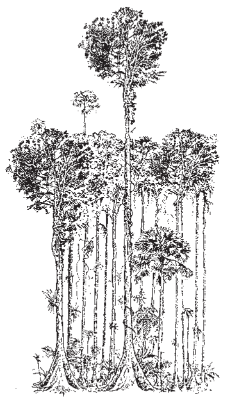
Ecological Indicator	Rating	Means of Collection & Verification
PATTERNS OF SEDIMENTATION/EROSION		
A) Erosion	1) serious erosion (90 degree cliffs, measureable shore erosion) 2) moderate erosion (sluffing in some areas) 3) less erosion	- sediment in streams - top soil thinning - database/information from records/reports of concerned agencies (forest & agriculture depts.) - field observation
B) Sedimentation	1) rapid accretion of sediment, abundant colonization of mangroves followed afterwards by terrestrial/beach vegetation, clogged tidal creeks 2) some sedimentation, some colonization of mangroves 3) low degree of sedimentation	- records/reports on annual yield and production of some selected crops from agricultural extension offices. - records/reports on the area and effects of problem soils
HYDROLOGY - FRESH WATER *CONDITION*		
C) Streams/rivers	1) overflow after rainfall 2) dry in dry season 3) relatively consistent flows year round	- records/reports on stream flow from irrigation stations
D) Occurrence of flood, drought	1) often 2) moderate 3) rare	- records.reports from the irrigation department, community development, etc. and key information interviews.
E) Access to Sources of FW/Ground Water	1) poor, much diversion of freshwater inputs, or blockage 2) average 3) natural	- records, reports from the irrigation department, community development, etc. and key information interviews

ECOLOGICAL INDICATORS



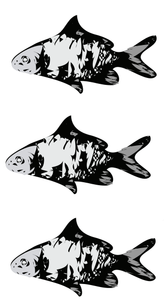
Ecological Indicator	Rating	Means of Collection & Verification
HYDROLOGY - INTERTIDAL *CONDITION*		
F) Substrate Elevations	1) unknown 2) estimated 3) measured and applicable at rehab site	- hydrological survey, participatory monitoring, remote sensing
G) Tidal Creeks Morphology	1) unknown 2) from historical images 3) ground truthed and measured	- hydrological survey, participatory monitoring, remote sensing
H) Extent of Tidal Creeks	1) unknown 2) from historical images 3) ground truthed and measured	- hydrological survey, participatory monitoring, remote sensing
I) Drainage from Rehab Area	1) standing water at low tide 2) tidal channels beginning to form 3) well formed tidal channels, good drainage at low tide	- hydrological survey, participatory monitoring
J) Condition of Dike Walls	1) walls in tact 2) walls moderately degraded 3) walls degraded or with functioning strategic breaches	- hydrological survey, participatory monitoring
EDAPHIC CONDITION		
K) Organic Content	1) low organic content - fine soil texture 2) adequate organic content - porosity 3) high organic contenty - porosity - some structure/roots/peat/ woody debris	- particle analysis or qualitative - visual assessment
L) Soil Density	1) fluid 2) semi-consolidated 3) consolidated	- shear strength test
M) Redox Potential	1) -100 to -200 mV 2) -99 to +149 mV 3) +150 to +300 mV	Redox Potential
N) Porewater Salinity	1) hypersaline (>40 ppt) 2) 26-32 ppt 3) < 25 ppt	Refractometer

ECOLOGICAL INDICATORS



Ecological Indicator	Rating	Means of Collection & Verification
VEGETATION O) Mangrove - Autecology	1) poor record of original species 2) some to most original species present 3) full range of original species known, phenology known	- vegetation monitoring - statistics/forest inventory reports - local NGO interviews with foresters and villagers - field observation - remote sensing
P) Mangrove - Community Associations	1) poor record of species associations 2) some to most species associations available 3) full range of species associations known	
Q) Mangrove - stem density	1) < 500 seedlings/ha or >7500 seedlings/hectare 2) 500-1250 seedW) lings/ha, no canopy closure 3) 1250 - 5000 seedlings/ha, canopy closure in at least some areas	
R) Mangrove - % canopy closure	1) <51% 2) 51-75% 3) >75%	
S) Mangrove Vegetation (diversity/species composition)	1) 1-2 species only 2) at least 2 representatives from each of lower, mid and mangrove zone 3) 75% representation of species from analogue forest	
T) Mangrove Vegetation (growth)	1) stunted 2) moderate growth 3) excellent growth, equal to reference growth rate (per species)	
U) Salt Tolerant Grasses	1) unknown, not-present 2) sparse, sporadic 3) presence of natural salt tolerant grasses, at various intertidal elevations	
V) Condition of Hinterland Vegetation	1) un-natural or unvegetated hinterland with permanent structures 2) mosaic of agriculture and some trees in hinterland 3) wetlands and forests in the hinterland	

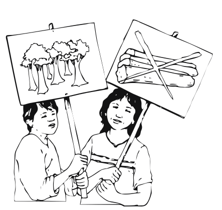
ECOLOGICAL INDICATORS



Indicator	Rating	Means of Collection & Verification
FAUNA W) Benthic Macroinvertebrates (shrimp, molluscs, crabs)	1) little evidence of mangrove benthic macroinvertebrates 2) some species becoming abundant 3) abundance of a diversity of molluscs, shrimp, small crabs and mangrove crabs	- B-IBI, paticipatory monitoring
X) Fisheries (Functional Fisheries Equivalent)	1) low fish populations - <50% of FFE 2) moderate fish populations 50-75% of FFE 3) 75% of FFE from Analogue	- fishing pressure assessment - fisheries survey
Y) Other Mangrove Fauna	1) few species (degraded habitat, hunting, overfishing) 2) average species (moderate hunting/fishing pressure) 3) diverse species (good reproduction, abundant habitats, no destructive hunting/fishing)	- participatory biodiversity survey
AQUACULTURE AREA *CONDITION* AA) Encroachment	1) significant on-going aquaculture development 2) little to no new aquaculture development 3) no new aquaculture development, moratorium	- records/reports, research papers from local universities, research institutions, NGO's - interviews with villagers - market survey
BB) Management Status	1) ponds actively managed 2) disused but no clear plans for rehabilitation 3) high degree of disuse, abandonment	- records/statistics/information on agriculture from agricultural extension offices, NGO's research institutions, development agencies, field school reports.
CC) Weed and pest controls	1) with chemicals 2) biological/mechanized 3) ecological, alternative pest management	
DD) Incidence of Disease	1) high incidence of disease (EMS, Taura, White Spot, Yellowhead, etc.), and escapes 2) some disease but not impacting on crop, few escapes 3) no disease, no escapes	- key informant interviews - field observations
EE) Use of External Inputs	1) high reliance on external inputs/chemical fertilizer, fish feeds, etc. 2) small production of local inputs/some organic 3) production of significant organic fertilizer, seeds, fish feed	

6.6 Scoresheet of Resilience Indicators

SOCIAL & ECONOMIC INDICATORS



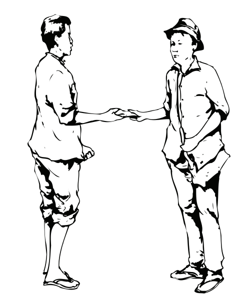
SOCIAL - INDICATORS	Year				
	2015	2016	2017	2018	2019
A) Settlement Pattern					
B) Food, nutrition & sanitation					
C) Structure/condition					
D) Peace and order					
E) Exposure to toxic chemicals and pollutants					
F) Access to support services					
G) People's participation in NRM					
H) Local rules and regs on natural resource use					
I) Participation by government offices in extension work and active co-management					
J) Integration of Culture & Tradition					
K) Long-term community perspective					
L) Community awareness of rights to Gov't service					
M) Access to Gov't funds for CBNRM					
N) Committment to partnerships					
O) Volunteerism					
NATURAL RESOURCE MANAGEMENT - Social Aspects					
P) Understanding of natural environment function					
Q) Adoption of sustainable environmental practices					
R) Understanding of relevant biodiversity					
S) Preservation and Application of Indigenous Knowledge and Appropriate Technology to NRM Mgmt					
T) Women and men's access to common property resrources					
U) Men and women involved in NRM planning which influences gov't planning					
V) Habitat restoration cost					

Scoring: The following pages contain data sheets where you can keep track of your resilience indicators as they change over time.

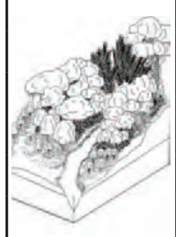
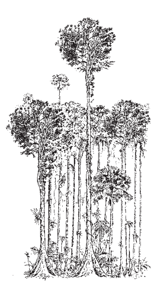
1 = not resilient
2 = building toward resilience
3 = resilient

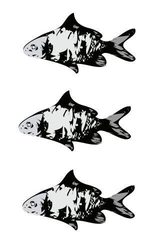
You will certainly want to monitor several indicators in a more quantitative fashion. This will be presented in Chapter 10 on Monitoring.

NRM - Social Aspects (cont'd)	Year				
	2015	2016	2017	2018	2019
W) Forest Restoration Methods					
X) Percentage & status of conservation areas					
Y) Connectivity of mangrove management to adjacent ecosystems					
ECONOMIC - INDICATORS					
A) Economic activity & employment					
B) Economic stability					
C) Distribution of wealth					
D) Livelihood diversification					
E) Unsafe livelihood activities					
F) Protection for small enterprise					
G) Local trade and transport linked to markets					
H) Mechanisms for women to inherit property, land use					
I) Household asset bases convertible					
J) Costs and risks of disasters shared through collective ownership					
K) Community/group savings, credit schemes, micro-finance services					
L) Sources of capital for livelihood activities					
M) Non-timber forest products use					



ECOLOGICAL INDICATORS

ECOLOGICAL - Indicators		Year				
		2015	2016	2017	2018	2019
Sedimentation/Erosion Patterns 	A) Erosion					
	B) Sedimentation					
Hydrology 	C) Streams/rivers					
	D) Occurrence of flood, drought					
	E) Access to fresh water					
	F) Substrate Elevations					
	G) Tidal Creeks Morphology					
	H) Extent of Tidal Creeks					
	I) Drainage from Rehab Area					
	J) Condition of Dike Walls					
Edpahic Condition 	K) Organic Content					
	L) Soil Density					
	M) Redox Potential					
	N) Porewater Salinity					
Vegetation 	O) Mangrove - Autecology					
	P) Mangrove - Community Associations					
	Q) Mangrove - stem density					
	R) Mangrove - % canopy closure					
	S) Mangrove Vegetation (diversity/species composition)					
	T) Mangrove Vegetation (growth)					
	U) Salt Tolerant Grasses					
	V) Condition of Hinterland Vegetation					

ECOLOGICAL INDICATORS		Year				
		2015	2016	2017	2018	2019
Fauna 	W) Benthic Macroinvertebrates (shrimp, molluscs, crabs)					
	X) Fisheries (Functional Fisheries Equivalent)					
	Y) Other Mangrove Fauna					
Aquaculture Area 	AA) Encroachment					
	BB) Management Status					
	CC) Weed and pest controls					
	DD) Incidence of Disease					
	EE) Use of External Inputs					

Numbers provided are examples of ratings for each indicator.

Remember 3 is better then 1. the more points accumulated the better.

Follow the trends year to year to determine if general improvement is being made.

Monitoring Resilience!

!

6.7 Resources

The concept for tracking resilience indicators in the simplified fashion presented above came from:

FAO/IIRR " Resource Management for Upland Areas in SE Asia; An Information Kit."

which is available online at the New Zealand Digital Library Project http://nzdl.sadl.uleth.ca/cgi-bin/library?a=p&p=home&l=en&w=utf-8

The above manual is also an excellent resource for many forms of socio-economic assessment activities.

Another pair of resources we recommend for undertaking socio-economic and forest resource assessments include;

- Asia Forest Network's

Participatory Rural Appraisal for Community Forest Management available at www.asiaforestnetwork.org (also available in Bhs Indonesia from MAP-Indonesia)

- CARE's

"Household Livelihood Security Assessments: A Toolkit for Practitioners." Prepared for the PHLS Unit by: TANGO International Inc., Tucson, Arizona 2002

7

COMMUNITY BASED EMR PLANNING

7.1 Introduction - Community Based EMR Planning Process

After essential assessments have been run, it is time to convene stakeholders (community members and other interested stakeholders) to plan and design the EMR project. Six important points to keep in mind during project planning are;

1. **Analyze** information from the assessments to inform your planning and design.
2. Develop clear, **quantifiable objectives** for the rehabilitation, based on a relevant benchmark for success, which can later be monitored to gauge project success.
3. Keep in mind any overarching **goals** of the project, such as conserving biodiversity or reducing poverty.
4. Carefully consider the **risks** or reasons why the project may fail.
5. Develop a process that allows for **sensible decisions** to be made, which are **based on science**.
6. Ensure **equal participation** by not only community leaders but marginal community members alike.

Comprehensive planning processes, such as ZOPP (ZielOrientierte ProjektPlanung = objectives oriented project planning) method (GTZ, 1997) or The Conceptual Model Approach to Planning Projects (Margoulis & Salafsky, 1998), are both very thorough, and suggested for planning large-scale multi-stakeholder projects.

For the purposes of this manual, we put forth a simple 6-step planning process, appropriate for rural first-hand natural resource users. This method was pieced together from original activities used by MAP during EMR training, as well as activities from FAO Community IPM program and the Global Rivers Environmental Education Network (GREEN) for use in farmer field school and action-research/problem solving programs, and has been adapted her for use in mangrove communities. It is also in line with processes used with Forest Management Learning Groups (FMLG's) a type of field school for community foresters (Miagostovich, 2002).

Activity 7.2 Participant Selection

Background Information
Prior to developing a social contract, a transparent participation process needs to be developed. Participant selection can be time consuming. Good participant selection should be informed by social and economic assessments. It is important to develop some type of process to ensure that women, poor, and marginal community members have equal opportunity to be involved in mangrove rehabilitation planning.

There is a strong bias, in many coastal communities, for activities such as mangrove rehabilitation to be geared towards men. There are also biases to involve already powerful community members, especially village leaders. While village leaders should certainly be involved in the EMR project, they should not be allowed to preferentially select all EMR participants. Instead, there is an opportunity to involve village leaders and elite, in explaining the social nature of mangrove rehabilitation, and engaging their assistance in selecting a wide-array of participants for EMR planning and implementation that can lead to shared macro-goals such as long-term mangrove recovery, poverty alleviation, and sustainable community development.

Goal:
- To ensure equal opportunity for participation, especially for women as well as vulnerable, marginal and poorer community members.
- To enlist village leaders to pro-actively support inclusion.

Time: several days before developing social contract (Activity 7.3)

Materials: This guide, a notebook, some pictures of Ecological Mangrove Rehabilitation process.

Outcome: Equitable list of participants to attend social contract meeting.

Procedure:
1. Prepare some simple visual aids depicting mangrove degradation at the site, failed mangrove restoration efforts, involvement of communities in EMR at other locations and a time-series of successful EMR.
2. With the visual aids, explain the intentions of an EMR program, and the potential to plan for and carry out such an initiative to local leaders, such as formal government leaders, natural leaders, religious leaders, or leaders of community organizations.
3. Ask for the village leader's assistance in selecting participants to plan and eventually implement an EMR project. Make it know that you strive towards equal participation by women and men, and also involvement of all segments of a community, including poor, vulnerable and youth. Ask for village leaders for ideas of how to fairly select program participants, and ask for their assistance.
4. Spend time informally, with a wide-range of community members. Take part in normal village activities. Spread yourselves around the village, avoiding bias towards single individuals or groups.
5. Enlist the assistance of potential natural leaders who are considered fair by a wide variety of people in the community. Ask for their assistance to help select around 20-25 people to play an active role in EMR planning.
6. If necessary, utilize tools such as stakeholder analysis, wealth analysis, gender analysis and participant analysis to improve participant selection.
7. Invite the selected participants to an initial meeting, to develop a Social Contract (Activity 2). Inform village leaders about the initial participants selected and the intent of the Social Contract meeting.

Discussion Questions
- What types of difficulties did you encounter in trying to create a equitable list of participants?
- Who, in the community, helped you overcome these challenges?
- Have you created any additional strife in the community? If so, note this down for the development of a strategy to resolve these new issues.

Activity 7.3 The Social Contract

Background Information
The motivations for mangrove rehabilitation, and participation in mangrove rehabilitation activities are not always pure. Many mangrove rehabilitation efforts are little more than budget spending exercises. Others fall out of the sky without genuine involvement of local communities. And, as we have seen in Chapter 2, the failure rate of over-simplified, poorly planned, and non-participatory mangrove restorations is high.

That being said, communities may also have become jaded by involvement in past projects, may be interested in participation in activities simply to feel part of the group, or perhaps with the expectation for direct financial benefit. It is not uncommon that community members walk away from a meeting nowadays disappointed that no envelopes for attendance were handed out. These issues can be avoided to a great extent by fully divulging the intent of any program, and receiving prior and well informed consent by all participants. The following activity, development of a social contract, is an effort to make participation in mangrove rehabilitation fully transparent, and to formalize the commitments of both participants and project staff.

Goals:
- ✓ So that community members will understand the goals of EMR planning and future implementation
- ✓ So that program participants formally declare their intention to participate in EMR planning activities.
- ✓ So that project staff/facilitators formally declare their own roles and responsibilities with regards to EMR (planning, implementation, monitoring and future management).
- ✓ So that participants can take part in determining the schedule of planning activities and in identifying any additional training needs.

Time: 45 minutes

Materials: This guide, a blank piece of paper, masking tape, felt-tipped pen

Procedure:
1. Begin by asking participants: "What will we be planning to do?" Some participants will already know that the purpose of planning activities is to move forward with mangrove rehabilitation they may answer: "To Plan Mangrove Rehabilitation," or something similar.

2. Refer the participants to the diagram, "The EMR Planning Process". Discuss each point with the participants. Ask them what they think these points mean, and why they are included .

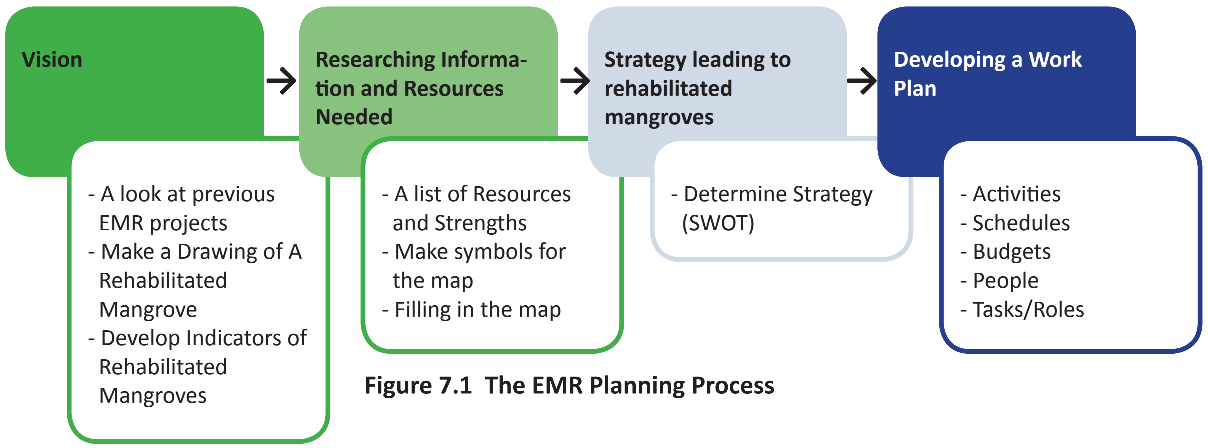


Figure 7.1 The EMR Planning Process

3. Ask the participants if there is anything that is unclear.
4. Ask the participants if they think there should be anything added to improve the process.
5. Ask the group, what they think their commitment to this process needs to be? Are there different levels or types of commitment? Is there a minimum amount of commitment?
6. At this time, it is best if the facilitators themselves write down their own roles and responsibilities throughout the entire EMR process, including Planning, Implementation, Monitoring and Future Management.
7. Next, the participants should be asked to pledge their level of involvement in the EMR planning process. The group should also, at this time, determine if there are any consequences of not following through with a commitment. Finally, their pledge of commitment should be formalized in some way, for instance by putting their name on a notice to the public, or receiving some sort of token
8. Once a social contract is made, participants can begin to discuss the schedule for the initial planning session (visioning), the role of the trainers, the anticipated role for participants, and ask whether this is acceptable or if there should be changes.

Discussion Questions:

- What kinds of issues were raised during social contracting?

Activity 7.4 Developing a Vision for an EMR Project

Background:
It is important in planning for mangrove rehabilitation, to have a future vision in mind, of what the community would like their mangrove to look like. Is it possible to return the condition of the mangrove to its previous condition (restoration), or is it preferable to try and rehabilitate the area to some form of mangrove forest which functions over the long term?

In terms of biophysical properties, What mangrove species does the community hope to bring back? The full local diversity of mangroves, or a subset? How many trees established per hectare would be considered successful? Is there a minimum and maximum number? What rate of growth would be considered healthy for the different species restored?

In terms of socio-economics, will the future mangrove have zones based on different uses such as logging, fisheries, non-timber forest products, research and education or strict conservation? Who will be able to access mangrove resources? What kinds of limits will be placed on economic activities? Will there be sanctions for breaking these limits?

The community may have gained insight into a vision for the future when they assessed their reference forest (Chapter 3). It may also be important, in developing a vision, to think about mangrove rehabilitation or similar activities that have previously been conducted in their villages, and how these activities fared.

For a more complete visioning process, please refer to "Do Your Own Mangrove Action Project," (Brown, 2004) where the visioning activity follows after development of past and present murals of the mangrove area.

Goal:

- Help coastal communities, whether at the village level or higher, to determine the ideal set of conditions that they would like to achieve in their rehabilitation area as part of their Community EMR plan.

Materials:

- Mural paper, colored markers and cray-pas, masking tape

Time: 90 minutes

Outcomes:
Mural of future vision of mangrove rehabilitation area
Lists of characteristics (ecological, social and economic) that the mangrove area should have.

