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ORIGINAL PAPER

A unified framework for the restoration of Southeast Asian mangroves—bridging ecology, society and economics

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Abstract The effect of intensive human intervention, poor socio-economic conditions and little knowledge on mangrove ecology pose enormous challenges for mangrove restoration in Southeast Asia. We present a framework for tropical mangrove restoration. Our proposed restoration framework addresses the ecology, economy and social issues simultaneously by considering the causes of mangrove degradation. We provide a step by step guideline for its restoration. We argue that although, ecological issues are of prime importance, economic and social issues must be considered in the restoration plan in order for it to be successful. Since mangrove ecology is not adequately studied in this region, local ecological knowledge can be used to fill the baseline information gaps. Unwanted human disturbance can be minimized by encouraging community participation. This can be ensured and sustained by facilitating the livelihood of the coastal community. We translated the restoration paradigm into a readily available practical guideline for the executors of the plans. We provide an example of mangrove restoration project that is closely related to our proposed framework. We are optimistic that this framework has the potential for universal application with necessary adjustments.

Keywords Community development · Community participation · Experiential learning · Ecological restoration · Ecosystem synthesis · Mangrove degradation

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Introduction

Ecological restoration is one of the most challenging branches of ecology (*sensu* 'acid test' of ecological theory; Bradshaw 1987) and mangrove restoration is even more challenging because of the very dynamic nature of the ecosystem, which experiences tidal flooding as well as other natural and anthropogenic disturbances. In Southeast Asia, especially in developing countries, two approaches to mangrove restoration have been used: (i) ecological engineering (Lewis and Marshall 1997; Callaway 2001; Lewis 2005) and (ii) human—ecological problem solving (Walters 1997). Mangrove restoration in Southeast Asia is much more complicated and challenging than the issues addressed by these two approaches for several reasons. First, although tropical mangroves are the most diverse and dynamic ecosystems in terms of species diversity and productivity (Fig. 1;

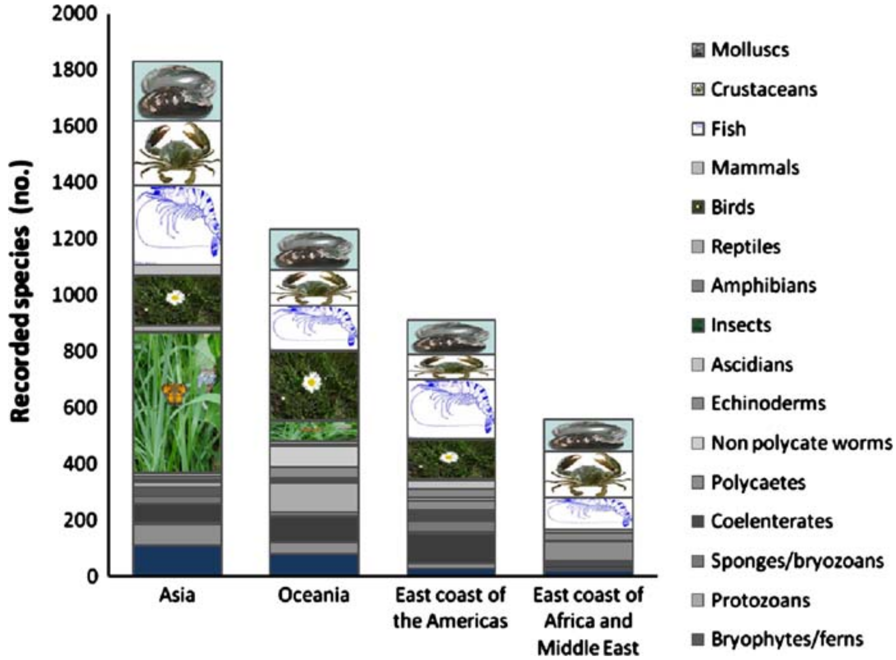

Fig. 1 Geographical distribution of mangrove biodiversity (data used from Saenger et al. 1983)

Saenger et al. 1983), the Southeast Asian mangroves are the least studied. Second, Southeast Asian coastal areas are highly populated with poor and marginalised people (Iftekhar and Islam 2004). These coastal people depend heavily on mangroves for their livelihood. Because of this dependency, people become a major determinant of the state of mangrove forests, often, by suppressing natural processes and must be considered components of the Southeast Asian mangrove ecosystem. Third, with few exceptions, most mangrove restoration efforts in Southeast Asia have followed a trial and error method without any explicit and integrated framework, baseline ecological information, or proper consideration of community involvement. It is not surprising then that most of the mangrove restoration efforts have met with limited success (Aksornkoae 1996; Al-khayat and Jones 1999; Alongi 1998; Bacon 1987, 1993; Bandaranayake 1998). Some failed immediately while others failed several years after initiation (see review by Ellison 2000). Opinions differ on the success rate of mangrove restoration programmes. Successful projects are often reported but failures rarely (Lewis 2005). However, there is no ambiguity for the need of mangrove restoration.

The importance of mangroves has been emphasised for their unique ecological, economic and protective functions. The major functions of mangrove forests include (i) habitat for flora and fauna, (ii) timber, pole, fuel wood and fiber production, (iii) diversified non-timber forest products, e.g. tannin, honey, wax etc., (iv) breeding and nursery grounds for fish, crustaceans, mollusks and a wide range of aquatic and terrestrial species, (v) effect on microclimate, (vi) protection from wave erosion, (vii) enhancement of sediment deposition/land accretion, (viii) input of organic detritus into the coastal zone to support the productivity of these waters, (ix) combating natural calamities such as tsunamis, cyclones and tidal surges and (x) amelioration of the environment by acting as a carbon sink (Macnae 1968; Fransworth and Ellison 1997; Primavera et al. 2004; Walton et al. 2006). Protective functions of mangroves against the most recent tsunami (i.e. 2004) excelled in their realisation of the significance of mangroves across the globe for the existence of people along tropical coastlines Dahadough-Guebas et al. 2005a, b; Danielsen et al. 2005; Kathiresan and Rajendran 2005; Barbier 2006). Although controversy continues to exist in the debate of whether the mangrove belt can provide total protection, there is no controversy over the significant role of mangroves as a barrier against natural disasters such as tsunamis and tidal surges (Kathiresan and Rajendran 2006).

The increasing rate of mangrove degradation (Duke et al. 2007) and lack of significant success in the scattered mangrove restoration programmes (Lewis 2000) are exposing tropical coastal communities to increasing vulnerability. Not only is it essential to stop mangrove degradation, but it is also important to restore the degraded tropical mangroves. This requires a holistic and comprehensive framework that could take the form of both curative and precautionary interventions. However, to date there is no such comprehensive framework available.

We propose a framework for the restoration of tropical mangroves by emphasising