Procedure:
1. Ask participants when mangrove rehabilitation and/or EMR activities began in their area. Write all the participants' answers on mural paper. Next ask clarifying questions about each activity (for example, when, where, source of funding, who facilitated the activity, who were the participants, what were the outcomes or results).
2. Now ask the participants what different roles community members have played across the sequence of these activities beginning with the earliest and concluding with the final? Write down their ideas.
3. Now ask the participants to think about how the role of coastal community members should evolve EMR activities. They can also think beyond EMR to think about the mangrove area and its management in the future. Write out the participants' answers.
4. After this ask the participants to brainstorm and agree on what would be the characteristics (what will a visitor be able to see) of their area if EMR program is successful after five years. Ten years. What do they expect to be able to see as a result of the impact of EMR activities in their area?
5. Ask if there are other programs or activities, beside EMR, that are needed to help achieve this vision, and to list these programs and activities.
6. Finally, ask the participants to draw a general picture that fits with the characteristics that were developed in the last step at some distinct geographical unit. Divide the large group up into small groups of around 5 people and have each group:
   a. Draw all the characteristics resulting from an EMR Programme,
   b. or Draw single pictures of each characteristic.
   c. Add some ecological characteristics. Remember to provide detail in the drawing. How many mangroves should be growing in the area after 3 or 5 or 10 years? What is the rate of colonization? What are growth rates? What species should be present? Should fauna be included?
   d. Add socio-economic characteristics. Will the mangrove be divided into different zones? What are these zones? What are some basic rules that need to be followed for each zone?

8. Ask each group to present their drawing to the large group and discuss how the drawing clarifies the characteristics that were developed in step five. Attach these drawings to the wall for the rest of the planning sessions.

Discussion Questions:
- What new thoughts were generated as a result of your visualization activity?
- Do you feel what you visualized can become a reality?
- Do you think you will need the help of others to make your visualizations a reality? Who can you ask for help?

Fig. 7.2: Visioning Process A Department of Fisheries staff from Takalar, South Sulawesi, Indonesia, presents her groups vision for a disused shrimp pond in Puntondo Bay

Activity 7.5 Researching Information and Resources Needed for EMR

Background Information: This activity is designed to help develop basic research skills which are essential to effective problem-solving. It is important to learn to gather information from diverse sources and to critically evaluate this information to resolve environmental problems.

This activity can be used to help research the problems around mangrove rehabilitation. The research you conduct will provide you with a better understanding of issues, and prepare you to develop a work plan (Activity 5).

Goals:
- Identify community resources
- Gather information related to mangrove rehabilitation.
- Develop phone and personal interviewing skills
- Effectively use the internet/social networks to search for information
- Learn how to write effective letters

Materials: Newspapers, telephone directories, government directories, reference books, internet, stamps, paper, envelopes, money for telephone calls.

Time: Approximately 1-2 hours

Outcomes:
- List of information needed to achieve successful mangrove rehabilitation
- List of resources needed to assist with successful mangrove rehabilitation

Procedures:
1. You have raised many difficult questions throughout the course of the previous assessments and activities. Now you have the chance to search out some answers. In small groups or individually, generate a list of questions you have related to mangrove rehabilitation.
2. Prioritize both the INFORMATION and the RESOURCES your community needs in order to both better understand the challenges of mangrove rehabilitation and the materials and methods needed to undertake mangrove rehabilitation. Keep track of information needed on one sheet of paper, and resources needed on a second sheet of paper. Keep these sheets for revision in Activity 6 – Work Planning.
3. Discuss what agencies, organizations or individuals would be appropriate to contact to find answers to your questions and assist in the provision of resources.

   a. Good contacts include local environmental NGO, international environmental NGOs, community groups with experience in problem area, local government agencies, academicians, nature lover's groups, local businesses with an interest in problem area such as dive operators, eco-tourism groups, model airplane clubs (for help with aerial photos), etc.
   b. Useful resources for finding contacts are: phone books, governmental directories, newspapers, magazine articles, internet, government workers or community members.
   c. A special E-mail group has been set up to discuss mangrove rehabilitation; emr_group@yahoogroups.com
4. Once you have identified contact persons or organizations, the next step is to phone, write or visit (whatever is most appropriate for the situation). If you wrote letters, read your letters aloud in front of your group before sending them to the contact person. To prepare for a visit practice what you will say in front of the group using a role playing exercise with someone playing the student, someone else the NGO member, the professor etc.
5. Search for contacts or other information leads. Often, people working in government, academia and NGO's have developed a network of contacts that your community might also utilize.
6. Report the results of your inquiries to the whole group. Be certain to discuss and analyze the information that each small group or group member presents.
7. Some additional suggestions:
   a. Because of their interdisciplinary nature, complex issues may require several rounds of information gathering. You will need patience and persistence!
   b. Keep a record of phone numbers, emails and addresses, when people were contacted, and the subject of the conversation or letter for later reference.
   c. Consider asking one or more contact persons to make a presentation to the group. This is an excellent way to learn about an issue.
4. After having contacting people and organizations, update your list of INFORMATION and RESOURCES required for mangrove rehabilitation. This will be referred to in the next activity.

Discussion Questions:
- Were the organizations and decision makers you contacted helpful to you?
- How could they have been more helpful?
- What surprised you in this process?

Activity 7.6 Strategy and Resource Analysis

Background:
Having a strategy is necessary to try to achieve a goal or ideal situation. To develop a strategy several things must be kept in mind:
- What is the goal?
- What resources or strengths exist that can be used to achieve the goal?
- What weaknesses exist that might inhibit the achievement of the goal?
- What opportunities exist that can be taken advantage of to achieve the goal?
- What threats might exist that could be obstacles to achieving the goal?

A general goal or 'vision' of the ideal was developed in the second activity. Existing resources in the area and information needed for mangrove rehabilitation were identified and contacted in the third session. Now two different but related issues will be the focus of this session. Looking at the resources that are available to the group, and keeping in mind the vision as the goal, an analysis of the strengths, weaknesses, opportunities, and threats (a SWOT Analysis) will be conducted. This analysis will be used to develop a general set strategies to guide the development of the mangrove rehabilitation work plan.

Goals:
- Using a SWOT Analysis existing conditions relevant to the achievement of the vision of mangrove rehabilitation will be examined.
- A set of general strategies to achieve the vision will be developed.

Materials: Mural paper, colored markers, masking tape, results of the 'vision' exercise (Activity 7.4), and results of information and resource identification exercise (Activity 7.5).

Time: 90 minutes

Outcome: A general set of strategies to guide the development of the mangrove rehabilitation work plan

Procedure:
1. Explain the purpose of this session by referring to what is written under 'Background' for this session.
2. Attach to the wall the following: the mural of the vision of the future mangrove, the list of characteristics that the community thinks the future mangrove should have, and the lists of information and resources need for mangrove rehabilitation.
3. Have the participants conduct a SWOT Analysis. Start by saying:

"Given the strengths or resources that we have identified and the vision for your Community EMR programme that we have determined, what are the existing strengths, weaknesses, opportunities, or threats that confront your mangrover rehabilitation activities?"

Remember:
Strengths are those "assets" which exist such as community members trained, trainers, information from assessments and studies, EMR or mangrove management groups, etc. which will support the achievement of the vision. External resources such as a pool of university students willing to assist, government extensionists, and use of equipment to undertake mangrove rehabilitation are also strengths.

Information may also be a strength such as information on patterns of sedimentation and erosion, ecological information from a reference forest, clarity of land-tenure, or government policy which supports community forest rehabilitation and management.

Weaknesses are those conditions which inhibit the achievement of the vision. Examples may be community strife (disagreement), lack of clarity over land-tenure, migration, or increasing instance of poverty.

Opportunities are conditions which exist that are potential in nature. They can be taken advantage of to achieve a vision. Examples might include supportive local officials, local funds that might be taken advantage of, discoveries made by local coastal communities that could be used to enhance mangrove rehabilitation and management, etc.

Threats are potential conditions which could inhibit the achievement of the goal. Examples include: sea-level rise, extreme erosion, change of government policy, development programs such as port, road or housing developments, continuing trends of aquaculture or agriculture development, revitalization of charcoal industry, etc.

4. Use at least four pieces of mural paper to do the SWOT Analysis. Each sheet gets a title. On one is written "strengths", on a second "weaknesses", and so forth. Ask the group to determine what should be listed below each of these "titles".\
5. General strategies for each of the elements in the SWOT Analysis can be determined by answering the following questions.
   - How can we make use of our strengths?
   - How can we minimize or strengthen our weaknesses?
   - How can we take advantage of our opportunities?
   - How can we avoid or minimize our threats?

   Have the group answer these questions in simple declarative sentences. No more than two sentences per question. These will be the strategies that the group's plans should respond to.
6. Attach the strategy statements to the wall and review with the group before finalization.
7. Post the strategies in public or find other ways of dissemination to make the community-at-large aware of the mangrove rehabilitation project. Press releases and radio or television interviews, or distribution of the strategy by social networks can be very helpful.

Discussion Questions

? In general, is your group endowed with resources, or do you still need a lot of assistance? Are you easily able to find assistance?
? Are you able to distinguish between strengths and opportunities?
? Are you able to distinguish between weaknesses and threats?

Activity 7.7 Developing Work Plans

Background: The last stage in this process is the preparation of work plans for both implementation of mangrove rehabilitation and monitoring. Using the results from the sessions focusing on vision, information and resources, and strategy development, the work plans will be as realistic as possible. The workplans should directly respond to the strategy statements given the context established by the vision of the ideal.

Goal: The development of detailed work plans at the project site level for both implementation of mangrove rehabilitation and monitoring.

Materials: Mural paper, colored markers, masking tape, and results from previous sessions.

Time: 90 minutes

Procedure: Give the group mural paper and markers. Provide the group 30 minutes to discuss and write work plans based on the results of previous sessions. As a full group a list of potential activities could be brain stormed. Then the large group could be divided into smaller work groups of five or more members, each of them designing a work plan for a specific activity. Work plans should be detailed including at least the following:

Type of Activity	What is the title or description of activity?
Schedule	How much time will be needed for the activity? When will the activity be conducted?
Process of Implementation	Will this be done by individuals or the group? How to ensure equal representation of women and men? How to ensure involvement of marginal, vulnerable and poor members of the community? How to involve community youth? Who will be responsible?
Materials Needed	What materials will be necessary? What needs to be purchased? What can be provided, in-kind, by the group?
Budget	How much will be needed? From what source will the budget be obtained? How to ensure equal pay for women and men? How to share benefit amongst the community? How to avoid unfair/unequal benefit sharing (by powerful community members and/or land-owners)?

2. Have work groups present their plans. Discussion should take place concerning each plan that focuses on the reality of the plan and its details and allows for suggestions. The full group should come to an agreement on these plans
3. If the group is a subset of the community-at-large, a communications plan should be developed to present the results to the community, and allow for public consultation.
4. A simple form of the finalized plan should be drawn up and posted in a public location.

Discussion Questions:
For your work plan, answer the following questions:

- How effective will this option be?
- How interested are you in this work plan?
- Do you and others in your group have the skills and resources needed to implement (do) this action plan?
- How much community support are you likely to have for this work plan?
- To what extent does this action plan address the cause of the problem?
- How long-lasting a solution will this action produce?
- How do the benefits of this action compare with any negative consequences?

8

IMPLEMENTATION

Implementation

Implementation is the physical process of undertaking the rehabilitation project based on designs developed in the planning stage (Chp. 7). This phase of the rehabilitation process may be achieved solely with manual labor, with the assistance of heavy machinery, or a mixture of the two. In developing countries, local communities are often eager to be engaged in this phase of work for pay, although a degree of volunteerism is important to build into the program to ensure a higher level of ownership after the rehabilitation work.

Large scale projects > 100 ha, typically require the use of heavy machinery, especially if considerable earth moving is required, such as dike wall breaching, digging tidal creeks, filling human-made drainage ditches or regrading substrate. An analysis of the cost of rehabilitation using manual labor vs. heavy machinery may be necessary to determine the best approach (see Fig. 8.1). Implementation may require a series of steps depending on the mangrove type, your project goals and objectives, and the extent of the degradation. Steps in implementation can be broken down to include; site preparation, hydrological repair, ecological amendment, as-built survey, monitoring, maintenance and mid-course corrections.

Fig 8.1: A choice needs to be made between use machinery and employment of community labor with hand tools. At smaller scales (<50 ha) community labor may be sufficient, while larger scales almost certainly require heavy equipment.

8.1 Site Preparation

During site preparation, the project site is altered either to allow natural processes to operate or to prepare it for additional human intervention. Common activities in this stage include:

- posting signage to make local communities aware of project;
- removing undesired species (ex: *Acrostichum aureum*, vegetation on dike walls);
- leveling mud lobster (*Thalassina* spp.) mounds;
- removing trash;
- amending soil with nutrients, dolomite lime, compost or other enhancements;
- bringing in appropriate soils or substrates;
- fencing out grazing livestock;
- setting up protective netting to reduce risk of eroded sediments disturbing near shore ecosystems.

Fig 8.2: Some site preparation measures include: clearing *Acrostichum* and levelling mud lobster mounds (A), fencing (B), posting signage (C) and placement of turbidity control screens (D).

8.2 Community Involvement

When engaging rural, coastal community members to work on a rehabilitation project, there is a fine balance to pay a fair wage in an equitable manner, but also to arrange for volunteerism, in the form of labor, equipment or both.

There will oftentimes be a prejudice to hire men for manual labour, especially heavy labor such as breaching dike walls, or digging tidal creeks. Women need to be given a fair opportunity to earn equal wages for involvement in the project, not only to ensure gender equity, but also as a means of reinforcing their connection, as important future stewards and managers, of the mangrove forest.

Fig 8.3: Offer equal pay for equal work to women and men. Ignore prevalent stereotypes regarding women and manual labor, and engage women to participate fully in EMR planning, implementation and monitoring!

- Based on results of prior assessments – ensure the inclusion of women, poor and vulnerable community members.
- Hold inclusive village meetings to discuss the implementation of the project, roles, responsibilities, wages and expenditures transparent.
- Engage the community-at-large to determine what type and amount of in-kind services they will provide on the project.
- Outreach to other communities, such as university students, environmental clubs, etc., to join the restoration as volunteers.

- The process of rehabilitation is hard work, but can be made fun as well. Make it a social event. Invite the media, have plenty of food and drink.
- Involve Youth! Mud = fun.
- Promote the fact that this project is more than just planting mangroves. Publicize the method of EMR and also the anticipated results.
- Take necessary safety precautions. Hold safety briefings. Have safety and first aid equipment on hand. Have medical assistance on hand.

8.3 Hydrological Repair

A wide array of activities can occur during this phase including large earth-moving activities, such as adding soil (fill) or re-grading. Some of the points below will be elaborated upon with examples at the end of this chapter. The case studies at the end of the manual (Chapter 10) also make mention of several of the techniques below. Minimize the temporary but destructive impacts that may occur at this stage. Limit the movement of heavy vehicles to the smallest footprint possible and use the methods that create the least disturbance possible. Implement appropriate best management practices.

Common Methods of Hydrological Repair may include:

- Strategically breaching dike walls and levees
- Filling artificial drainage channels
- Digging appropriate sized tidal creeks
- Mounding soils to build elevated patches
- Re-grading existing soils
- Placing and grading new soil
- Placing wave breaking apparatus

Fig 8.4: Floating dredge restoring a tidal creek to improve tidal exchange which is causing die-off of mangroves in Tampa Bay, Florida, USA, (Lewis).

8.3.1 Some Techniques Related to Hydrological Repair

a) Strategic Breaching

It is common for mangrove areas and other wetland types to have been diked and channelized during their conversion. Dike walls clearly obstruct the natural flow of tidal waters. A common and low-cost method of restoring functional wetland hydrology to a mangrove system is to strategically breach these dike walls. Although in some instances, a single dike wall may have been constructed around the perimeter of the mangrove forest (see Fig. 8.5), in the case of aquaculture development, numerous dike walls are constructed, commonly enclosing areas ranging from half a hectare up to 10 hectares

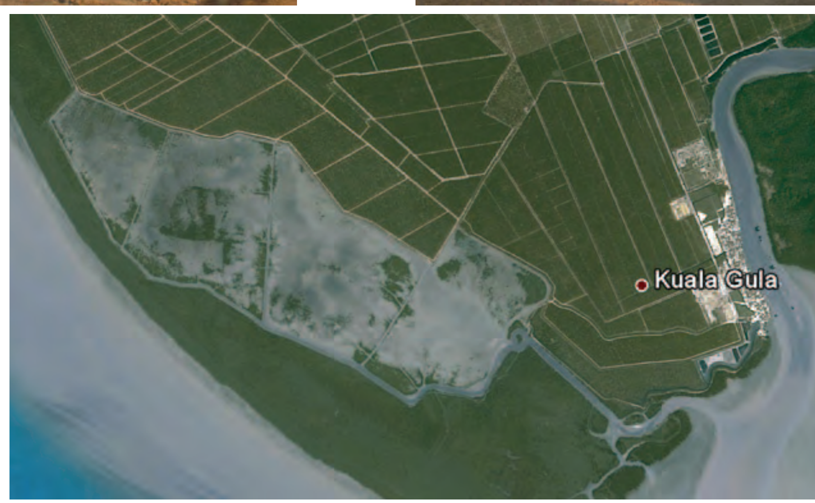


Fig 8.5: 500 hectares of mangroves at Kuala Gula, Malaysia (a wildlife sanctuary), were diked, on the coastal side, ostensibly to reduce impacts of erosion, and on the landward side where back mangroves and hinterland forest have been converted to an oil palm plantation. Recent mangrove die-offs in the artificial lagoon due to flooding have been significant. Syme Darby, the owner of the plantation, currently operates several pumping stations to drain spring tides from their oil palm. Rehabilitation here would require strategic breaching of both dike walls, but also requires significant political will.

The expense of re-grading these dike walls may prohibit some restorations, and complete regarding or dike wall removal may not be required.

A breach in a dike wall, is a hole, no wider than the natural width of a tidal creek (refer to tidal creek channel width from reference forest), through which tidal waters may ebb and flood. These breaches may occur naturally overtime in disused or abandoned shrimp ponds, which, during normal operation, requiring continual dike walls maintenance.

Fig 8.7: A natural breaches in this abandoned shrimp pond dike wall made it possible for natural revegetation of 6 species of mangroves inside a single pond over 6 years. Gorontalo Province, Indonesia.

Strategic breaching involves intentionally making holes in dike walls, with the intention of creating, over time, a natural meandering drainage channel. These breaches are narrow at the landward side, widening as the approach the coast. The resultant tidal creeks should meander, i.e. do not create strategic breaches in a straight line. (see Fig 8.7)

It is not good to make too many breaches, as this will reduce the amount of water flowing through a single point, hence reducing tidal scouring. Tidal scouring is the erosive force of tidal water flowing in and out of a wetland, which maintains a tidal water-course. When tidal scouring is minimal, a tidal creek may fill with sediment and cease to function. In addition to strategic breaching, it may be necessary to fill in straight, human made channels, which otherwise "rob" the flow needed to create natural, meandering tidal creeks.

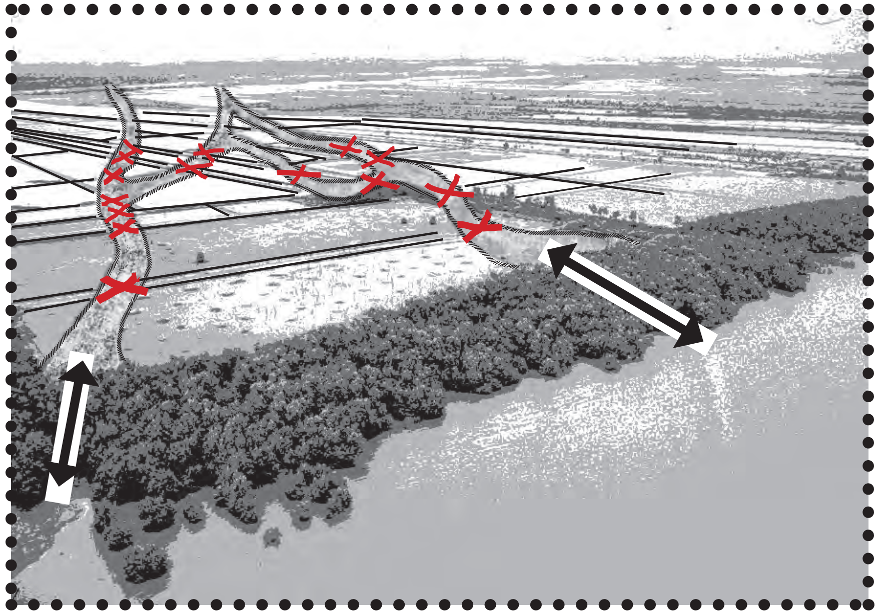


Fig 8.7 Connect ponds with the sea by creating well designed tidal channels. which meander and widen as they flow toward the coast. Red X's mark the spots where strategic breaches can be made in dike walls, in lieu of digging tidal channels, although a combined approach may work better.

b) Excavation

Mangrove areas may have been degraded or destroyed from addition of too much sediment, either naturally or due to human activity. The mangroves no longer flood and drain, as they have been raised, either wholly or partially, out of the tidal range.

A natural example of this occurred on Simeulue Island, where tectonic uplift of 1.0 – 1.5 meters on some parts of the island, lifted the mangroves completely out of the intertidal zone, which only exhibited a 78 cm annual tidal range.

Examples of anthropogenic sedimentation may be gradual or sudden. In the case of Segara Anakan Lagoon, in Central Java, insidious erosion resulted in the near total sedimentation of the lagoon over a time period of 30 years. This was caused largely by erosive upland farm practices. Attempts to dredge the lagoon, to promote mangrove growth, failed as the root cause of drastic upland erosion was never addressed. (See Fig 5.5 from Chapter 5 on Segara Anakan, Central Java).

In Florida, dredge spoils from the periodic clearance of shipping lanes raised substrate levels in 500 ha of mangrove forest above intertidal levels. Resultantly, *Casuarina* pine (an invasive exotic species in Florida) grew on the supra-tidal substrate. IN 1988, an excavation project was commissioned, to remove invasive *Casuarina*, scrape down and remove excessive sediment (to recreate a natural intertidal profile) and excavate tidal creeks. Within 14 years, canopy closure of naturally regenerated mangroves was complete (Fig 8.9)

Addressing the root causes of sedimentation is essential before undertaking an excavation project, but these projects are relatively easier than projects requiring the placement of fill material and the removed fill may be useful in local construction projects.

Fig 8.9 West Lake, Florida, USA.

The former mangrove area was overgrown with invasive *Casuarina* pine, growing on dredged material from the adjacent shipping lanes.

In 1995, EMR was carried out, which involved excavation of dredged materials and creation of a network of tidal creeks, based on nearby reference forest characteristics.

In 2003, complete canopy closure is evident along with a system of functioning tidal creeks. (all photos by R. Lewis)

No mangroves were planted as part of this project!

c) Tidal Creek Creation

Tidal creek creation may or may not be associated with a fill project (described below in section d). In the case of a fill project, tidal creeks can be dug, usually with the use of heavy machinery. They should be sized based on measurements from a reference creek system, which includes linear meters per hectare (measured easily from remote sensing imagery), as well as the size and morphology (shape) of the channel itself. Undersized creeks may erode to an appropriate larger size, while over-sized tidal channels may fill in to some degree with sediment.

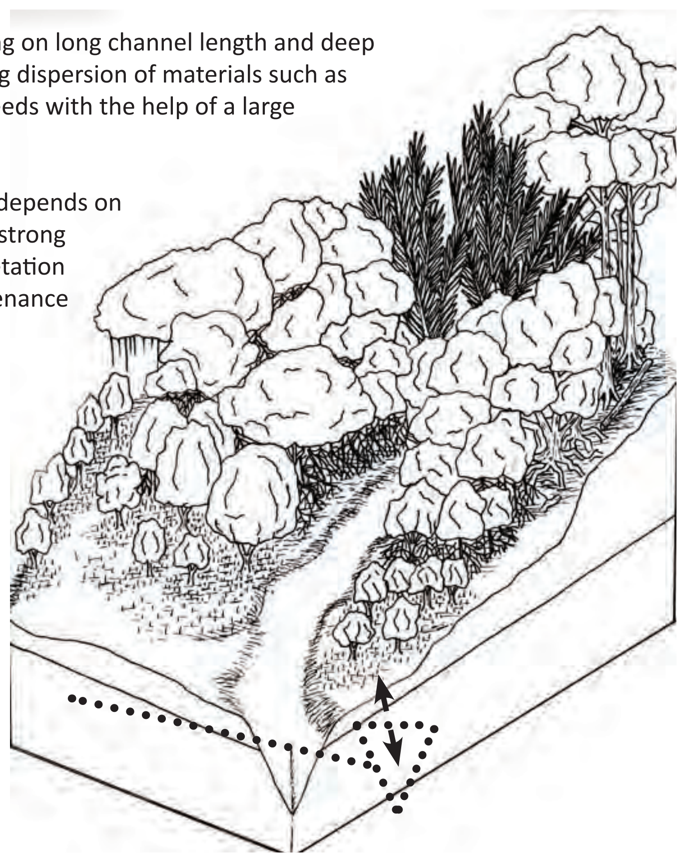
On a large project – it may be necessary to calculate the size of the tidal prism in order to appropriately size created tidal creeks. (see Fig 8.10)

Tidal creeks can also be dug without the use of heavy machinery. See the example in 8.7.5 below, as well as the case study from Tanakeke Island in chapter 10, where communities were involved in hand-digging tidal creeks, in order to facilitate drainage and flooding of disused shrimp ponds.

Fig 8.10 Tidal Prisms

Strong tidal flow, depending on long channel length and deep channel depth forms strong dispersion of materials such as nutrients and mangrove seeds with the help of a large tidal prism.

The size of the tidal prism depends on wide-flat swamp area and strong friction depending on vegetation density, resulting in maintenance of mangrove colonies. (Mazda et al., 2007)



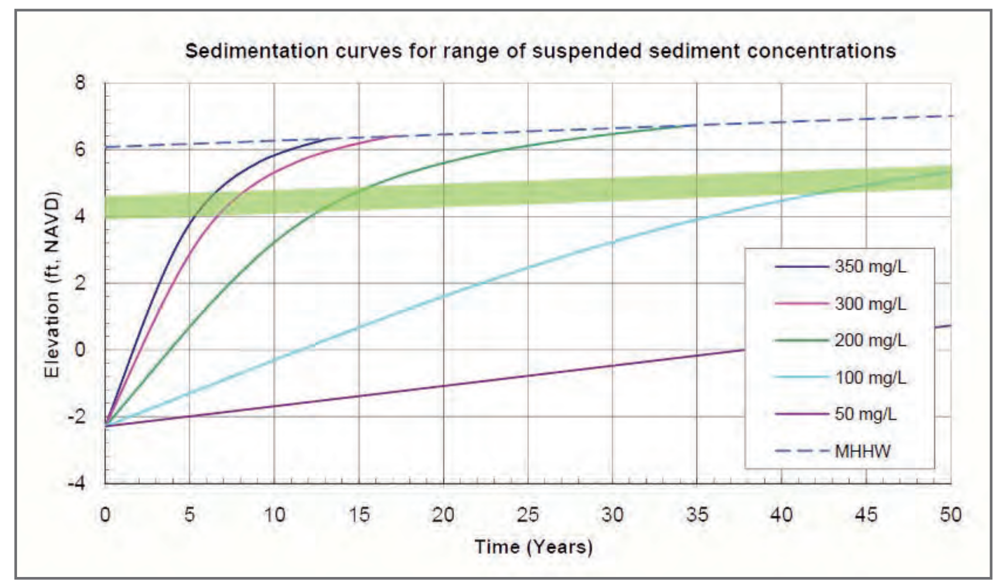
The tidal prism can be measured by calculating the volume of water flowing through the exit tidal creek during a falling tide.

d) Regarding Sites Requiring Fill:

A mangrove restoration site may suffer from low substrate elevations. Where coastal energy is high, in the form of waves or currents, it may be difficult, expensive or impossible to raise substrate elevations. For a discussion of erosion control methods and artificial breakwaters, refer to section e below, as well as examples 8.7.7 and 8.7.8 towards the end of this chapter.

If an area is not experiencing significant erosion, but still suffers from low substrate elevations, you will need to increase substrate elevations either naturally (by working with natural sedimentation) or artificially by adding fill. From your understanding of rates of sedimentation during the assessment phase, you need to predict if natural sedimentation will be adequate to fill the site in a short enough time frame, or if you will need to add fill.

Fig 8.11 The time taken to restore tidal wetland area depends greatly upon the degree to which the diked wetland has subsided and the availability of mineral sediment to rebuild intertidal mudflats to a substrate elevation that supports colonization. The curve below depicts the time needed for an intertidal surface to reach a target elevation (thick green line) for colonization of salt marsh vegetation, based on the amount of total suspended solids (TSS) measured in the nearby water column. Sea Level Rise is indicated by the slope of the thick green line, which effectively increases the time needed for restoration. (Crooks et al., 2011; PWA, 2009)



Petaluma River, CA, USA: Tidal range = 6.1 ft, Ambient Sea Level Rise = 5.67mm/yr
Source: MARSH98 Sedimentation Model, ESA PWA.

When natural sedimentation rates are slow, you may decide to add fill to a site. There is, of course, a significant cost associated with adding fill, which usually comes from nearby dredge material. Once fill is added, it will likely need to be re-graded, with tidal channels initially dug to encourage proper functioning. If there is a dike wall or levee to breach, re-grading the fill should take place before breaching.

In some instances, it may be necessary to protect coastal ecosystems from runoff of sediment. This can be attempted in several ways.

1. Halophytic grasses may be planted on the regarded substrate at appropriate substrate elevations, to hold sediment in place. These grasses also act to catch mangrove propagules, and also to enhance edaphic conditions of the substrate (temperature, salinity, redox potential, available nutrients) to improve recruitment of mangroves.
2. A geofabric can be laid over the substrate to hold it down during colonization.
3. A geofabric or net can be set between the restoration site and the coast, to reduce impacts of erosion/sedimentation onto other coastal systems such as seagrass beds or coral flats.

Over time, as tidal drainage evolves, mid course corrections may be called for.

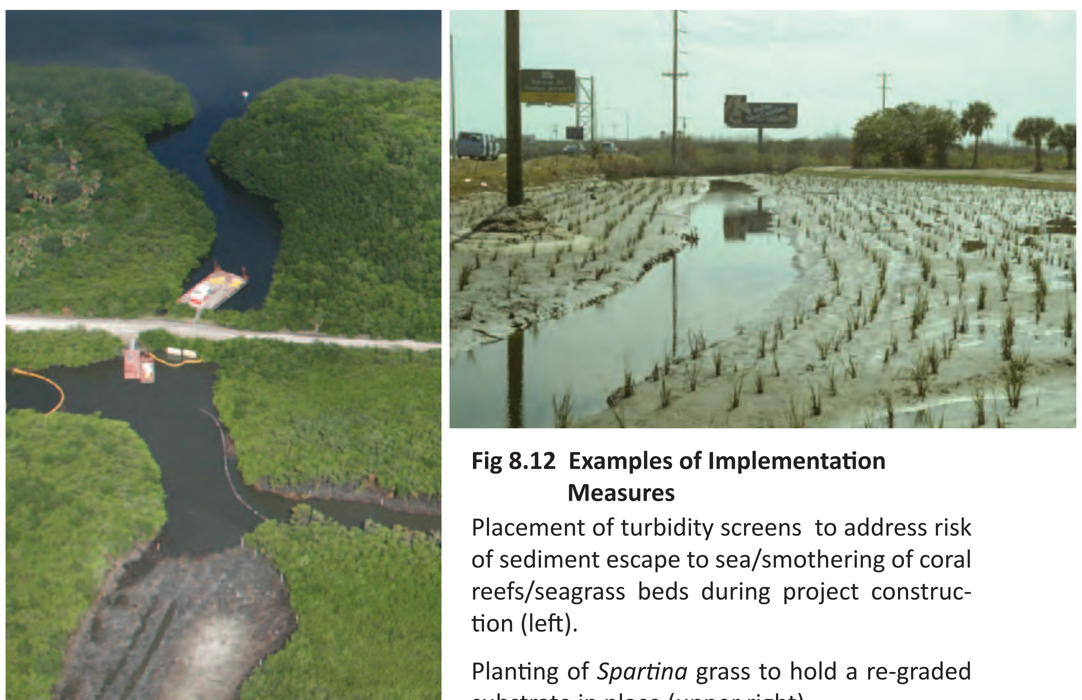


Fig 8.12 Examples of Implementation Measures

Placement of turbidity screens to address risk of sediment escape to sea/smothering of coral reefs/seagrass beds during project construction (left).

Planting of *Spartina* grass to hold a re-graded substrate in place (upper right).

e) Artificial breakwaters

These structures are developed in order to buffer the effects of currents and waves, to allow for the recruitment and growth of vegetation, such as mangroves, halophytic grasses or other salt-marsh species.

It should be noted, before beginning this type of activity, that experimenting with breakwaters can have unexpected negative consequences, both on site, and in adjacent coasts. Numerous "permanent" concrete breakwaters fail, as their leeward face gets undermined by eddying currents, and the whole investment can collapse leading to disastrous results.

In other instances, accumulating sediment in one portion of beach, may rob sediment from an adjacent section, causing problems for habitats, settlements or infrastructure. It is recommended to engage a multi-stakeholder team of ecologists and coastal hydraulic engineers before undertaking a breakwater construction. Models should be created beforehand, and a variety of scenarios developed.

We will briefly discuss techniques which are being used to accumulate sediment along an eroding coastline in efforts to increase mangrove and salt-water marsh habitats.

The first set of techniques involves use of recycled dredge materials or rubble to create **low rock break walls**. The former has been documented extensively (see downloads #`13, 400, 401 and 402 at www.mangroverestoration.com) while the latter is discussed towards the end of this chapter in section 8.7.8. These techniques have been documented to successfully increase both salt marsh and mangrove habitat in the U.S.A.

Another technique currently being trialed along tropical coastlines the creation of ***brushwood polders*** which have been around for centuries and are proven to work in lower wave energy high sedimentation areas of the Dutch coast and North Sea. In this method practitioners have created marsh areas outside of massive sea dikes by placing brush piles on mudflats and capturing suspended soil to raise elevations. Trials are currently underway using this technique in Thailand, Vietnam, along the North coast of Java in Indonesia and in Guyana. Early reports show mixed success. On a per hectare basis these are expensive projects, and have not yet been shown to be effective over the long term in tropical world.

These techniques are depicted in Fig 8.13.

Fig 8.13 - Types of Breakwaters

This low oyster-shell breakwater at Pelican Island (see 8.7.8 in this chapter) successfully increased mangrove and salt marsh habitat. (Lewis, above left)

This artificial breakwater in Florida was also effective trapping sediment and increasing mangrove habitat over time (Lewis, above right).

A floating reed marsh (bottom right) in the Netherlands (Deltares, 2010) consists of floating brushwood mattresses to allow development of reed vegetation and reduce wave impact on dike wall in foreground to restore shallow freshwater habitats. Use of brushwood plodding is also a common technique in the North Sea. Trials like these are being attempted in higher wave and current energy systems in the tropics in conjunction with mangrove restoration attempts, but results are still inconclusive.

f) Mounding

In disused aquaculture ponds, MAP Indonesia has been experimenting with creation elevated mounds, to promote the recruitment of mangroves in areas where substrate elevations are below MSL or the substrate is composed of fluid mud. These mounds are created with the fill from dike walls breaches, or the spoils from the digging of tidal channels. Sometimes the mounds are kept in place with low bamboo fences which will biodegrade over time.

The mounds can be planted or allowed to colonize naturally. In South Sulawesi, where this is being trialed, we have not come across halophytic grasses which grow at lower tidal elevations. If such grasses were found, they would be ideal to help hold together the sediments to promote mangrove colonization. Communities have been experimenting with soil augmentation in the mounds, applying low-grade charcoal (not marketable), beach wrack, or peat/old mangrove root material from nearby areas with an abundance of peat/old roots.

The results of these mounding trials are not yet conclusive, at the writing of this book, but experiments of this nature are very much encourage. Creation of small patches of mangroves, in a system, may lead to consolidation of sediment, and also provide a propagule source for future natural revegetation.

Fig 8.14 A mounded area (elevated 20 cm above pond bottom) with temporary bamboo fence next to a hand dug tidal channel. Tompotana, South Sulawesi, Indonesia.

g) Creating Open Water for Fish Refugia

Mangroves do not occur in dense, homogenous stand. There are a variety of ecotones in any given mangrove system, such as tidal creeks, supra-tidal benches and cheniers, as well as areas of open water. Areas of deeper open water (sub-tidal) act as important refugia for fish when the tide is out. Shallow water refugia and intertidal mudflats are also important habitats for fish and shellfish as well as migratory and wading birds. Figure 8.15 shows open water, intentionally created in a rehabilitation project in West Lake, Florida, USA.

Fig 8.15 The intentional design of open water refugia in a mangrove rehabilitation project, increases fisheries habitat and can speed up the achievement of a functional fisheries equivalent, and wading seabird feeding habitat, common objectives of mangrove restoration projects.

h) Tidal Warping

Warping was the former practice of letting turbid river water flood onto agricultural land, so that it's suspended sediment could form a layer, before letting the water drain away. In this way poor soils became arable with the addition of nutrient laden silt.

Warping requires the creation of sluice gates and dike walls, but these may already be present in the case of disused aquaculture pond rehabilitation. To implement warping, tidal waters are allowed to inundate the enclosed substrate during high tide, and the gates are closed. As the tide ebbs, the water is slowly allowed to escape back into the river or sea, having deposited fine silt on the surface on the enclosure in which it had been penned. The result, over time, can be a raised substrate elevation, potentially more appropriate for mangrove colonization. This technique may also increase the organic matter and nutrients in a site, which can improve recruitment and early growth.

One issue with this technique, is that although substrate elevations may raise, sediments, dominated by fine silt, may not be consolidated enough to allow for mangrove recruitment. See the discussion under mounding (section f above) for experiments to augment substrate edaphic conditions and consolidate sediment.

i) Back-Basin Creation

In this technique, a large wide depression is excavated in the back of a rehabilitation area. This depression is created in order to retain tidal water, before it returns back out to sea via tidal channels. This increases the tidal prism, and encourages scouring of the tidal channel, maintaining their functioning. Although this back-basin creation may lead to standing water at the rear of the rehabilitation site, the assurance of a functioning tidal creek which will not fill with sediment is the priority.

Fig 8.16 Back-basin Creation

Fig 8.17 Tips for restoring mangrove hydrology

- Plan any hydrological works for minimal maintenance and allow for nature's ability to self-design.
- Avoid over-engineering with rigid structures and channels where these do not occur in nature. They will result in unnatural water velocities (possibly leading to erosion), unrealistically high and stable water levels or excessive amounts of open water.
- Drains should be filled with locally sourced materials (e.g., original excavations). Filling entire lengths of drains may be preferable to plugging drains at one or two locations as open, flowing water can develop considerable erosive power during floods. The greatest maintenance issues will occur where water flows steepen and accelerate, potentially "blowing out" any earth plugs.
- Utilize the natural energy of water rather than fight against it. Wetlands form in parts of the landscape where water flows naturally converge. Wetlands adjacent to rivers or estuaries will be linked to them, and pulses of water into and out of wetlands may be dominant natural drivers of nutrients and sediments.
- Natural ecosystems have resilience to cope with cyclic and extreme phenomena. In a hydrological context, water stored in a wetland (reflected by wetland water levels) will have seasonal highs and lows, and extremes associated with floods and droughts. At the extremes, plants may die, weeds may invade, and erosion may occur. A resilient restored ecosystem should be able to recover from these impacts given enough time. Remember that wetlands, like other ecosystems, are always changing.

From: "Wetland Restoration: A Handbook For NZ Freshwater Systems": (Peters & Clarkson, 2010)

8.4 Ecological Amendment

Although all mangrove species can colonize appropriate, open substrates, several mangrove species are excellent pioneers (*Avicennia* spp., *Sonneratia* spp., *Lumnitzera* spp.) and will quickly re-colonize a former mangrove site as long as the substrate elevation is of the appropriate height and the site experiences good drainage during low tide. Appropriate edpahic conditions also assist colonization, but are not as crucial as the duration and frequency of tidal inundation, which are controlled by substrate elevation and drainage.

The key then, to re-establishing mangroves, is first to repair the hydrology of the site. Then, if there are sufficient sources of propagules (mangrove fruits and seeds), both locally available and able to enter the rehabilitation site, colonization will likely take place naturally over time.

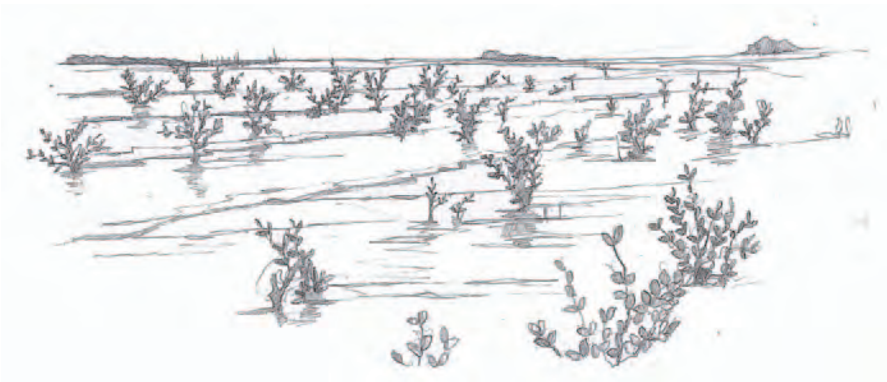


Fig 8.18 A pair of naturally vegetated intertidal flats

8.4.1 Some Techniques Related to Ecological Repair

a) Human Assisted Propagule Distribution
When propagules of one or more important local species are not available, you can assist their re-introduction to the area. The simplest way is to collect an abundance of ripe propagules and distribute them into the site on a rising tide. Nature will do the rest. This form of natural recruitment is known as hydrochory. In nature, mature mangroves produce an over-abundance of fruits and seeds, which fall to the forest floor (or directly into the water) to be distributed by tides, creeks and currents. Indeed, many of the propagules will not establish themselves, but they decompose and contribute to the benthic food chain. There is little cost associated with human assisted propagule distribution. It can be made into a fun, community activity, and should be run periodically, as propagules come into ripeness, until the site has achieved an adequate density of seedlings.

One activity to assist in human assisted propagule distribution is taking a phenology survey, which was discussed during the Biophysical Assessment chapter (Chp 4). A phenology survey provides information on the flowering and fruiting of the various mangrove species that occur in the rehab site, reference forest, or general region. Asking field staff and interested community volunteers to keep a running phenology log book [illegible]n excellent way of obtaining this information.

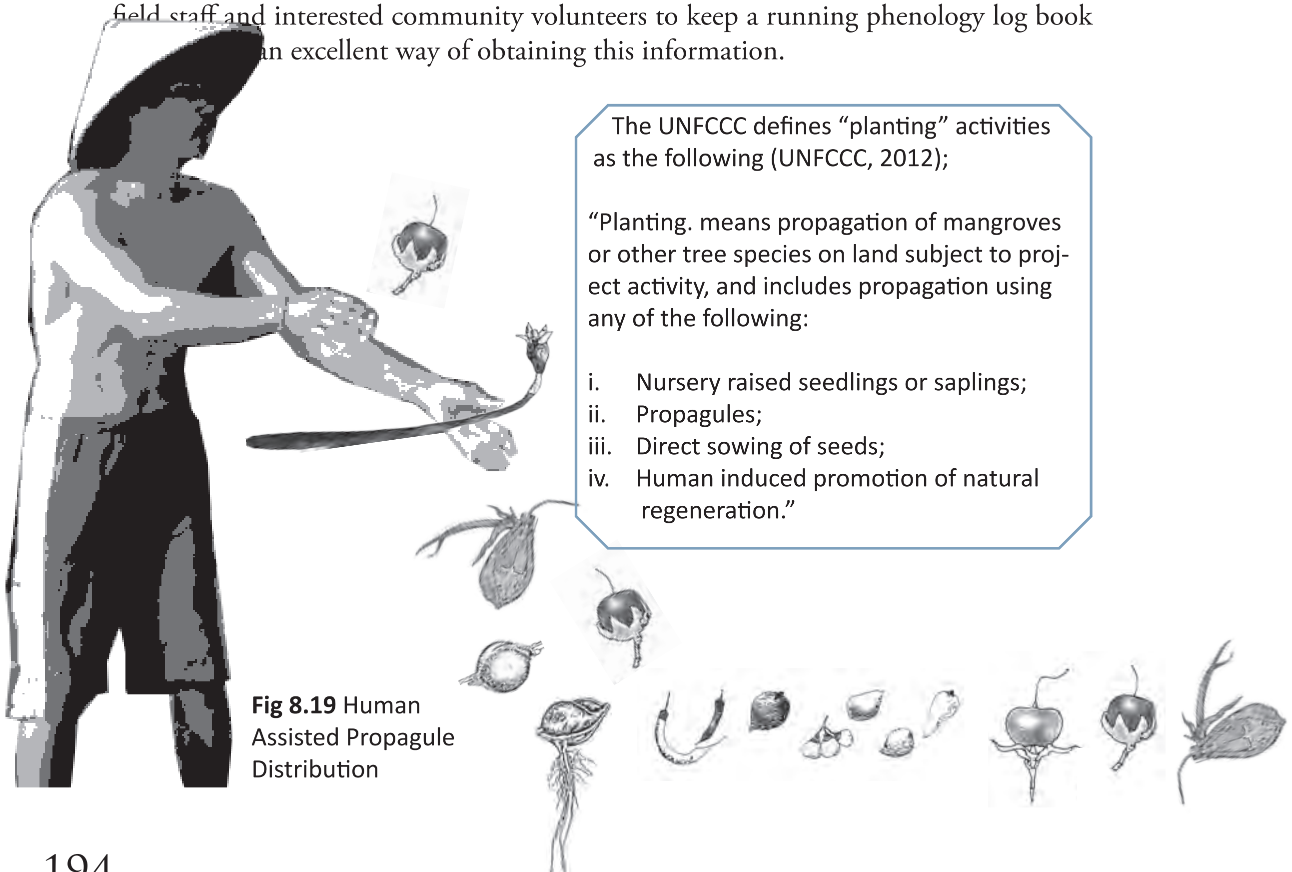


Fig 8.19 Human Assisted Propagule Distribution

Human assisted propagule distribution is now considered a type of planting, based on the IPCC CDM methodology (see Fig to right). This is good news for project managers who have inherited a mangrove rehabilitation project that calls for planting. It is seldom necessary to directly hand plant mangroves at a site.

b) Hand Planting
There are three types of hand planting;

1. Direct planting of propagules (what terrestrial foresters would call "bare-root")
2. Transplanting of wildlings – or naturally occurring wild seedlings
3. Rearing propagules in a nursery and planting the resultant seedling.

All three of the above methods can work given the right setting. Direct planting of propagules has the best track record of the three, and is a nice community event, but often fails due to lack of identification of appropriate substrates and elevations of the substrate for planting (Samson and Rollon 2008). Even when an appropriate site has been selected, care must be taken avoid planting mangroves too closely together. It is common, especially in rice planting countries, to plant mangroves in straight lines at very close spacing – 25 cm – 100 cm apart. This can result in stunting of the mangroves, and also create a very unnatural hydrology and should be avoided. (see Fig 8.20)

Planting clusters of mangroves with some areas with space in between may be preferable. Another option is to plant mangroves in a random pattern (no straight lines) spaced plantings of 1.25 – 2 meters. Large spacing allows room for natural seedlings to establish themselves over time. (see Fig 8.20)

Raising seedlings in polybags for planting is not difficult for most species, but planting out the resulting seedling can be tricky. Seedlings tend to go into shock when transplanted and can experience stunted growth. Some communities leave polybags on, while others take the polybags off. There are also, on the market, biodegradable polybags. MAP seldom attempts to rear seedlings in polybag, as most mangroves fair better distributed or directly planted. At the very least, we caution that before spending the time and money to rear seedlings in a nursery at large scale, conduct some trials and compare the growth rates and costs of seedlings raised in polybags, with direct plantings of propagules and natural recruits (see Figure 8.9).

Allowing Mother Nature to do most of the mangrove planting work makes sense and can save a lot of money.

Fig. 8.20 Spacing
Planting in a random pattern, with spacing to allow water flow in Balang Datu Pesisir, Sulawesi.

This 6 year old project was planted at less than 1 meter spacing, the resultant dense forest is purportedly good crab habitat, but high risk of poor drainage. makes this system vulnerable to extended flooding and potential mortality. Pambala, Sri Lanka.

c) Planting Marine Tolerant (Halophytic) Grasses

There are a number of marine tolerant grasses that inhabit the intertidal zone. Some of these may form the basis of an entire tidal marsh ecosystem, while others appear sporadically in a mangrove system. These grasses can be excellent colonizers of open mudflats or other substrate types in the intertidal zone. The grasses function to both physically capture mangrove seedlings,

and also to improve edaphic conditions of the substrate (decreasing soil temperature, buffering pH and salinity, oxygenating soils [improved redox potential], improving soil structure, enhancing nutrient availability, and promoting growth of beneficial microorganisms) all of which allow for improved conditions for mangrove recruitment and early growth.

In New World mangrove systems, halophytic grasses which live all the way down to Mean Sea Level, such as *Spartina* spp, have been used for decades in mangrove rehabilitation and coastal erosion control projects (see Figures 8.2, 8.23 and 8.29). In Old World mangroves (SE Asia) species such as *Porteresia* provide the same function.

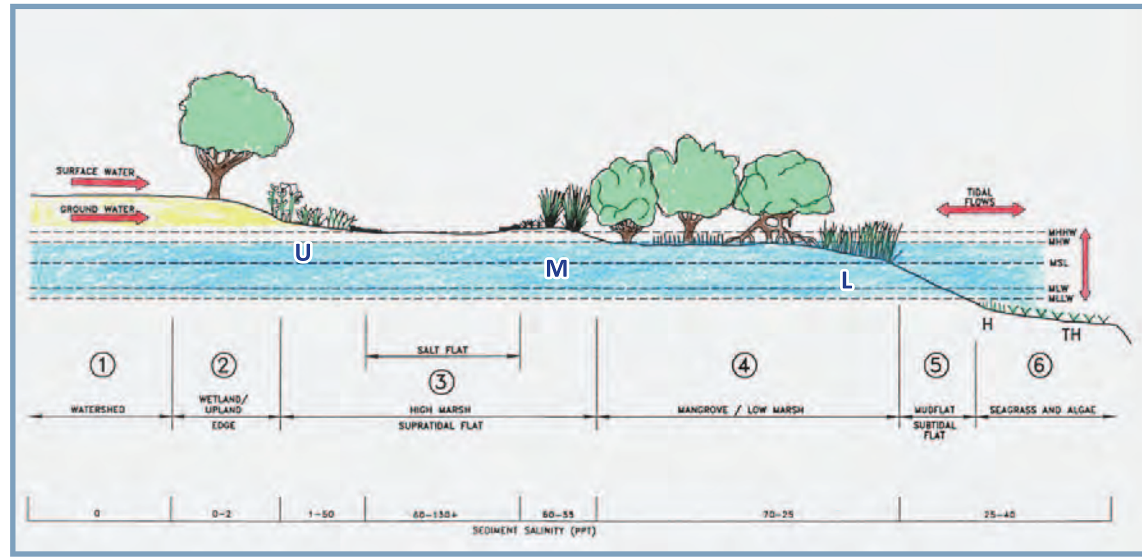


Fig 8.21 A typical cross-sectional profile, showing halophytic grasses growing in the upper intertidal (U) the middle intertidal (M) and the lower intertidal (L). (Lewis, 2005)

In Indonesia, we are just starting to find halophytic grasses that grow down to MSL, while working in Indonesian Papua (Fig. 8.22). Prior to work in Papua, the majority of grasses that we came across in Indonesia occurred in the upper end of the intertidal, which is not as useful to rehabilitation practitioners. We urge people to learn more about marine tolerant grasses native to their area, and to experiment with planting them in mangrove rehabilitation sites to assist colonization of mangroves.

d) Placement of Large Woody Debris

Large woody debris (LWD) is a common feature in a natural mangrove system. The wood breaks down over time, enhancing soil structure. Large woody debris, however, in a degraded, unvegetated system can be a danger, as the movement of the LWD with the tides can destroy mangrove seedlings.

Fig 8.22 Halophytic Grasses

Photos A-D depict a variety of grasses growing in the lower mangrove zone, down to Mean Sea Level. These photos were taken along an eroding shoreline in Mimika, Papua, where mangrove species tolerant to higher inundation frequencies are replacing large, dying *Lumnitzera littorea*.

Photo E shows a close-up of one of the grasses of Mimika, found lowest in the tidal profile, around Mean Sea Level.

The aerenchyma cells of their spongy rhizomes hold oxygen, an adaptation to frequent and long-lasting tidal inundation.

Photos F & G from an abandoned shrimp farm in South Sulawesi show common halophytic grasses in the upper tidal profile, also capturing a variety of mangrove seedlings (*Rhizophora apiculata, Sonneratia alba, Brugueira gymnnorhiza and Lumnitzera racemosa*)

Therefore, if placing large woody debris, anchoring should be considered.

Permanent LWD can act to sort out sediment, leaving coarse sediments on one side of the wood with finer sediments on the other, and promoting more diverse micro-habitats. The LWD also acts to stimulate decomposing communities, enhancing the natural diversity of mangrove fauna.

To review, some methods of ecological enhancement may include:

- Human assisted propagule distribution
- Direct planting of; propagules, wildlings & nursery-reared seedlings
- Planting marine tolerant grasses
- Placement of Large Woody Debris (LWD)

8.5 As-Built Documentation

After the project is installed, conduct an “as-built” survey, which is a detailed description of the site conditions, including topography, as determined by a professional survey crew or trained local villagers, done immediately after the construction is completed. If you and your volunteers constructed the site, document whether everything was built as expected. If the work was done by a contractor, the as-built survey should be conducted by a site inspector who is not employed by the contractor to document whether the project plans and specifications were followed by the contractor. This also ensures that the site complies with any regulatory (e.g., permit) requirements and your plans for the site. It is likely that there will be some deviations from the site plan caused by human error or unanticipated characteristics of the site. Use adaptive management: any deviations should be documented and discussed with your technical team to determine whether they need to be corrected to ensure that the project meets its goals. If the final project deviates in important ways from the plans, have the construction crew correct the problem--but only if the benefits of corrections outweigh the impacts of potential further disturbance. If corrections are needed, they should be made as soon as possible. The as-built assessment also provides a “baseline,” or starting point, for measuring change during subsequent monitoring.

8.6 Maintenance and Mid-Course Corrections

Implementation does not end with installation. Maintenance of a site includes the on-going control and care provided to ensure healthy mangrove growth.

Maintenance may require:

- Removal of trash, debris, especially trash that is impacting negatively on mangrove growth,
- Controlling herbivores (goats, sheep, camels, water buffalo), and potentially providing fencing or repairing fencing
- Continued distribution of propagules into the site
- Reducing or preventing human intrusion; and
- Minor hydrological repair – such as connecting tidal flows, re-opening dike walls breaches that were improperly excavated, etc.

If, during the course of a project, it is apparent that rehabilitation goals are not being met, an assessment to determine the cause of the problem followed by “mid-course corrections” is required. Common reasons necessitating mid-course corrections are poor drainage, inappropriate elevation, or an issue with the source of propagules (unable to enter the site, poor natural colonization, bad planting material). It may also be determined that although original project goals are not being met, the resultant situation is adequate (has some degree of improved ecological value), or will self-repair given more time.

Mid-Course Corrections may require:

- Re-digging/clearing main tidal channels
- Adding branches to tidal channels
- Adding fill to low/poorly draining sites
- Re-grading and stabilizing eroding banks
- Planting only after it is determined that natural colonization of mangrove propagules is not occurring over a period of several seasons of propagule production in the area

8.7 Examples of Projects Combining Different Hydrological and Ecological Rehabilitation Practices

Below we offer brief snapshots of some representative projects that have been undertaken to demonstrate the use of different techniques for mangrove rehabilitation. More detailed examples are provided in Chapter 10 under “International Case Studies.” The examples below include;

- Hydrological Rehabilitation Requiring Excavation, No Planting
- Hydrological Rehabilitation Requiring Fill, No Planting of Mangroves
- Strategic Breaching and Tidal Creek Excavation, No Planting
- Strategic Breaching, Mixed Planting/Natural Re-vegetation
- Coastal Re-grading with Planting of Marine Tolerant Grass
- No Hydrological Rehabilitation, Direct Replanting

8.7.1 Hydrological Rehabilitation Requiring Excavation, No Planting
Site: West Lake, Florida, USA – 500 ha
Lead Practitioner: Roy R. Lewis III, Lewis Environmental Services

Overview: The original mangroves in an 80 ha section of this overall 500 ha restoration had died off as the section was filled with dredge spoils, raising the substrate elevation and prohibiting tidal exchange. Before rehabilitation, this section was overgrown with *Casuarina* pine, which is an invasive, non-native species to Florida. Rehabilitation required;

- clear-felling of the *Casuarina*,
- excavation of the dredge spoils,
- grading (excavation) to an appropriate sloping substrate elevation which supports mangrove growth and
- digging sinuous tidal creeks mimicking reference tidal creeks nearby in terms of morphology (shape) and channel depth.
- The additional 420 ha at the site underwent hydrological restoration with some excavation and culvert placement after hydrological modeling.

for photos - refer to the time series from section b) "excavation" earlier in this chapter. (Figure 8.2)

8.7.2 Hydrological Rehabilitation Requiring Fill, No Planting of Mangroves
Site: Sunken Island, Mouth of Alafia River, Hillsborough Bay,
Florida, USA – 1.7 ha
Lead Practitioner: Roy Robin Lewis, Lewis Environmental Services

Overview: Most sites which require fill, but are not planted with mangroves, are still at least planted with marsh grass to stabilize the sediments (typically dredged material forming islands).

The Sunken Island site was an attempt to stabilize dredge spoils, and create nesting and foraging habitat for bird species utilizing this island managed by the National Audubon Society. Smooth cordgrass completely covered this planting area within three years, followed by mangrove colonization (principally *Avicennia germinans* and *Laguncularia racemosa*) which have dominated the area. The site's insular characteristics moderated freeze damage as suffered by mainland mangroves. Also, foot traffic was minimized due to protection by the Audubon Society. This project was an actual enhancement without mitigation requirements.

Paper available on-line: Download #13 Lewis, R.R. 1990. "Creation and Restoration of Coastal Plain Wetlands in Florida." Pages 73-101 In Wetland Creation and Restoration, The Status of the Science. Eds. Kusler & Kentula. Island Press.

Fig. 8.23 Time sequence photographs of a planted smooth cordgrass marsh on a dredged material island (Sunken Island extension) in Tampa Bay, Florida. A - Time Zero; B - T0+ 12 months; C - T0+ 24 months; D - T0+ 84 months showing mangrove invasion of marsh.

8.7.3 Hydrological Rehabilitation Requiring Fill, No Planting
Site: 40 Dredged Material Islands, East and West Florida Coasts
Lead Investigators: R.R. Lewis and Carolyn S. Lewis
(see Downloads #400, 401 and 402 at www.mangroverestoration.com)

Overview: A study was commissioned to characterize pioneering plant communities on 40 small islands created with dredge material by the US Army Corps of Engineers as colonial seabird habitat. No plantings were undertaken in these projects, which noted substantial mangrove colonization of the leeward side of dredged islands, protected from waves and human/boat traffic. This protection is necessary in order to allow waterborne propagules time to establish root systems on the unstable, and often eroding shorelines, of dredged material islands.

Red mangroves (*Rhizophora mangle*) have historically been considered the pioneer species, but as Carlson (1972) noted, black mangroves (*Avicennia germinans*) and white mangroves (*Laguncularia racemosa*) are the true pioneers in disturbed natural areas and on new dredged material deposits.

Along the central coasts of Florida, the intertidal pioneer is more commonly smooth cordgrass (Spartina alterniflora) (Lewis and Dunstan, 1975). Mangroves gradually invade and replace the shade intolerant cordgrass (see also Figures 8.23 and 8.24), which persists on older dredged material islands only as a fringe in the front of the outer band of red mangroves.

In northern Florida, very few mangroves can survive the periodic freezes, and the pioneering cordgrass may persist or be replaced by black needlerush (*Juncus roemerianus*) at higher elevations as sediments
accumulate.

The vegetative analyses of islands is this study confirm the basic pattern as outlined for the central coasts of Florida. Showing that smooth cordgrass and black mangroves have approximately the same relative frequency on the younger island. In contrast, on the older island, mangroves are very abundant with no smooth cordgrass present in any of the quadrats sampled. It is known to be present on the island, but only as a fringe in front of the mangrove forest where it can apparently withstand more inundation time than any of the mangrove species.

The most dominant mangrove species on older islands is the black mangrove. This may is part be due to differences in elevation since this is known to greatly effect the distribution of mangrove species (Davis, 1940; Detweiler et al., 1975).

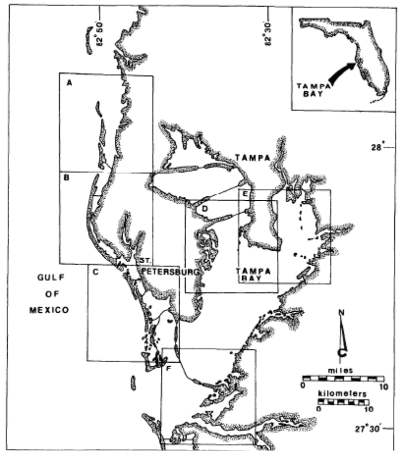
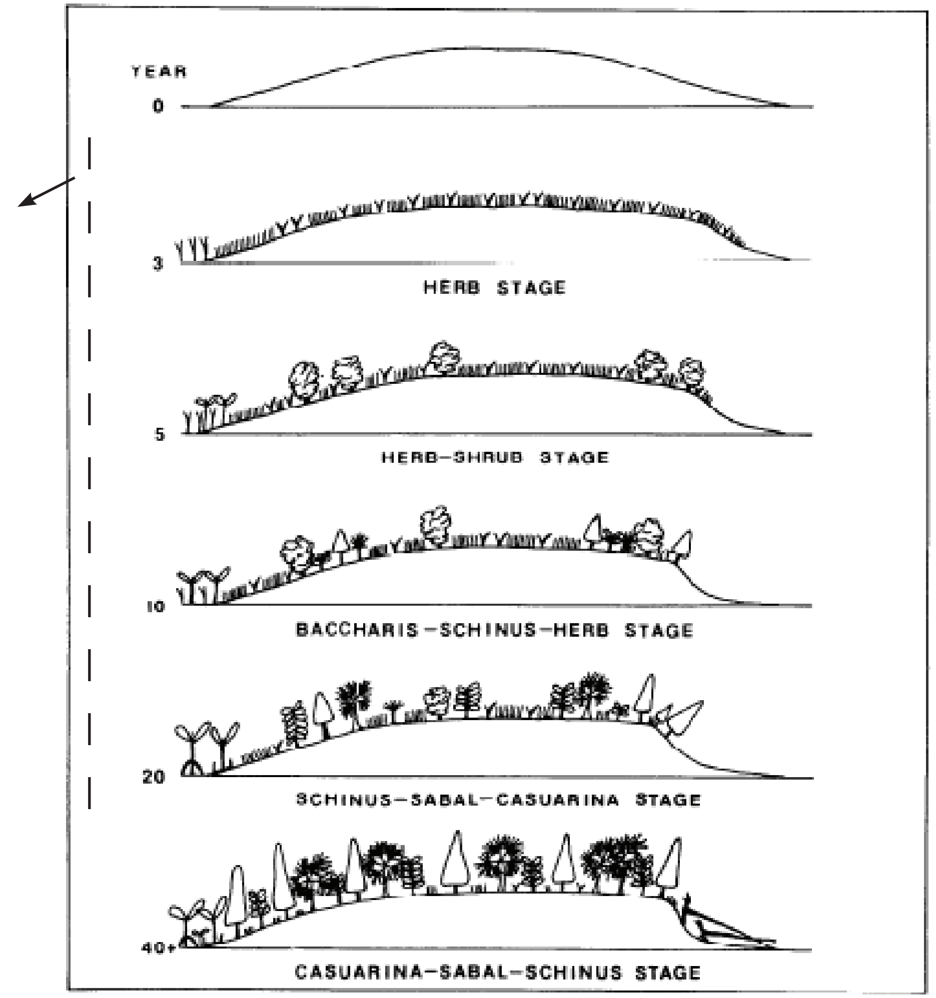


Fig: 8.24 Generalized habitat succession on dredged materials islands in Florida. Lewis & Lewis, 1978. (Mangroves and marsh grass occur left of the dashed line indicated by the arrow).



8.7.4 Strategic Breaching and Tidal Creek Excavation,
Mostly Natural Revegetation
Site: Tiwoho, North Sulawesi, 20 ha
Lead Practitioner: Rignolda Djamaluddin, University of Sam Ratulangi

Overview: This site comprised around 20 ha of abandoned shrimp ponds. They were clear-felled in 1990, but only approximately 8 hectares were constructed into brackish water ponds and operated for a period of 6 months before abandonment. A set of 5 ponds near the natural forest grew back healthy due to natural breach erosion and recruitment. The rest of the site still experienced disturbed hydrology. It was planted 5 times completely unsuccessfully by local government agencies. Hydrological rehabilitation included strategic breaching of dike walls, in-filling of un-natural aquaculture drainage channels, and limited construction of tidal channels to connect flows to larger tidal outflows. The site was planted, coincidentally, a 6th time by government directly prior to hydrological amendment. The site was also experienced some degree of planting by local students, who reared 12 species in a nursery. The majority of the 20 ha experienced natural revegetation.

Fig: 8.25: Natural revegetation ranging from 6000 - 14,000 seedlings/ha 8-10 years since EMR.

8.7.5 Strategic Breaching and Tidal Creek Excavation,
Mostly Natural Revegetation
Site: Tanakeke Island, South Sulawesi, 400 ha
Lead Practitioner: Ben Brown, MAP Indonesia

Overview: 400 ha of disused shrimp ponds were rehabilitated using the following methods; strategic breaching of dike walls, hand-digging of tidal creeks, distribution of mangrove propagules, limited hand-planting. Mid-course corrections consisted of creating branches on tidal creeks, connecting waterways, and trials with soil mounds, to artificially raise elevations (using spoils from tidal creek creation).

This full case study appears in Chapter 10.

Fig: 8.26: Hydrological rehabilitation leading to significant recruitment in less than 3 years on Tanakeke Island.

8.7.6 Strategic Breaching, Mixed Planting/Natural Revegetation
Site: NE Langkat Wildlife Sanctuary, North Sumatera, Indonesia – 12 ha
Lead Practitioner: Ben Brown, MAP Indonesia

Overview: This 12 ha shrimp pond complex was made of 10, one hectare ponds in a row, with a pair of outlier 1 ha ponds across an artificial channel. Minimum funds for this project necessitated reliance on strategic breaching alone. Substrate elevations were not measured in pond bottoms, yet all ponds exhibited some degree of naturally occurring mangroves inside. Pond walls were breached ranging from 3 to 7 meter widths, from upstream to downstream. After breaching, half of each pond was planted with one of 6 species by the local community (*R. mucronata, R. apiculata, B. gymnorhizza, B. sexangula, S. caseolaris, and X. granatum*). The other halves of the ponds were allowed to regenerate naturally. This was done in a zig-zag pattern. After 18 months, significant growth of remnant *Avicennia alba* inside the ponds was noted, with many growing 6-8 meters tall over that time period.. All planted species grew well, with *Rhizophora mucronata* most notable.

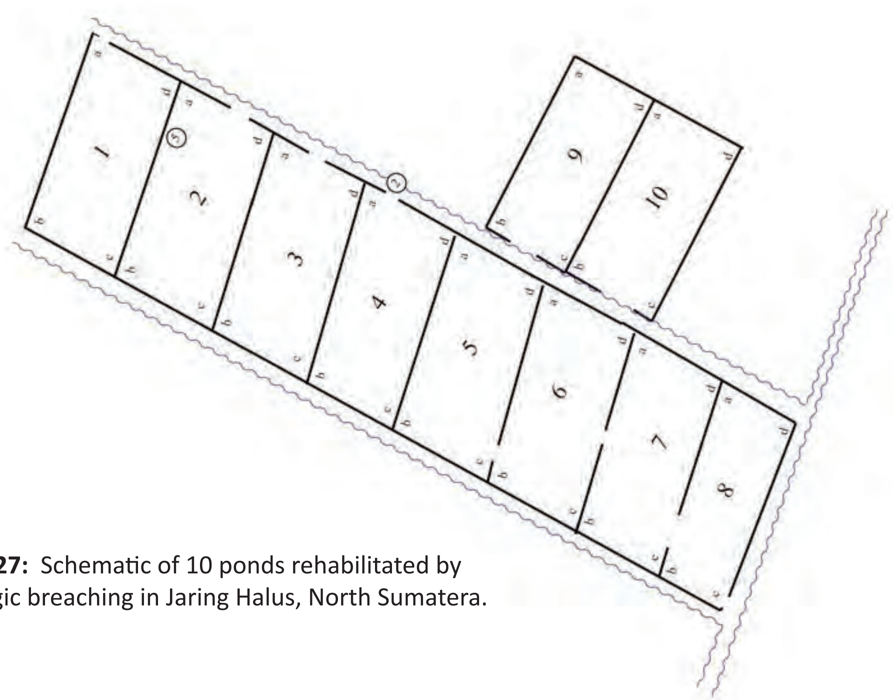


Fig: 8.27: Schematic of 10 ponds rehabilitated by strategic breaching in Jaring Halus, North Sumatera.

Fig: 8.28: A pair of time series. The top photo pair shows pond 3, shooting from corner "a" to corner "c." The red arrow indicates a remnant *Nypa fruticans* which was in the pond before breaching. The bottom photo pair shows the same for pond 5 (see key, Fig 8.27).

Ponds were half planted, and half allowed to undergo natural revegetation.
Pre-existing *Avicennia marina* in the ponds grew from small, stunted seedlings (under 1 meter tall) up to 7 meters in two years once dike walls were breached.

Planted *Rhizophora mucronata* and *R. apiculata* performed well.

8.7.7 *Coastal Re-grading with Planting of Marine Tolerant Grass*

Site: Hillsborough Bay, Tampa, FL, USA. Cargill Fertilizer, Inc., Bayside Shoreline – 5 ha
Lead Practitioner: Lewis

Overview: This five hectare site was experiencing severe erosion. A perpendicular erosion bluff was evident across much of the coast, which would continue to erode without intervention. The intervention in this case, was to re-grade the buff, by cutting back into the hillside, using the erosion bluff as a midpoint. A slope, between Mean Sea Level was created, up to a supratidal area beyond the point of the original erosion bluff.

This site was planted with grass a pair of times. The initial planting was supra-tidal to hold the upper elevations in place. Afterwards, smooth cordgrass was used to fix intertidal substrates, and allow for natural colonization of mangrove propagules.

Fig: 8.29: Vertical erosion bluffs at the site indicated severe erosion (A - opposite page). The erosion bluff was cut back and re-graded to create a stabilized slope (B-C). Terrestrial grass was planted to hold the upper slope, followed by marine tolerant smooth cord-grass which stabilized the intertidal substrate (D-G). Thirteen years after the intervention, mangroves are shown, having succeeded the marine tolerant grass. Shoreline erosion at this site is no longer an issue.

8.7.8 Erosion Control - Low Shell Breakwater
Site: Pelican Island, Sebastian, Florida, USA

Overview: Pelican Island shrank by 50% over the past century and a half (2 ha to 1 ha), due to a mangrove die-off of the natural oyster bed protecting the island, and subsequent erosion, leading to lowered elevations. Capture of sediment was required, in order to re-establish mangroves.

A pair of activities took place in phases to rehabilitate mangroves. The first step included planting of smooth cordgrass and Rhizophora mangle at appropriate elevations, and the anchoring of oyster bags around stressing mangroves as an attempt to increase substrate elevation.

A second stage involved "cresting" a natural wave break off the NW (windward) side of the island. This was achieved by airlifting 250 cubic meters of oyster shell (weighing 450,000 lbs) with a helicopter and enhancing the natural "sand-bar, oyster reef." The resultant low-relief shell breakwater was permeable in nature, but reduced wave energy allowing for sediment deposition over time on the leeward side of the wall. (Figure 8.30).

Expansion to 1.3 ha of salt marsh and mangrove forest took place within 2 years after the intervention and totaled 1.5 ha within 4 years.

Fig: 8.30: Loss of mangrove and salt marsh coverage over time on Pelican Island (a). A low rock break-wall was constructed (airlifted by helicopter) in 2001 (b-d), resulting in the deposition of sediment on the lee side of the breakwall (e), and subsequent increase of mangrove and salt-marsh coverage (f-g).

8.7.9 No Hydrological Rehabilitation, Direct Planting
Site: St. Croix, Virgin Islands – 10 ha
Lead Practitioner: R.R. Lewis

Overview: Mangroves at this site were destroyed due to an oil spill. Although sediments were cleaned and could once again support mangrove growth – biologically, and substrate elevations were not altered significantly, the lack of nearby propagules limited colonization of this site. Ten (10) ha of *Rhizophora mangle* were planted at appropriate substrate elevations and grew well. Canopy closure was achieved five (5) years after this planting.

Fig: 8.31: Before and after planting at an appropriate substrate elevation in a propagule limited site. (Lewis - St Croix, U.S. Virgin Islands)

8.8 Lessons Learned

Although in some ways, the science or art of mangrove rehabilitation has progressed in a number of important ways since the 1960s, there are some older documented projects that should be re-visited. Mangroves are en vogue nowadays for a variety of factors, but the majority of rehabilitation projects are largely oversimplified, poorly planned and implemented. Lessons need to be learned from both past and present projects, requiring practitioners to openly share their data and reports.

Below are some lessons learned leading towards better practice regarding the implementation of mangrove rehabilitation.

- Key stakeholders, including the local community, need to be engaged from the inception of the project, all the way through implementation, monitoring and adaptive management.
- Women need to be equally considered in all phases of mangrove rehabilitation and management.
- The key to successful restoration is insuring that physical processes are restored.
- The best way to ensure natural mangrove recruitment, is to focus on re-establishing appropriate substrate elevations, and functional tidal flows in the rehabilitation site.
- Natural recruitment can take time, even when conditions are right.
- Mangrove propagules only require "planting" when the site is propagule limited. To plant mangroves where sufficient natural propagules will colonize a site is a waste of resources, including time and money.
- A broader definition of planting is now understood to include human assisted propagule distribution or broadcasting.
- Planting mangroves on mudflats below mean sea level almost never works, and is never a good practice.
- In some cases, planting of marine tolerant grasses helps prepare a site, maintaining substrate elevation, physically capturing mangrove propagules and enhancing edaphic conditions for mangrove recruitment and early growth.
- It is very important that rehabilitation projects have clear statements of measurable, achievable ecological objectives agreed upon by all relevant stakeholders.
- Manipulated systems do not work well as long term sustainable wetland ecosystems: natural tidal rhythms are not maintained, plants and invertebrates cannot tolerate the extreme conditions that occur and consistent operation is rarely maintained over time.
- Both Rehabilitation and Restoration are best viewed as re-establishment of an immature system that evolves towards maturity over time.
- Monitoring of projects is mandatory if lessons are to be learned for future projects.

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9
MONITORING

1. **Why Monitor?**
2. **Quality Assurance**
3. **Creating a Monitoring Plan**
4. **Academic Monitoring (Higher QA)**
   - **Hydrological Parameters**
   - **Ecological Parameters**
   - **Analysis**
5. **Participatory Monitoring (Lower QA)**

This chapter is closely linked to Chapter 5, "Biophysical Assessments." Many of the activities initiated during assessments will be continued as routine monitoring after implementation of EMR. This chapter also introduces a method of participatory monitoring useful for working with rural fisherfolk communities (section 9.4).

9.1 Why monitor?

Why monitor? There are several reasons why it is important to monitor a rehabilitation site following implementation:

- To record how the actual rehabilitation compares to earlier designs. This is accomplished through an as-built survey and a Time Zero Monitoring Report, which is provides a benchmark to assess change over time.
- To quantify the recruitment, establishment and early growth of mangroves in an initial period after restoration (usually 3-5 years)
- To identify, early on, potential issues inhibiting establishment of mangrove seedlings, and to inform mid-course corrections.
- To increase community involvement, knowledge and understanding of the entire rehabilitation process.
- To inform future management strategies of mangrove area.
- To contribute to international knowledge bank of rehabilitation projects successes, failures and lessons learned.

It is important to ensure monitoring is planned and budgeted for at the onset of the project, is in line with project goals, and that success criteria are clearly established to determine what aspects of a site must be measured. Ideally a monitoring protocol should be developed prior to the initial assessments specified in Chapter 5 (Biophysical Assessments), but is adaptable to local conditions and unforeseen field constraints.

Elzinga et. al. (1998) identified several important points to keep in mind while developing a site-specific monitoring method;

- o What are the parameters of interest?
- o What is an appropriate sampling unit size and shape?
- o How should sampling units be positioned?
- o Should sampling units be permanent or temporary?
- o How many sampling units should be sampled?
- o How will data be presented?

The challenges of successful monitoring involve efficient and specific design, and a commitment to implementation of the monitoring project, from data collection and analyses, to reporting and using results.

9.2 Quality Assurance – Higher and Lower

Quality assurance/quality control measures are those activities you undertake to demonstrate the accuracy (how close to the real result you are) and precision (how reproducible your results are) of your monitoring. Quality Assurance (QA) generally refers to a broad plan for maintaining quality in all aspects of a program. This plan should describe how you will undertake your monitoring effort including: proper documentation of all procedures, training of volunteers, study design, data management and analysis, and specific quality control measures. A monitoring program will have a varying degree of QA, from high to low, which will specify how the results can be used in the future.

Higher QA– usually quantitative in nature. Either measured to a particular confidence level or accurate GPS positioning. Data is presented scientifically, based on predetermined mangrove rehabilitation success criteria. Useful for influencing policy.

Lower QA – is more qualitative in nature, not necessarily involving direct counts. Data can be presented visually or verbally. It is more difficult to reproduce accurate data when using low QA methods. Useful for building community awareness.

EMR monitoring methodologies and events should have some degree of community participation if possible, in nature – however we distinguish between academic and participatory monitoring as these discrete activities have different purposes and need to be planned for individually.

Academic monitoring – – uses higher QA methods, implemented in smaller groups us- ing trained field personnel and/or volunteers. Data collected for academic monitor- ing is compiled into technical monitoring reports. MAP Indonesia has developed a monitoring method in consultation with mangrove scientists from around the world. Even at the level of academic monitoring, we often have to choose between levels of QA. Very high QA methods are appropriate for academic studies, while slightly lower QA methods are used for project reporting (due to time and human resource constraints). Activities 9.3 delineates a process of undertaking academic monitoring.

MAP Indonesia does not recommend routine quantitative sampling of biota such as fish, invertebrates or birds. Proper sampling to generate scientifically accurate data sets is very time consuming and expensive. For example, proper scientific collection and analyses of benthic infauna like polycheate worms requires a minimum of ten cores per site per month and these then need to be transported to a proper lab, sorted and all organisms identified to species. Fish sampling requires similar intensive work. We believe that sampling too infrequently and generating worthless data is just a waste of time and money. Observations and reporting of obvious fish seen and epibenthic (living on the surface) invertebrates seen is about all we recommend unless a well funded research project is underway.

Similarly, detailed water quality sampling is also expensive and labor intensive. Even taking salinity readings to generate real data sets reflecting real salinity regimes on a site are difficult to justify as even a passing rainstorm can lower salinities in a matter of minutes. If changes in water quality is a research subject of interest, and funding is provided for in situ recording meters, and someone is going to place, retrieve, read and analyze the data from the meters, then looking in detail at water quality changes may be appropriate, We would only caution that vandalism of such expensive equipment is likely in most remote locations.

Participatory monitoring – uses lower QA methods, designed to be inclusive, or usable by individuals and groups without rigorous scientific training. The parameters to be monitored are decided by the group, and data is usually presented visually. Activity 9.4 discusses a participatory EMR monitoring method used on Tanakeke Island, South Sulawesi with rural fisherfolk from 6 villages.

9.3 Creating a monitoring plan

Monitoring of a rehabilitation site occurs directly following rehabilitation implementation and continues usually for six months to a year or two – or the duration of a project depending on allocated resources. If mangroves are planted at a site, monitoring for successful survival of those plants needs to occur over a minimum of three years (five preferred). Planted mangroves under stress may appear healthy for a year or two as they deplete there stored carbohydrate reserves and struggle to survive, and a project may be called successful only to see most of the planted mangroves die within 3-5 years. Unfortunately, longer term monitoring is rare, and actually reporting of the monitoring as a report available at least on the web is rarer still. Finally, publication in a journal of these data are almost non-existent (see Lewis et al. 2005 – download #34 at www.mangroverestoration.com as one of the few)

A recommended sampling regime consists of ten events starting with a Time Zero (T0) report and progressing and on a regular schedule with sampling events at T0, T0+3, 6, 9, 12, 18, 24, 36, 48 and 60 months. The frequency of sampling is not as important as the actual completion of SOME quantitative sampling and reporting program. A minimum of four reports are likely needed: T0, T0+12, 24 and 36 months. The proposed more frequent sampling during years one and two are

sug- gested in order to quickly detect and correct any problems with the project, such as domestic animal grazing (sheep, cattle, goats, camels, etc.) which may require quick intervention with fencing to prevent loss of colonizing or planted mangroves. You can find a typical Time Zero report as download #301 (Lewis 1999), and a typical Time Zero Plus 60 months report (Lewis 2004) as Download #302 at www.mangroverestoration.com.

9.4 Academic monitoring (Higher QA)

9.4.1 Hydrological Parameters

A) Constructed tidal channels (recommended for each monitoring event)

Purpose: The creation of tidal creeks is used in EMR to correct problems flooding and drainage of water from the restoration site. Tidal creek design and construction is modelled on nearby reference creeks. Monitoring the development of tidal creeks allows the practitioner to prescribe mid-course corrections, to re-establish natural patterns of flooding and drainage.

Objective
- Track changes in channel shape (morphology) and path over time.
- Identify areas of excessive sedimentation/erosion within channels which may inhibit channel functioning over time.

Materials
- Current remote sensing image of rehabilitation site.
- GPS coordinates of cross section measurements.
- Original rehabilitation design.
- GPS unit
- Meter stick
- Measuring tape (fibreglass)
- Bamboo stakes
- Auto level/laser level

Time 1 – 2 low tides, depending on number of new tidal creeks.

Procedure

1. Recording channel path
   a. Record channel code on data sheet

b. Locate the seaward mouth of the constructed water channel in the field.
c. Using the GPS tracking function, walk the entire length of the new channel

2. Sedimentation and erosion
    a. Note any areas of significant sedimentation or erosion along the channel path on map or sketch map.
    b. Note general comments on water flow as observed on outgoing tide.
3. Channel Cross Sections (Channel Width and Depth)
    a. Relocate GPS coordinates for previous channel cross section measurements. These should be evenly dispersed along the channel – one close to the seaward mouth (approximately 5 meters from the mouth), one in the middle and one toward the landward end.
    b. Place bamboo stakes on either side of the channel, where the bank meets the verge. (Diagram)
    c. Measure channel width.
    d. Extend this measurement either side of the channel and place bamboo stakes. For example, if the channel width is 1 meter, extend 1 meter on either side. This will make the total width of the cross section 3 meters.
    e. To measure channel depth
        - With auto level; sight back to a bench mark tied to tidal datum, measure height of substrate at 20 - 50 cm intervals along the entire length of the cross section. Take measurements at the bamboo stakes in the creek bank as well. Subtract measurements from tidal datum to get substrate heights.
        - Without auto-level; return to the bamboo stakes placed at high tide. Note time and predicted tide height. Take measurements from water surface to substrate at 20 – 50 cm intervals. Subtract measurements from predicted tide height to get substrate heights.
4. Note channel type, weather, last precipitation, recent weather, air temperature, water temperature and channel bottom on date sheet as described in Chapter 5.1.2 Channel Cross Section, Flow and Total Discharge – Reference Forest and Rehab Area
5. Input all data and GPS location into database.

Data Analysis

1. Input GPS track of tidal channel into GPS program and record on map. Indicate new tidal channel paths with a different colored line on map.
2. Mark locations of erosion and/or deposition on map.
3. Mark permanent cross section measuring stations on map.

4. Channel cross sections can be drawn on transparent paper – and overlayed to track changes in morphology over time.

Discussion questions

- How are both natural and constructed channel dimensions changing over time?
- How are the paths of both natural and constructed channels changing over time?
- How are previous, straight canals or ditches changing over time?

B) Monitoring Major Water Flows and Standing Water (recommended for each monitoring event)

Background

In a natural mangrove system, continuous tidal flushing and adequate water circulation ensures mangrove health not only in part by regulating physiochemical properties of the soil, but also by acting as a vehicle for propagule distribution. In a healthy system, water enters and exits through naturally created and reinforced tidal channels. If water is not draining from a site correctly, standing water accumulates creating anoxic areas within the mangroves, preventing recruitment in these areas. Monitoring drainage and any persistent ponding in the rehabilitation area allows for identification of hydrological issues that could be hindering recruitment early on and allows for quick remediation.

Objective

Identify and monitor all current major water flows, and map areas of standing water to determine if hydrology is conducive to natural recruitment.

Materials

- Current aerial photograph of rehabilitation site and any site hydrology maps created in past surveys.
- Markers
- GPS

Time 1 – 2 tides from high to low, depending on site area.

Procedure

1. A major water flow is classified as a water channel that is critical to assist in the flooding and drainage of the mangrove wetland. A properly functioning tidal channel is self-maintained, due to the scouring effect of flowing water on the substrate during flood and ebb tides. As a results, sediment is not able to build

up and eventually clog in a properly functioning tidal channel.

2. Observe site during ebb tide to gain the best view of major water flows. Using the tracking function of the GPS to walk the length of each major tidal channel, taking note of instance of excessive sedimentation. Also observe areas of excessive channel erosion. A properly functioning tidal channel will find a dynamic equilibrium between sedimentation and erosion.
3. Look into the interior of the mangrove rehabilitation site for incidence of significant standing water at low tide. Standing water at low tide inhibits mangrove recruitment and growth. Some areas of standing water may be appropriate for fish refugia, but the forest floor should not have significant ponding during low tide.
4. Record observations on map .

Discussion questions

- Is there evidence of sedimentation in tidal creeks? Is it occurring on the ebb or flood tide?
- How do you recommend correcting sedimenting tidal creeks?
- Is there evidence of extreme erosion due to tidal channels? Is this part of the natural change taking place in the rehabilitation site, or might this be problematic?
- Is there evidence of significant standing water in the site? Is it a problem? If so, what do you suggest as a mid-course correction to remedy this problem?

C) Monitoring Dike Wall Conditions and Functioning of Constructed Breaches. (recommended at T0 and annually for disused shrimp ponds)

Background

One goal of rehabilitation within shrimp ponds is the eventual degradation of dike walls through weathering and tidal force. Monitoring the changes of dike wall conditions annually will identify if there are any areas in need of further assistance in degradation. Monitoring also allows us to analyze patterns of degradation, for example, is there rapid degradation of walls closer to the ocean in comparison to walls closer to land or water channels? The construction of breaches within dike walls helps this degradation process as well as strategically channels water to assist tidal flushing. Functioning of these breaches should be monitored to identify any sedimentation occurring, indicating a lack of flow at the breach.

Objectives

- Review and reclassify all relative dike wall conditions.
- Review location of human made and major natural breaches in dike walls.
- Establish if sedimentation is occurring at the position of the breach.

Materials

- Laminated current remote sensing images with current marked breaches and waterways.
- Pen
- GPS
- Data sheet with key for categorizing condition of breaches
- Markers (different colours)

Time – one day for field work (up to 25 ha) and half day for data entry on map

Procedure

1. Relocate major breaches identified in activity 5.1.3. Mapping dike walls/breaches and instance of sedimentation and location of all planned breaches in rehabilitation plan. Record GPS location and code.
2. Two independent observers are required to classify each dike wall to reduce bias. If possible, use same observers each monitoring event.
3. Follow procedure and use key specified in activity 5.1.3 Mapping dike walls/breaches and instances of sedimentation.

Analysis

Add information from this activity as a map layer to the above maps created for hydrological parameters for an entire view of current hydrological patterns to be used in mid-course corrections.

Discussion questions

- How are the conditions of dike walls and breaches changing over time?
- Is it better to have many or fewer dike wall breaches in the initial stages of restoration? Explain.
- What is the relationship between tidal creek formation and breaches in dike walls?

9.4.2 Monitoring Ecological Parameters

On Sample Size
Globally, mangrove deforestation rates are above 100,000 ha per year. Forgetting for a moment of the need for conservation, reforestation projects, and by default monitoring needs to take place at large scales to even attempt to keep up with these losses.

This places a lot of pressure on development of a monitoring methodology which provides scientifically significant data, while at the same time being efficient in terms of use of human resources and ultimately the cost.

If resources are adequate, we recommend two permanent plots (25 – 100 m^2 in size) for each hectare of restoration. These plots should be monitored for percent cover by species. Fixed photos stations are also requisite.

If resources are extremely limited, we recommend 5 permanent quadrats per ecotone (for instance seaward, mesozone and landward mangrove area) for up to 50 ha of restoration. With a reduction in sample size, comes a reduction in statistical accuracy. Consult with a statistician to determine appropriate and bare minimum sample plots for your restoration area.

On Ecological Success
The survival of planted seeds or seedlings has little to do with final overall ecological success of a restoration effort. A little known fact is that when you look at data about the density of mangroves in both planted and natural forests over time, the number of mangrove trees per hectare declines over time as plants compete with one another for nutrients, sunlight, etc. (See Fig 9.1.) Thus if plants or propagules are planted on one meter centers you are putting in 10,000 planting units per ha. Natural forests or recovering forests typically have around 1,000 trees per ha. Thus a successful natural restoration project usually results from a 90% death rate for installed plants! No one would consider that a success, but it is how Mother Nature defines success. For this reason, percent cover by species as reported by Lewis (1999 and 2004) and Lewis et al. (2005) is one of the preferred parameters to be measured to define success.

Basal area is another important quantitative characteristic of forests in general, and the methods described in Cintron and Novelli (1984) should be followed to ensure high quality assurance but recheck the suggested methods of calculating BA as there are typos in the paper. (See also download #306 at www.mangroverestoration.com for the corrections) We would note that these methods were developed to describe mature mangrove forests, not newly restored forests. Thus with large numbers of small volunteer or planted seedlings in the early stages of a restoration project, none

Fig 9.1 Natural thinning of stem density over time.

The table below depicts the natural thinning of stem density in a logged over area of a mangrove concession in Bintuni Bay, Papua, Indonesia over a 21 year period. (Inoue, 2013)

Time after logging (yrs.)	5	10	15	21
Stem density per hectare	57,500	17,600	1,875	1705

are likely to meet the criteria of having a height of at least 1.3 m, and a Diameter at Breast Height (DBH) of 2.5 cm to qualify as a "sapling" or "tree" that would then be used to calculate basal area. Thus, in the early stages of a mangrove restoration project, the basal area will be 0. As time progresses, and the volunteer or planted seedlings grow, some will eventually first reach a height of 1.3m but many of those will not have a DBH of 2.5 cm or greater. We would suggest that all mangroves that reach a height of 1.3 m should have a DBH taken, and those with a DBH of less than 2.5 cm should be categorized within a "DBH less than 2.5 cm" category in order not to compromise data comparisons with older basal area data collections. It is not unusual to have the dominant plant cover in the first few months or years of a project made up of just such sapling mangroves, or even marsh grasses.

Once data has been collected over multiple monitoring events, data can be analyzed over time and statistical tests of significance can be applied.

A) Monitoring Vegetational Profiles

A baseline cross sectional profile of substrate height and associated vegetation was surveyed as part of Biophysical Assessments (Chap. 5). These profiles should be updated at each monitoring event.

Objective
Continue taking measurements along permanently established transects from activity 5.2.5 (Vegetation profile).

Materials and Procedure
Refer to materials and procedure outlined in activity 5.2.5 (Vegetation profile).

Fig 9.2 Presentation of vegetational profiles in Kuala Gula, Malaysia as part of an EMR training.

B) Monitoring Autecology and Community Associations

Background information
Baseline information for individual species of vegetation and community associations was established within a reference forest and the rehabilitation site in activity 5.2.1 "Vegetation Survey" Permanent quadrats were established which should be inspected and data collected periodically based on your monitoring schedule. Reassess the number of quadrats if necessary, to increase robustness of the data set.

Objective
To track changes in vegetation over time and to measure against success criteria.

Materials
- Extendible height stick
- Dress makers tape measure or dbh measuring tape
- Scientific calculator
- Pre-assembled 1m x 1m quadrats (from PVC)
- Data sheets
- Canopy reader
- Field guide for mangroves, associates and halophytic grasses
- Rope/string
- Stakes (for corners of quadrat)

Time
15 – 30 minutes per quadrat

Procedure
- Locate GPS coordinates of quadrats in the rehabilitation area
- Follow procedure 5.2.7 "Vegetation Survey."
- Store data in database.

9.4.3 Data Analysis

Once ecological data has been collected, there are several ways in which it can be analyzed –either per monitoring event or cumulatively over time. Data should be analyzed to a specified confidence interval to depict the reliability of your data and analyses. Ideally this should be specified when developing the monitoring protocol as it will influence the number of sample quadrats required – the more samples taken the higher the confidence of our data. The most widely used level of confidence is 95% (alpha = .05). Other common confidence levels are 90% and 80%. Confidence levels are used to construct confidence intervals. A confidence interval gives an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. A common statement would be: We are 95% sure that the true population mean lies within 250 plant/hectare of the sample mean.

There are many numerous scientific analyses that can be calculated from a single set of data. Here we have outlined basic analysis that can be calculated on data collected in individual monitoring surveys and then compared over time. Additional to this an explanation of Statistical tests are outlined that compare data collected over time within the same rehabilitation area. Statistical tests answer the questions: Has there been any real change in our data or is exhibited change due to sampling variability?

A) Types of Analysis

1. Density

Calculating the density of vegetation in each monitoring event is the most basic of analysis to be made and helps to both see if a project is reaching specified project success criteria as well as inform the need for mid-course corrections. Densities are calculated as stems/m^2 which can then be converted to stems/hectare by multiplying by 10,000 (m^2 in 1 hectare).

Density(stems/ha) =Total number of stems/Total area sampled X 10,000

Pre-rehabilitation stem densities are used to create a baseline to which all ensuing survey densities are compared.

2. Average Rate of Recruitment

Average recruitment rate is the average no. of plants that enter and establish the rehabilitation area over a given time period. This analysis is more telling of a site and rehabilitation effort than density calculations alone as it indicates if there is a change in recruitment due to human interventions.

Recruitment rate is not constant, but rather fluctuating - both seasonally with fruiting events, and in the longer term. The equation for average recruitment rate is:

Average Recruitment Rate = average number of plants per hectare /time since disturbance (months/years)

Ideally it would be best to calculate the fluctuating rate of natural recruitment since the time of disturbance. This can be achieved by measuring recruitment rates each quarter or 6 months from the time of disturbance and plotting on a time series graph. This is mostly unfeasible in rehabilitation programs as data collection would need to have been carried out from the very onset of disturbance. Therefore we must measure the 'constant rate of natural recruitment' and compare change in recruitment rate following human interventions. Generally within a degraded site we could expect the following recruitment patterns:

Fig 9.3 Average Recruitment Rate

- *Scenario a:* Low rate of natural recruitment immediately following disturbance which then increases over time (eg. A propagule limited site)
- *Scenario b:* High rate of natural recruitment immediately following disturbance which then tails out overtime (Areas where disturbance has left fruiting trees intact but die over time, creating a lull in recruitment until new plants reach fruiting age – (eg. Areas of tectonic uplift where mangrove habitat is lifted out of the intertidal zone).
- *Scenario c:* No natural recruitment (areas which have no or very low supply of propagules and/or the site has been so modified that it does not support growth and establishment of seedlings).

Average rate of recruitment should be graphed to clearly depict change in recruitment rates.

3. Relative Dominance

Relative dominance gives an indication of which species are most dominant within the rehabilitation site. This is calculated from Basal Area of a species – therefore as explained above, relative dominance might not be calculable from early monitoring events, until plants reach tree maturity with a DBH above 2.5 cm, which could take 3 – 5 years at the earliest depending on site growth.

Total Dominance = Total Basal Area (m^2)/Total area sampled (m^2)

Relative dominance (species A) = Dominance (species A)/ Total Dominance

To convert dominance to hectares, multiply relative dominance by 10,000

In the early stages of monitoring, before Basal Area is a significant measure, relative densities can be calculated of both plant maturity and species to give an indication of plant species and maturity compositions.

4. Average Height
Average height of trees, saplings and seedlings is a simple way to communicate plant growth within monitoring reports:

Average height = total height/no. of plants sampled.

5. Canopy Closure
Canopy closure is a point estimate of the coverage of a forest canopy, and is measured in the field with a spherical densiometer (also called a mirror optometer) or by analyzing upward-looking hemispherical photographs.

Although not previously discussed in biophysical assessments or as a monitoring practice, canopy closure is a useful form of success criteria, that should be considered more for mangrove rehabilitation projects. Canopy closure of 75% or more can be considered a rough target 7-10 years after a rehabilitation effort.

B) Statistical Testing

Once data has been collected and basic analysis has be carried out, we can begin to ask the question: Is the change seen in a particular sample parameter due to an actual change in the population parameter, or is the change seen due to sampling variation? Statistical tests of significance compare critical values with calculated values which answers this question.

Statistical tests almost always test hypotheses, which usually follow the following format:

- *Null Hypothesis*: There is no real change in the population parameter.
- *Alternative hypothesis*: This is a real change.

A test then allows us to either reject the null hypothesis in favour of the alternative ie. There is a real change in the population parameter, or accept the null hypothesis that there is no real change in the population parameter ie. There is no real change to the true population parameter and changes seen are due to sampling variability.

Both the paired-sample t-test and One-way repeated measure ANOVA are appropriate for comparing scores in pre-implementation and post-implementation surveys IF the same permanent quadrats are sampled in each survey. Experience has led us to use paired sample t-tests.

It is important to decide which test is to be conducted on data during the development of monitoring protocol as it will influence the amount of samples needed to conduct tests with accuracy.

Note: If test conducted conclude one cannot reject the null hypothesis in favour of the alternative, this does not necessarily mean there has not been a real change to the true population parameter, only that data collected has not managed to demonstrate this change at the given level of significance through monitoring. An increase in sample size, or decrease in level of significance could show a different result.

9.5 Participatory Monitoring (Lower QA)

Background
Neither mangrove rehabilitation nor mangrove planting are traditional practices. Traditionally, there was no need for this activity, and therefore communities have not built a great store of practices, skills, knowledge or experience around mangrove restoration. Coastal communities have, however, spent their entire lives living and working in mangrove habitats, and quickly become astute mangrove rehabilitation practitioners. In recent decades, coastal communities have also witnessed and participated in a number of failed mangrove planting projects, and are usually eager to learn what went wrong.

One set of activities essential to encourage continued coastal community involvement in mangrove restoration and mangrove forest management is monitoring followed by reflection. Monitoring mangroves does not need to be difficult. Qualitative measurements of mangrove recruitment and early growth, the development of a functional hydrology, and the return of mangrove fauna to a restoration site can be achieved with simple observation and data keeping techniques.

Here we present a participatory monitoring method, using a simple, illustrated, two-sided data sheet (see Fig. 9.4), that coastal community members can use to record their observations for reflection and analysis. The results of these surveys are largely

Fig. 9.4 **Participatory EMR Monitoring - Data Sheet**

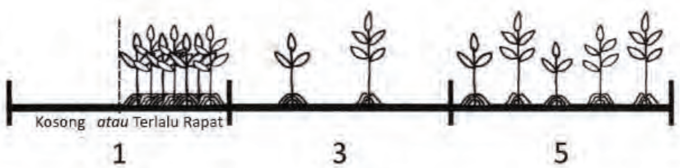
Village:______________________ **Site:**______________________________

Data Keeper :____________________ **Group:**_____________________________

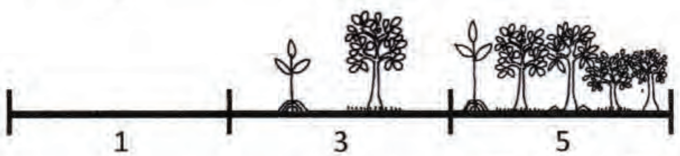
Date:___/___/___ **Time:**_____ **a.m./ p.m.** **Months After Initial Rehab:** Time Zero + _______

Eco and Hydrological Indicators:

A1 - Density of Recruits



A2 - Diversity of Recruits

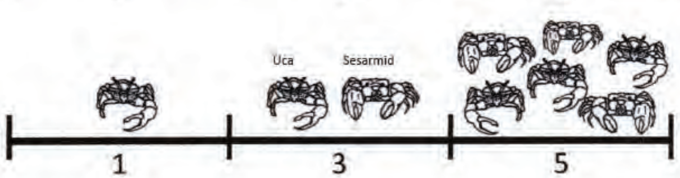


B1 - Fish & Shrimp Populations

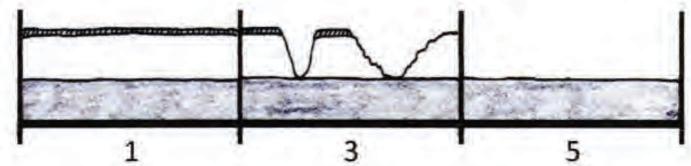
B2 - Population of Molluscs

B3 - Population of Mangrove Crab (*Scylla* spp.)

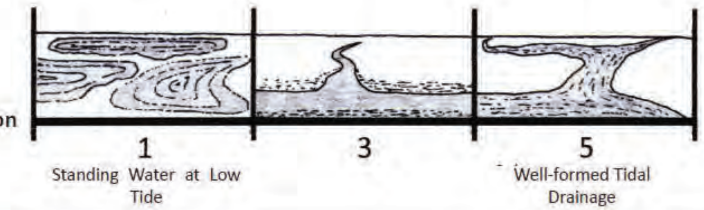
B4 - Population of Uca and Sesarmid Crabs



C1 - Dike Wall Condition



C2 - Tidal Creek Formation



Sketch Map of Location

Demarcate 6 Observation Points

Results of Observation:

Indicator	1	2	3	4	5	6	Sub-Total	Weight-ing Factor	Sub-Total		Total
	Observation Point										
A1								/2		A1 +	
A2								/2		A2 =	
B1								/4		B1 +	
B2								/4		B2 +	
B3								/4		B3 +	
B4								/4		B4 =	
C1								/2		C1 +	
C2								/2		C2 =	
Interpretation: 18 - 36 Unchanged; 37 - 54 Improved; 55 - 69 Good; 70 - 90 Excellent										**Quality Index**	

used to inform mid-course corrections, but also used to increase general community awareness of a mangrove restoration effort, and also in presentations to other stakeholders, primarily government to advocate for community involvement in mangrove management.

The indicators for this monitoring activity were chosen in close consultation with the communities themselves. Use of local terminology is essential. Monitoring schedules and methods are also developed in close partnership. An emphasis is placed on involvement of women and also youth, enabling more equitable mangrove management for the future. This exercise is similar to the participatory biodiversity survey presented in Chapter 5.

Community Organizing/Participant Selection
Form a restoration monitoring group with between 12-25 members. Women, men and youth should be involved equally. Monitoring as a school activity, expressly for youth is also a good way to ensure skills and knowledge around mangroves will persist over time. Make sure that participants understand the objectives of forming a monitoring group. Developing a learning contract is recommended.

Emphasis should be placed on educational approaches, rather than technical, scientific approaches, although the monitoring method should be scientifically sound. Engagement in monitoring, and reflection will increase participants confidence, awareness and responsibility to conserve a mangrove restoration area .

Monitoring Schedule
Once success criteria have been established, and the site restored through application of EMR principles, monitoring, and reporting should begin. A typical monitoring schedule would consist of the following 10 reports:

- Time Zero (T0)
- T0 + 3 months, T0 + 6 months, T0 + 9 months, T0 + 12 months
- T0 + 18 months, T0 + 24 months
- T0 + 36 months, T0 +48 months
- T0 +60 months

A Time Zero report is prepared after all the site restoration changes have been accomplished and any proposed planting completed. It should include photographs taken from fixed stations where future photography will also be taken. The shorter intervals in the early years of monitoring are designed to insure that any corrective actions necessary due to problems encountered during monitoring are quickly corrected. These are termed "mid-course corrections." Lewis (2009).

Objectives
The objectives of this activity are similar to the participatory biodiversity survey objectives from Chapter 5. Participatory mangrove monitoring has the following aims;
- ✓ Increasing the awareness of local community members in responding to changing environments.
- ✓ Building skills, knowledge and confidence in mangrove management practices.
- ✓ Encouraging observation and research skills and trial and error.
- ✓ Comparing typical mangrove planting practices with EMR.
- ✓ Building community and stakeholder awareness over the mangrove restoration and subsequent management.

Time: 1.5 days:
- ½ day for briefing,
- ½ day for mapping, collecting data
- ½ day for data analyzing.

Materials
- Flipchart
- Maps
- Stationery (data analyzing)
- Pens/pencils
- Data sheets
- Previous data (baseline and previous monitoring data)
- Cameras (Cell phone cameras)
- Field guide
- Note book
- Calculator

Method
1. Before rehabilitation, form a monitoring group, with 12-25 women, men and children. Hold a discussion on why monitoring is important. Develop learning contracts.
2. Before rehabilitation, the community group must be facilitated to make a monitoring workplan and timeline. and establishment of success criteria is essential. The monitoring schedule above can be used as a guide for monitoring events, but development of a locally appropriate schedule is necessary, taking into account seasonal cultural, economic events and also environmental factors such as tides or weather.
3. After rehabilitation, facilitate the community group to develop and explain indicators that will be monitor as the data. Steer the selection towards a few key species of flora and fauna as well as several hydrological (and potentially edaphic) factors. Develop a scoring system for each indicator. Simple scoring systems, from 1 to 3, 1 to 5 or -1 to +1 are common. Summing up the score from each monitoring event will provide a rough index for rehabilitation success.

•

Examples of indicators;

- Vegetation; diversity, density, rate of recruitment
- Fauna; diversity, abundance
- Hydrology: tidal creek formation, dike wall condition, ponding/standing water

4. Draw sketch maps of the rehabilitation area, open base maps or provide poster size remote sensing images for reference. Randomly place six monitoring/observation stations for each restoration area (ranging from approx 10 – 50 hectares). A numbered grid, overlayed on the map, and a random number generator function on a calculator is a good way to generate random sampling points.
5. The group can be divided to monitor 2-3 stations each, or all members can visit all six stations.
7. Ask the participants to take on clear roles and responsibilities before going into the field. Identify all tools that will be needed to conduct the survey. Aim for all field work to take place at low-tide.
8. Collect data at the six selected site. Create permanent photo stations at each site, using a PVC pipe cemented into a hole. This can act as the transect or quadrat starting point. Photos should be taken at all four major compass directions (N, E, S, W).
9. Back in the village, collect all the data from the group. Tally the scores of each indicator and average them across the sites.
10. Analyze the data together. Refer to older data sheets and compare results across time. Pay special attention to practical determinations of whether or not more hydrological or ecological repair is necessary, or whether the restoration can be considered a success.
11. Show pictures taken from the monitoring event to stimulate discussion. Print and post some of the photos in a public space. Have the group develop appropriate captions.

6.0 Discussion Question

- Why is monitoring after EMR necessary?
- Why is biodiversity important to the mangrove ecosystem? To the community?
- Is the data collected during monitoring useful to inform mid-term corrections and future management?
- When will success at your site be reached?
- What information from the monitoring activity do you need to pass on to government and other stakeholders?

10

INTERNATIONAL CASE STUDIES

7.1 Introduction - International Case Studies

The following case studies come from across the globe, and represent trials of both Ecological Mangrove Rehabilitation and other mangrove restoration attempts. These case studies currently differ in length, detail and focus, but all are meant simply as learning tools. Indeed, the only wrong practice in mangrove restoration, are those which are hidden. Without monitoring, open sharing and communication, the art of mangrove restoration will not progress.

Note to authors - We are still accepting international case studies of all types of ecological mangrove rehabilitation projects. Case studies should be chosen which illustrate both success and failure due to site selection, due to planting practice, and the application of EMR principles. Case studies should also include examples of stakeholder engagement and community based management, examples of education and training projects and examples of particular restored wetlands which achieve various objectives including biodiversity enhancement, coastal protection, wastewater treatment, and carbon sequestration.

The following template can be used to guide contributing authors.

Case studies should have less than 3000 words with an abstract and short "facts and figures" section featuring: location; ecosystems; size of the community (number of inhabitants); size (volume) of restored area; budget; duration; institutional, technical and scientific partners; main objectives and benefits; five keywords.

Each case study article should consider addressing:
- presentation of the challenges;
- description of the pool of expertise;
- funding resources and mechanisms;
- regulatory context: facilitating actions or constraints;
- details of restoration plans and results;
- methods used for monitoring;
- governance: forms of cooperation, innovations etc;
- analysis of the key factors for success/failure (context-based or general);
- knowledge gaps; and
- main challenges and innovations.

Send case studies to;
Roy Robin Lewis: <LESrrl3@aol.com>
Ben Brown: <seagrassroots@gmail.com>

7.2 West Lake Park, USA

Location: West Lake Park, Hollywood, Florida, USA. 26º 02' 2.49" N, 80º 07' 25.67" W

Size of Project: 500 ha

Methods of Restoration: 80 ha of dredged spoil excavation back to historical grade, volunteer colonization of mangroves, 420 ha of hydrologic restoration of stressed and damaged mangroves.

Project Description: Privately owned lands were purchases or donated to the Broward County Parks and Recreation Department (BCPRD) totally approximately 600 ha, and mitigation required for development of approximately 100 ha was undertaken by the BCPRD over a period of ten years starting in 1985 (Phase 1). Phase 2 was completed in 2011 with an additional excavation of 20 ha. No planting of mangroves took place. See images to the right of a typical part of the restoration.

Web Sources of Information: www.mangroverestoration.com, download documents #13, 24 and 42.

R. Lewis (lesrrl3@aol.com) provided this description.

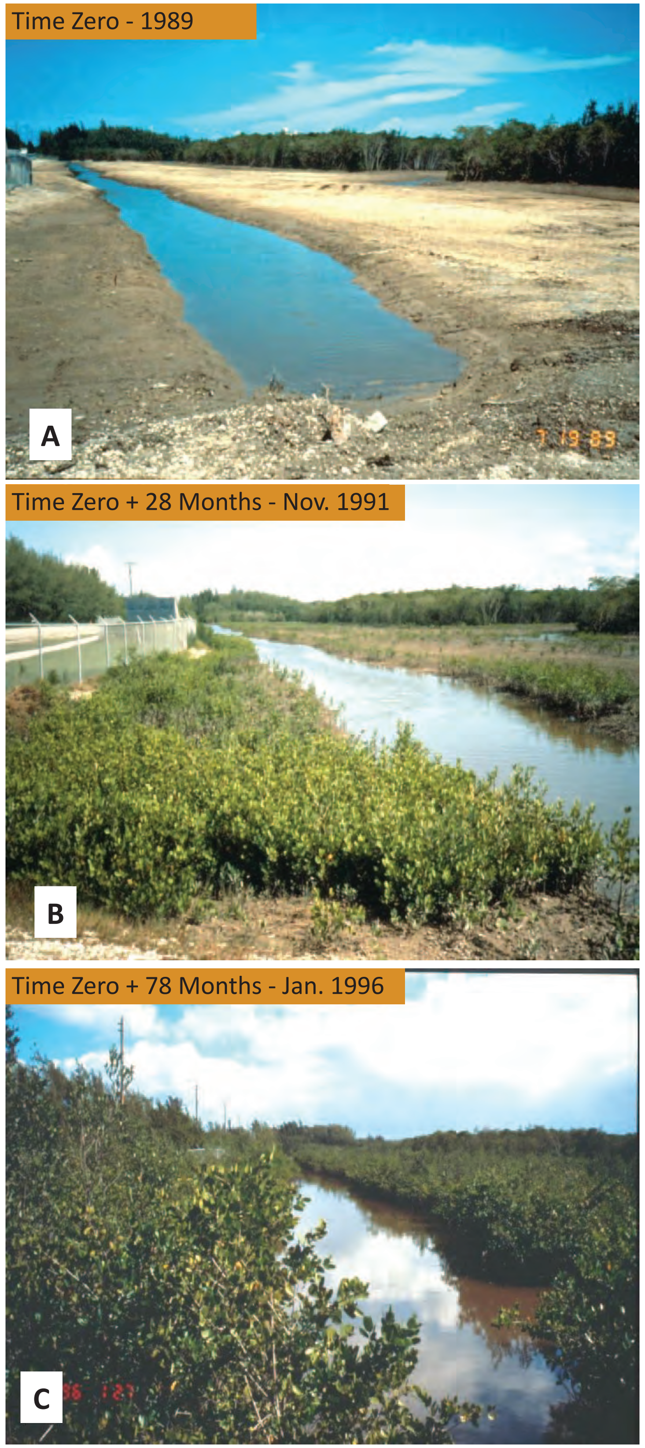


Fig 10.1 Time series of natural recruitment at West Lake Park over 6.5 years.

7.3 Barnabe Island - Brazil

Location: Barnabé Island, Santos, São Paulo, Brazil.
23º 55' 25.35" S, 46º 19' 30.04" W

Size of Project: 0,1 ha

Methods of Restoration: Riley Encased Methodology (Riley and Kent 1999).

Project Description: On September 3, 1998, the mangrove stand surrounding the Barnabé Island was affected by a fire due to the accidental spillage of a flammable chemical substance called dicyclopentadiene - DCPD (Fig. 7.2). The State environmental agency requested from the responsible for the accident a restoration project based strictly on planting of *Rhizophora mangle* propagules using the REM (Riley & Kent 1999). The project completely failed to restore mangrove coverage.

The loss of the vegetation cover severely altered the sediment dynamics. Topographic surveys carried out between 2004 and 2008 demonstrated the increased sediment loss where the mangrove used to fringe before the damage (Figure 7.3). Erosion condemned natural and PVC planted propagules/seedlings mainly in three different ways:

1. with the loss of the mudflat in front of the mangrove stand, wave energy was increased and together with floating debris it struck many of the seedlings;

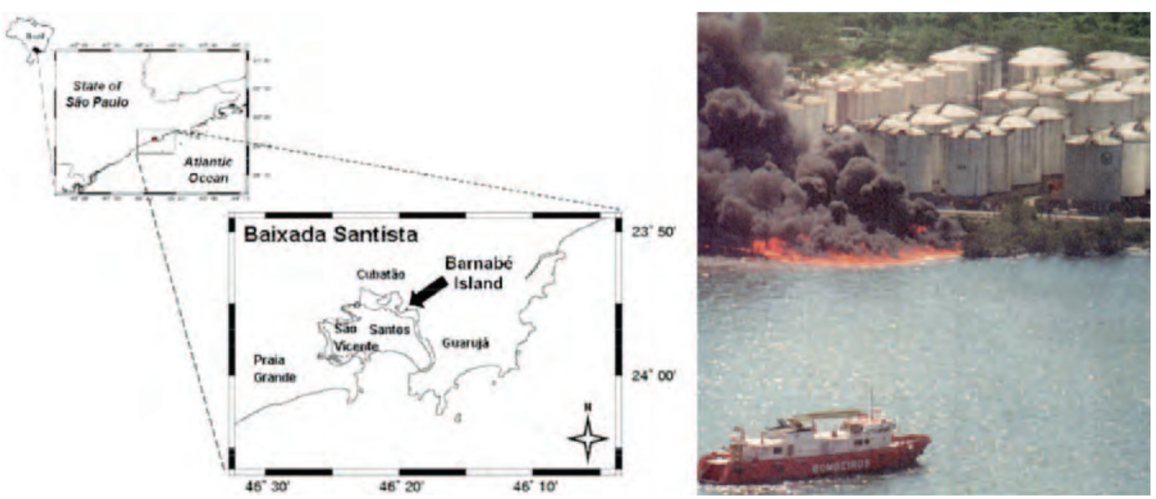


Fig 10.2 Study area location (right). A black arrow indicates the Barnabé Island. Mangrove stand at the moment of the accident in 1998 (left; image by Edison Baraçal, reproduced from A Tribuna Newspaper from September 4th, 1998).

2. it exposed the root ball, loosing up the seedlings which were then carried away by the tides and;
3. with the lowered substrata level, seedlings experienced higher and longer submersion periods, what made them suitable habitat for barnacle infestation, rotting the seedling due to excessive moisture.

Others facts that proved the methods inadequate were: (1) the composition of species prior to the impact, and (2) the secondary successional processes undergoing in the area. Formerly, the area was dominated by *Laguncularia racemosa*, followed by *Avicennia schaueriana* (Fig. 7.4). Also, natural regeneration was being primarily represented by *L. racemosa* and *A. schaueriana* while *R. mangle* seedlings, from both the strategies Figs. 7.4 and 7.5).

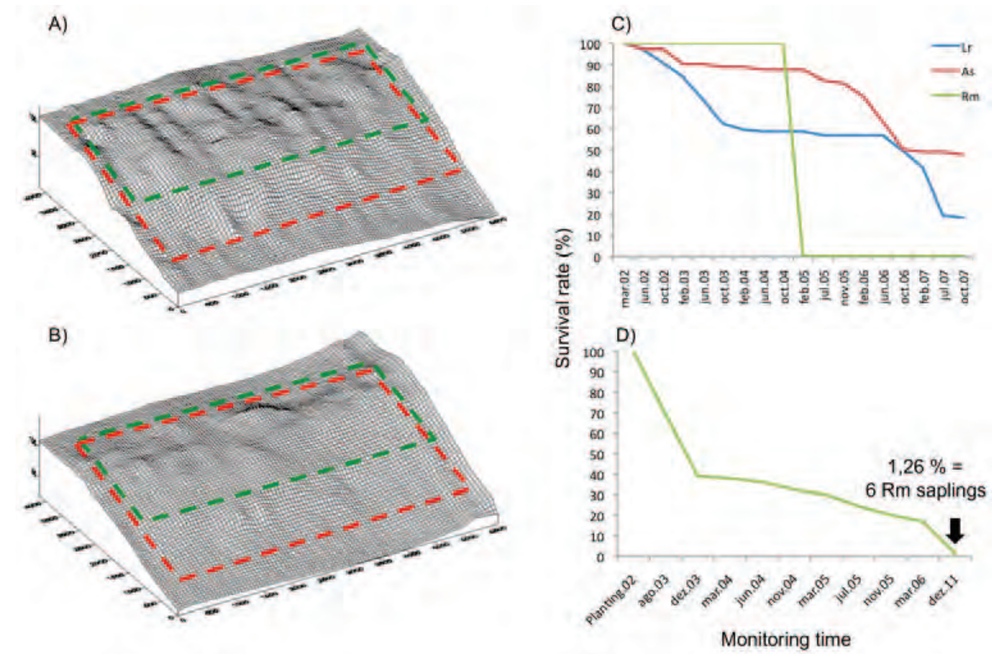
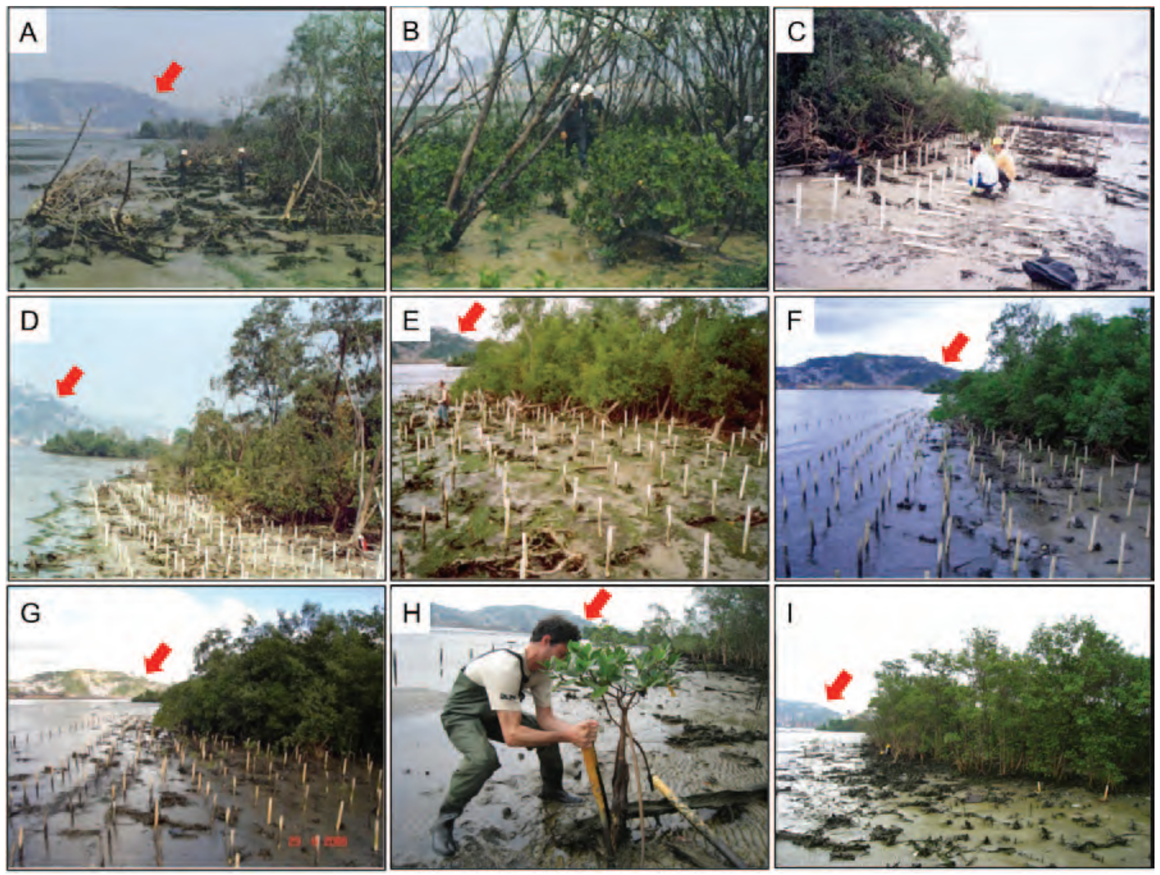


Figure 10.3 Micro-topographic 3D survey from the restoration site in two different moments: (A) in 2004 and (B) in 2008 showing the sediment loss during this period. The green line denotes the remaining stand (trees that survived the fire and natural regeneration patches) and the red line the area occupied by mangroves before the accident. The spatial difference between then in the fringe represents the area planted with R. mangle inside PVC encasements. Survival rates of (C) naturally regenerated stands (assessed from 2 forest structure plots, according to Cintrón and Schaeffer Novelly 1984) and (D) planted mangroves in the restoration site. Lr = *L. racemosa,* As = *A. schaueriana*, Rm = *R. mangle*. Adapted from Coelho-Jr (2007, unpublished report); Menghini (2008) and Menghini et al. (2011).

Figure 10.4 Photo sequence - Barnabe Island Mangrove Restoration
Images from the restoration site between 2001 (A) and 2010 (I). A and B show the remaining stems and the early stages of secondary succession with *L. racemosa* and *A. schaueriana*. C illustrates the beginning of the plantings using REM. In D it is still possible to see the "white" of the PVC pipes while in E – G (2004-2006) the pipes were already infested by barnacles and algae. After the manual removal of PVC encasements out of the few left over saplings (H) the lost mangrove fringe remained the same as if no planting had ever been carried out (I). The only patches of vegetation that still thrive in the restoration site is composed by volunteer mangroves. Red arrows indicate a mountain as a landmark.



After nearly a decade (2001-2010) the project turned into a complete failure (Figures 2C, 2D and 3). The planting and redundant replanting (n=477, without considering replantings), at a total cost of US$105,000, resulted at only 1.26% of survival (Coelho-Jr 2007, unpublished report).

Fig 10.5 Species composition and dominance in the restoration area before the impact. Plots were established inside the restoration site (remaining trees) and contiguous to it aiming to provide a good representation of the site before the damage. Lr = *L. racemosa*, As = *A. schaueriana*, Rm = *R. mangle*. Adapted from Coelho-Jr (2007, unpublished report); Menghini et al. (2011).

Plots	Alive Basal Area (m2/ha)			Dead Basal Area (m2/ha)				
	Rm	Lr	As	Total	Rm	Lr	As	Total
1	-	27,3	13,5	40,8	-	58,9	0,3	59,2
2	11,5	60,0	-	71,5	0,5	28,0	-	28,7
3	6,1	27,6	5,0	38,7	-	60,7	0,6	61,3

Citations:

Cintron and Novelli, 1984
Coelho, 2007
Menghini, 2008
Menghini, et al., 2008
Riley and Kent, 1999

This case study description was provided by
Andre Rovai (asrovai@gmail.com)

7.4 Fishbone Canal Bank Mangrove Planting Projects in India

Location: The Muthupet (10°20'21"N-79°29'58"E) and Pichavaram mangroves (11°25'47"N- 79°47'29"E) of Tamil Nadu, India; the Krishna and Godavari (15°2' 15°55'N - 80°42'81°01'E) mangroves of Andhra Pradesh, India; the Devi and Mahanadi mangroves 19ºN- 22º N 85º E 87º E of Orissa; and the Sundarbans 89°00'89°55'E -21°30'22°30'N of West Bengal, India

Size of Project: 1,447 ha of degraded mangroves. The healthy *Suaeda* swamp ecosystems (termed as degraded mangroves/saline blanks by the project team) were converted to develop fish bone canal bank planting models.

Methods of Restoration: Fishbone design: A feeder canal leads to distribution canals on either side, angled at 30° in the direction of water flow. Width of feeder canal is 3 m (top), 1 m (bottom) and 1 m (depth). Width of distribution canal is 2 m (top), 75 cm (bottom) and 75 cm (depth). Distribution canals are linked to avoid blind end points. Feeder canals are at 50-m distance and distribution canals are at 20-m distance. The distribution canals are angled at 30°, not perpendicular to the feeder canal.

Project Description:
Joint Mangrove Management (JMM): Between 1996 and 2004, a total of 33 villages in the four states and about 5,200 families participated. Planted about 6.8 million mangrove saplings in the restored areas, of which 75–80% survived. A substantial increase in plant density due to natural regeneration was noted after one or two years in the restored areas. About 12,000 ha of mangrove forests were brought under JMM. Mangrove plants *Rhizophora apiculata, Rhizophora mucronata* and *Avicennia marina*) were planted along the main and feeder canals at 1-m intervals. In the first year, the survival rate was about 80%; thereafter, the total number of plants in the demonstration area,

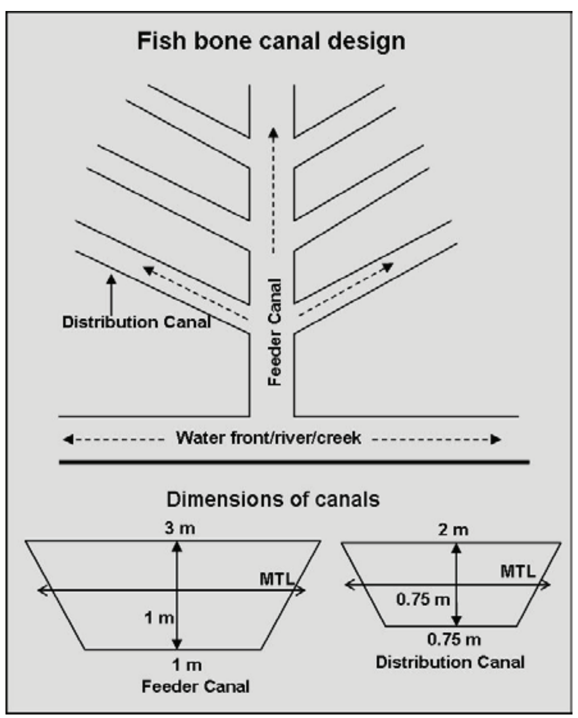


Fig 10.6 Fishbone Canal Design

and density of mangroves increased because of the natural establishment of propagules flushed into the site by tidal waters

Status of the rehabilitation design/projects:
The planted mangroves along the canal banks of the fish bone model sites were inspected on December 15-18, 2012 to understand the status of mangrove replenishment happened during the years between 1996 and 2012 (16 years).

- The design of the feeder and distribution canals did not match with the natural sinuous pattern of tidal water circulation.

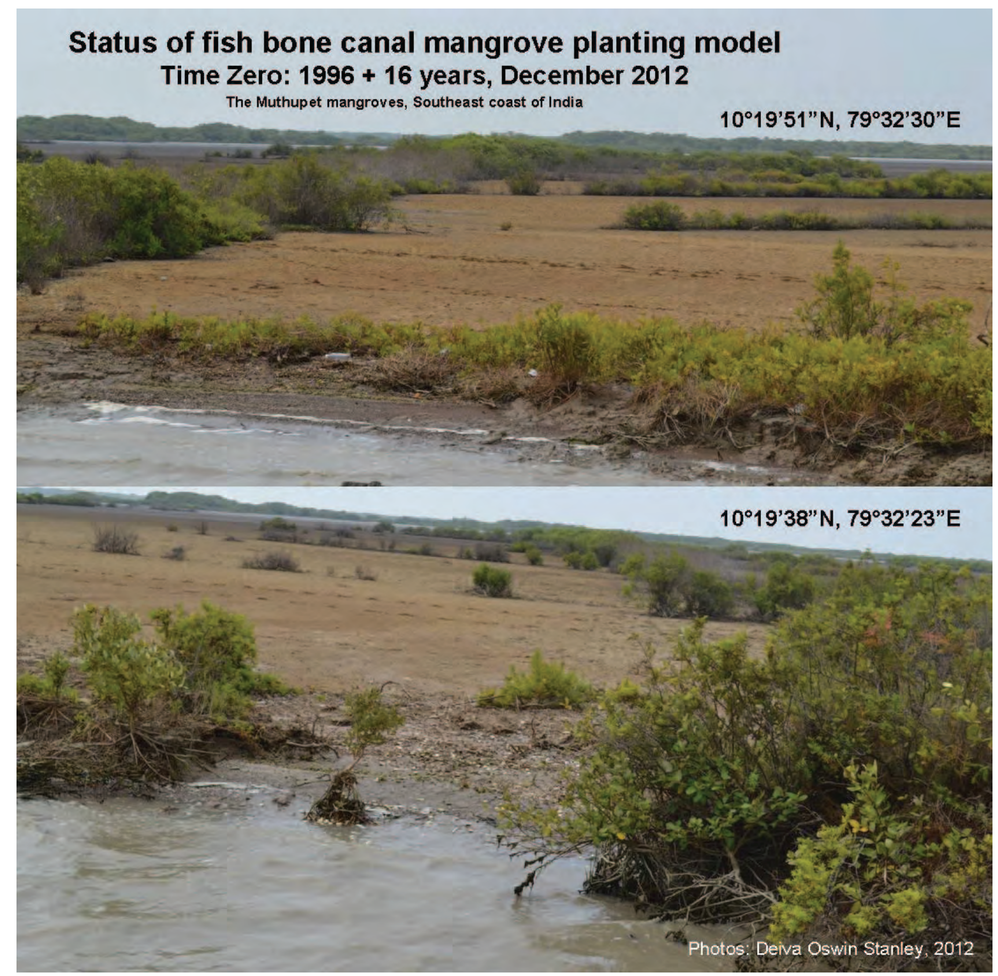


Fig 10.7 Time Zero + 16 years after fish bone canal construction and canal bank planting.

Fig 10.8 Snapshots of developments over time of fishbone canals (This page and next) Initially, canals supported adequate mangrove growth at appropriate substrate elevations. Over time, however, siltation of tidal channels caused mangrove stunting and mortality.

- The depth and width of both feeder and distribution canals are extremely narrow for long term existence and the directions of canals dug were also against the natural water circulation pattern.
- Out of the entire feeder canals checked for water depth, the maximum depth of water measured was 30 cm; virtually, at present all the distribution canals have vanished showing few remnant dry patches of planted mangroves.
- The lagoons and estuaries are tidally dynamic and the silt deposited in these narrow fish bone canals are not flushed off due to the inappropriate canal design with limited tidal prism. The feeder and distribution canals were found silted and in several places tidal flows were blocked by the both planted and volunteer mangrove pneumatophores and prop root systems.
- The mouths of all the feeder canals from the water front/river are fully blocked by roots, debris and silt. The evidence for a successful 'fish bone canal mangrove planting project' itself is not visible in several locations.
- Canals become silted in the very next year after the withdrawal of the project from sites (perhaps 3-6 years project duration), as the most expensive proportion of the project's activity called 'canals de-silting' rarely happens thereafter to regulate water for the planted seedlings, or only happens for a few years as money is available.
- Mangroves along these fish bone canals muddled through to survive as long as they were wet and at present these planted as well as the naturally established ones recorded during the project duration have vanished as the canals are no more in existence to flush the plants with tide water.
- The ecosystem is turning to its original *Suaeda* spp swamp in several places and in areas where the water is still reaching was marshy and in a verge of returning to its former natural conditions.

Web Sources of Information: www.mssrf.org

Citations

MSSRF, 2002. The Mangrove: Decade and Beyond. Activities, Lessons and Challenges in Mangrove Conservation and Management 1990–2001. Chennai: M. S. Swaminathan Research Foundation, 41 pp

Selvam V., Ramasubramanian R. and K. K. Ravichandran, 2012. Genesis and present status of restoration practices in saline blanks in India,pp 133, Sharing Lessons on Mangrove Restoration, Proceedings and a Call for Action from an MFF Regional Colloquium 30–31 August 2012, Mamallapuram, India

This case study description was provided by;
Oswin Stanley (oswinstanley@gmail.com)

7.5 Community Based EMR in 400 hectares of Disused Tambak, Tanakeke Island, South Sulawesi.

A) Location

Tanakeke Island is located just off the mainland of South Sulawesi Province, Indonesia (see Fig A). A coral atoll, the island exhibits coral reef, seagrass and overwash mangrove forest ecosystems, with little terrestrial area. The main livelihood of most islanders is seaweed farming which takes place in expansive sub-tidal areas lagoons. Fishing along the reefs and out to sea is undertaken by the entire community of 10,073 inhabitants. During the 1990's, 1200 ha of the island's 1776 ha of mangrove forest were converted to shrimp/milkfish aquaculture ponds (Ukkas, 2011). Of this total, 800 ha are community owned – yet largely disused – as Tanakeke Islanders have difficulty purchasing external inputs, maintaining dike walls and productivity, and have largely converted to seaweed mariculture.

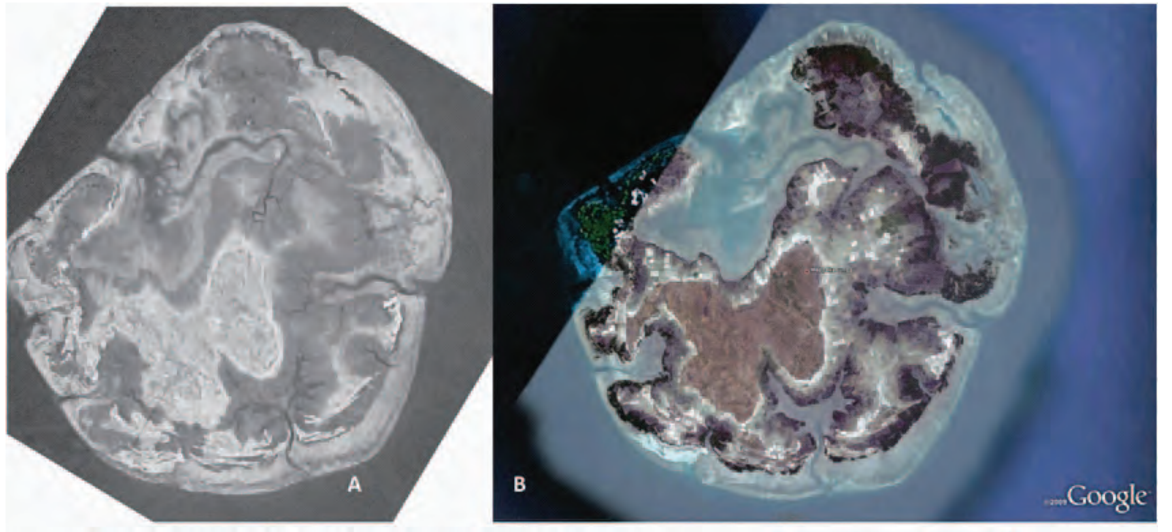


Fig 10.9 The landsat photos above (A) was taken in 1976, depicting 1776 ha of in-tact mangrove forest. This 2013 Google Earth image (B) shows 1200 ha of tambak development.

Tanakeke Island occurs 12 km from the mainland of South Sulawesi, a difficult crossing in rough seas for the local community.

Tenure over 400 ha of converted mangrove forests has been granted to the Ministry of Transmigration, and as such have not yet been considered for mangrove rehabilitation (ibid). The remaining 576 ha of mangroves is frequently clear-felled, for charcoal production, fuelwood, construction poles, fishing equipment and structural supports for seaweed mariculture.

Of the 800 ha of community owned ponds, 400 ha were made available for Ecological Mangrove Rehabilitation (EMR) over a 4 year period, the process and results of which are discussed below. CAD 440,000 was made available for both the social-organizing processes, as well as physical restoration of the site. An additional CAD 150,000 was required for project management and technical assistance, bringing the total investment to CAD 590,000.

Social organizing and physical work were initiated and implemented by Mangrove Action Project – Indonesia as part of the 4.5 year, CAD 7.7 million Restoring Coastal Livelihood (RCL) project funded by the Canadian International Development Agency (CIDA) and OXFAM-GB. Yayasan Konservasi Laut, a local NGO partner based in Makassar, provided community organizing and policy assistance. Numerous government agencies were involved in terms of coordination, training, and policy development at three levels;

- Village level: Village Leaders (4) Community Representative Board (BPD)
- Sub-district/District level: Fisheries Dept., Forestry Dept., Planning Dept., Social Agency, Technical Outreach and Extension Agency
- Provincial level: Fisheries Dept, Forestry Dept, Planning, Technical Outreach and Extension Agency

The University of Hasanuddin provided technical support, background studies, guidance and eight (8) university undergraduate and graduate volunteers.

Additional, on-going technical support is being provided by National University of Singapore – Geography Department (modeling, substrate elevation measurements) and Charles Darwin University – Research Institute for Environment and Livelihoods (carbon stock assessment, livelihood monitoring guidance).

B) Main Objectives:
- Improved hydrology and promotion of natural revegetation in 400 ha of disused aquaculture ponds.
- 1250 – 3750 seedlings established and growing healthy (compared to benchmark) 3 years after initial hydrological rehabilitation.

- Re-establishment of the natural biodiversity of mangrove fauna (species and-community associations) – based on previous surveys and interviews with elders.
- Development of community based mangrove management regulations; primarily delineating sustainable timber harvest practices and zones, as well as village conservation forests (*hutan pangandriang*).
- Improved community awareness and vigilance through formation of forest management learning groups (FMLG's) and "Womangrove" groups, development of sustainable livelihood alternatives and support of environmental education for school children.
- Formation of a multi-stakeholder mangrove management working group (KKMD) at the district level with a long-term mandate to guide conservation and sustainable utilization of Tanakeke Island's mangrove ecosystem.
- Legitimization of village community management plans by the KKMD.

C) Benefits to Community:
- Storm protection. Villages on the Western edge of the island have experienced extreme flooding events and erosion of landforms after conversion of mangroves to aquaculture
- Enhanced fisheries. Although not scientifically monitored, communities are currently monitor crab, shrimp and fish populations in tidal creeks twice a year through participatory monitoring. Fisheries studies will be built into future projects, with the intent of re-establishing 75% of a functional fisheries equivalent to the mangrove area within 7 years of restoration.
- Improved growth of tree biomass. Current clear-felling practices (on 6-8 year cycles) and dense re-growth have resulted in low overall biomass production.
- Increased resilience of the mangrove system due to enhanced biodiversity; especially re-establishment of mangrove species at lower intertidal elevations (*Sonneratia alba*, *Avicennia marina* and *A. alba*).
- Development of non-timber forest products for subsistence use and local markets.

D) Presentation of the Challenges
Four challenges were identified by local communities and other stakeholders during this project, which are described below.

1. Resolving land tenure/utilization rights
2. Challenge to normative, project-oriented, over-simplified planting practices
3. Developing near term sustainable livelihood assistance while communities wait for mangrove recovery.
4. Building gender awareness, ensuring equal female participation throughout process,

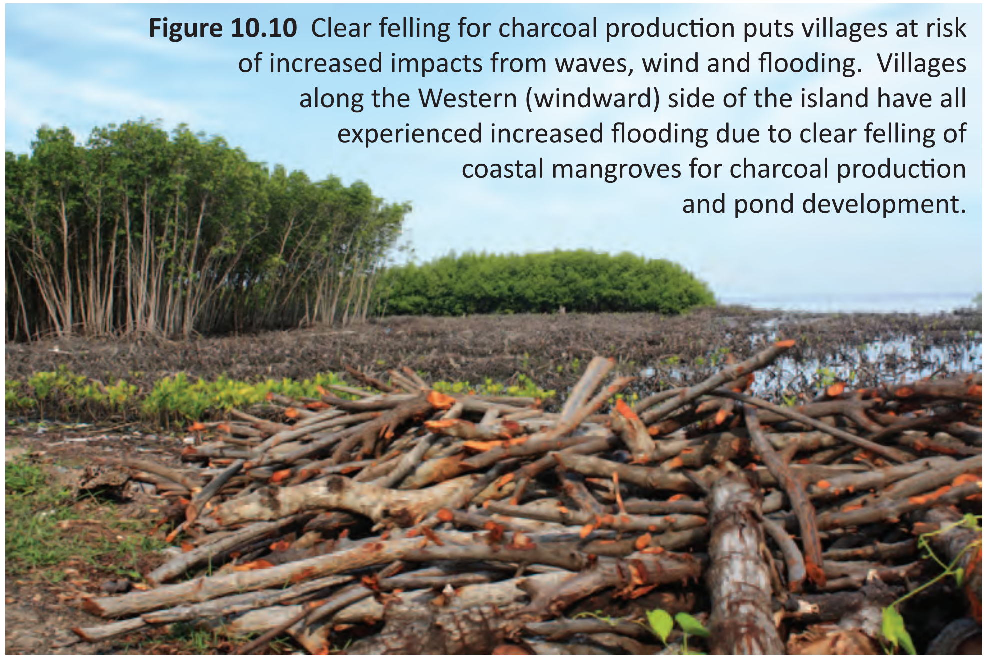


Figure 10.10 Clear felling for charcoal production puts villages at risk of increased impacts from waves, wind and flooding. Villages along the Western (windward) side of the island have all experienced increased flooding due to clear felling of coastal mangroves for charcoal production and pond development.

E) Funding Resources and Mechanisms

The Restoring Coastal Livelihoods (RCL) project totals CAD 7.7 million, funded 90% by the Canadian International Development Agency (CIDA) and 10% by OXFAM-GB who also facilitate the project out of Makassar, South Sulawesi. The project works in four (4) districts in South Sulawesi; Takalar, Maros, Pangkep and Barru. Amongst its goals are 400 hectares of mangrove rehabilitation and 2000 hectares of improved management of intertidal resources. Mangrove rehabilitation at Tanakeke Island totals 400 hectares with an additional 25 hectares are being implemented on the mainland in the district of Maros. The total cost of 425 ha of mangrove rehabilitation is $440,000 (including physical rehabilitation, community organizing and governance work) plus $150,000 to support MAP staff assigned to EMR over a 4 year period. This works out to a project total of 425 ha of restoration at a cost of $590,000 or $1388/ha

The value of mangroves, once restored, has not yet been determined. A participatory Total Economic Valuation is being carried out at a reference forest in the province. A multi-stakeholder mangrove working group (KKMD) is being formed at the district level in Takalar, enabled by Presidential Decree 73, 2012 and described in the National Mangrove Strategy. The KKMD will be able to access short and medium term government budgets in order to continue support of rehabilitation, monitoring and management activities, being termed Adaptive Collaborative Management. No form of carbon finance has yet been considered for this site.

F) Policy Context

Forest coverage on Tanakeke was never under the jurisdiction of the Forestry Department. Individual forest ownership and use rights (both legally titled and traditional) were the most common form of tenure, with small areas designated by the villages as conservation commons (*hutan pangandrian*).

Both a bottom-up and top-down approach was used simeltaneously leading towards collaborative management. Bottom-up approaches included mangrove rehabilitation, livelihoods work and preparation of community groups to present management plans to government leadership. The top-down approach involved formation of the Provincial and then Disitrct level multi-stakeholder mangrove working group - mandated by national law. Preparation of government representatives on the working group took place through seminars, meetings and field exposure.

Fig. 10.11 A fuel-efficient cookstove building and comparison activity was one method employed to build the capacity of communities to become engaged in collaborative management with government stakeholders.

G) Details of Restoration Plans and Results

An expanded 10 step EMR process was used to facilitate communities in learning about, planning for, implementing and monitoring mangrove rehabilitation activities.

1. **Rapid Assessments**. Establishing land tenure, community interest, and ecological feasibility of mangrove rehabilitation.
2. **Social Assessments**. More in depth understanding of community structure and activities. Included stakeholder analysis, gender analysis and development of a seasonal calendar. Land tenure issues were further clarified.
3. **EMR Technical Training**. 5 day training of trainers on the entire EMR process for select community participants. Three such trainings were held over 4 years.
4. **Baseline Biophysical Surveys**. See chapter 5 of this manual.
5. **Stakeholder Meetings and EMR Design**. Numerous meetings with community, government agents and university researchers. Very detailed community based design process, including technical design, biophysical work planning, equitable labor contracting.
6. **Implementation**. All six mangrove rehabilitation projects on Tanakeke Island involved;
   - Local community labor with hand tools
   - Strategic Breaching of Dike Walls
   - Creation of tidal channels
   - Periodic hand distribution of all native propagules into the rehabilitation area
   - Planting trials
   - Mounding trials (increasing substrate height with fill from dike walls. Occasional inclusion of beach wrack, charcoal or bamboo into the substrate.

No substantial addition of fill, or erosion control measures were attempted in the Tanakeke project. Some amount of hand planting is taking place in certain villages, up to 10% of any given village site.

Heavy machinery was not used on Tanakeke Island, due to distance from the mainland and lack of excavated ponds to repair. The 25 hectare trial in Maros District, scheduled for 2014, will use heavy machinery to breach dike walls, dig tidal channels and created mounded areas, in combination with local labor and hand tools.

7. **As-built Surveys**. See chapter 5 of this manual.
8. **Development of Forest Management Learning Groups**. MAP-Indonesia translated a pair of training manuals from the Regional Community Forestry Training Center (RECOFTC) on development of Forest Management Learning Groups (Margostovich, 2002). These curricula use the field school methodology, which was already familiar to community participants and extensionists in South Sulawesi, who took part in the RCL Coastal Field School program, as well as prior farmer field school programs in the region.

The long term objectives of FMLG's are (Margostovich, 2002);

- Identifying, generating and testing locally appropriate forest management practices to ensure local users' needs are being met.
- Improving the capacities, knowledge and confidence of users to more actively manage local forest area to satisfy local needs.
- Strengthening the capacities, knowledge, analytical skills and confidence of facilitators in working with local forest users.
- Improving the relations between users and forest department staff.

Fig 10.12 A) Members of the Womangrove group hand-dig a 1.2 km tidal channel, to facilitate drainage of disused shrimp ponds at Lantang Peo village as part of mid-course corrections 12 months after initial rehabilitation (above left). B) The resultant, meandering tidal channel. Material on the side of the channel was eventually moved away into island-like mounds in the middle of ponds (above right). C) Natural recruitment of *Sonneratia alba* and *Rhizophora apiculata* 32 months after initial rehabilitation (bottom left). D) The middles of some ponds are being recruited as well, again by *Sonneratia alba and Rhizophora apiculata* (bottom left).

- Gradually improving existing management plans to ensure that they are addressing the changing needs of local people.
- Generating locally developed information and create opportunities for networking and the spread of locally appropriate information.

9. **Mid-course Corrections.** Informed by analysis of data collected during both participatory and academic monitoring activities (see section 2.6). Communities and mangrove rehabilitation practitioners determine appropriate mid-course corrections during community meetings. Common mid-course corrections on Lantang Peo included;
   - Hand-digging perpendicular branches on tidal channels,
   - Connecting tidal channels,
   - Closing off select dike wall breaches to increase flows and (scouring effect) through primary channels,
   - Continued propagule dispersal,
   - Augmentational planting,
   - Creating mounded areas above MSL.

   A search for halophytic grass species growing near mean sea level was undertaken but unsuccessful. In other projects, planting of halophytic grasses is used to stabilize substrates, capture mangrove propagules, and enhance edaphic conditions for mangrove colonization (Friess, 2012; Lewis and Dunstan, 1975)
10. **Monitoring**. Academic & Participatory (See Fig 10.13 below and Chapter 9 on monitoring)

Fig 10.13 MAP EMR team during a long-plot survey at Balaang Datu Pesisir (below left). Community members tally scores to create an index of rehabilitation success from participatory monitoring (below right).

H) Findings

A representative pair of charts depicting recruitment are presented for two of the six sites; Lantang Peo - Time Zero +32 months and Balang Datu Pesisir – Time Zero + 10 months (Figures 5 and 6).

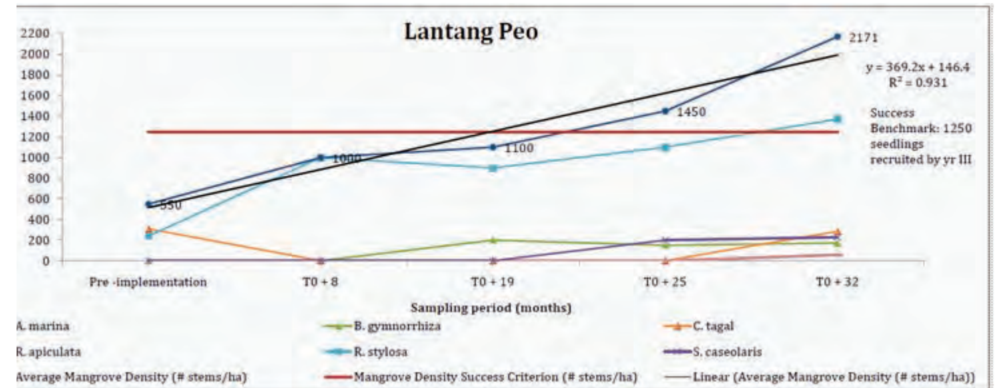


Figure 10.14: Density of mangrove plants per hectare over time - Lantang Peo (T0 + 32 months) There is an increase in species present within the site, from 2 prior to rehabilitation to 5 species established and growing after 32 months. The additional 3 species are the same as species that have been dispersed within the site during rehabilitation. A linear analysis has indicated there is a strong positive relationship between average site density and months since initial rehabilitation (R2 is close to 1.00). An independent two tailed-tailed t- test shows there is a real change in the average density of the population, i.e. the change seen is not due to sampling variability (t Stat = 2.44 > t Critical two–tail = 2.07)

The oldest site of the six villages, Lantang Peo, has already exceeded success criteria for mangrove recruitment and early growth, averaging 2171 plants per hectare, and showing a natural biodiversity for the site based on comparison with references (historical and Panikiang Island reference forest). Note, there is no upper mangrove or terrestrial area at this site, which explains the relatively low species diversity.

A pair of sites rehabilitated between 2 years ago will be monitored in February, 2013, and the data is not presented here.

Three relatively new sites which were monitored in November, 2013 along with Lantang Peo included Balang Datu Pesisir (T0+10 months), Bangko Tinggia (T0+10 months) and Dande Dandere (T0+7 months), and were already exhibiting densities of 1450, 900 and 767 mangroves per hectare. All sites showed a strong positive linear correlation between average mangrove density and time after rehabilitation except for the Bangko Tinggia site which showed weak positive linear correlation. This data is summarized in figure 10.16.

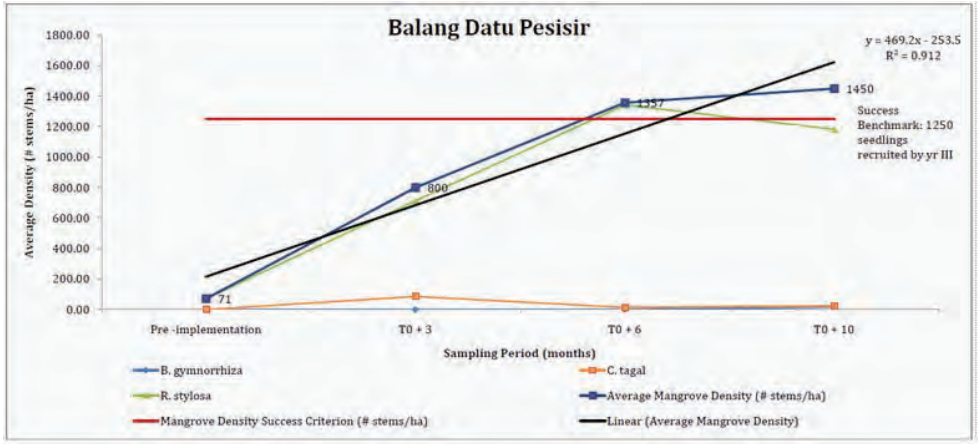


Fig 10.15: Density of mangrove plants per hectare over time - Balang Datu Pesisir (T0 + 10 months) An increase in species present within the site is not yet evident in our monitoring results however a linear analysis has indicated there is a strong positive relationship between average site density and months since initial rehabilitation (R2 is close to 1.00). A paired two tailed-tailed t- test shows we cannot yet conclude there is a real change in the average density of the population, i.e. the change seen is possibly due to sampling variability (t Stat = 1.81 < t Critical two–tail = 2.45)

Figure 10.16: Recruitment at Four Sites on Tanakeke Island Monitored in Nov. 2013

Site	Size (ha)	Months After Rehabilitation	Mangrove Density Stems/Hectare	Species Recruiting
Lantang Peo	64	32	2171	6
Balang Datu Pesisir	54	10	1450	3
Bangko Tinggia	39	10	900	4
Dande Dandere	33	7	767	2
Average	47.5	14.75	908	3.75

A full monitoring summary for this data is available upon request from the author.

In terms of analysis, mangroves are significantly recruiting into rehabilitated ponds, reaching target densities between 2-3 years after ecological and hydrological rehabilitation. Nearby chronoseres 6-8 years of age show that mangrove densities can reach upwards of 6000-8000 plants per hectare, currently dominated by *Rhizophora apiculata*, which was anthropogenically selected for by local fisherfolk over time.

G) Lessons Learned and Knowledge Gaps

The apparent success of the low-cost method of strategically breaching dike walls is clear to villagers from Tanakeke Island. The method seems feasible for similar large areas of disused aquaculture ponds that have not been excavated with heavy equipment. Deeper ponds, with stronger dike walls, may or may not require the use of heavy equipment and fill material. At a certain scale, greater than 100 hectares, heavy equipment may also be required, even in non-excavated ponds.

Certainly at larger scales, landscapes requiring thousands of hectares of repair, use of heavy equipment will be required, but the same use of strategic breaching and tidal creek creation may be feasible. Projects have already been identified in Indonesia of up to 7500 ha (Tanjung Panjang, Gorontalo) and up to 60,000 ha (Mahakam Delta, East Kalimantan). Political will of local stakeholders to rehabilitate a portion of disused ponds is already established, and Ecological Mangrove Rehabilitation - with a high degree of genuine community involvement - is recommended as a best practice approach.

Knowledge Gaps

- Low cost methods for substrate elevation measurement at large-scale,
- Sizing tidal channels during restoration,
- Solutions for enhancing recruitment in fluid substrates,
- Calculating rates of sedimentation with low-cost methods,
- Developing benthic macroinvertebrate indicators,
- How to convince government, aid projects, to abandoned simple planting practices,
- Clear cost benefit analysis of mangrove vs. aquaculture.

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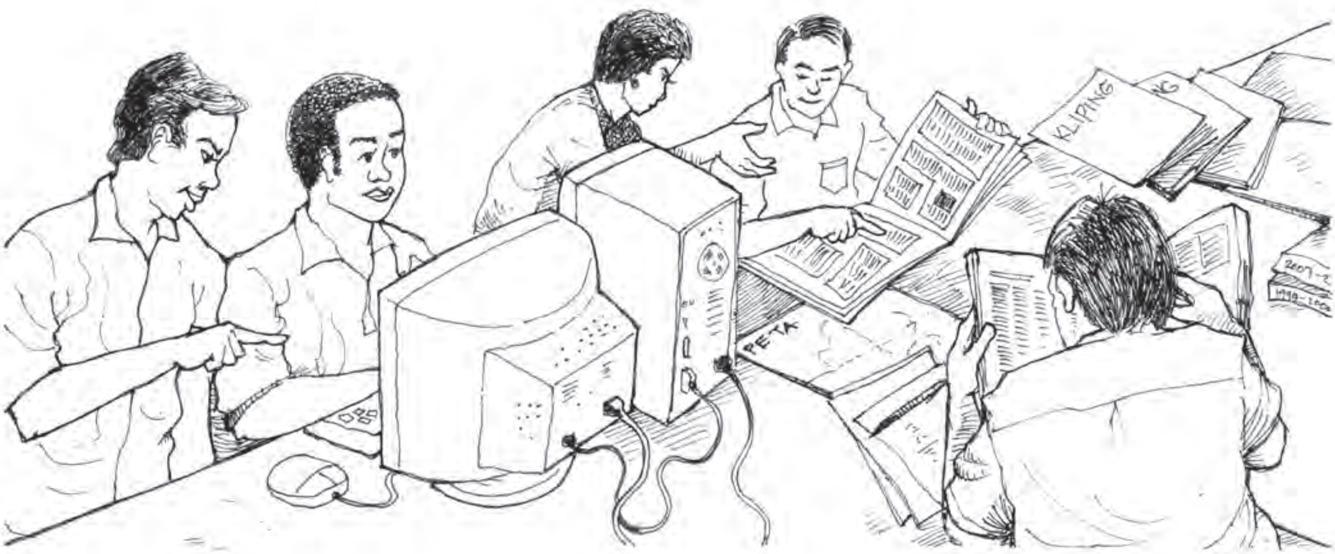

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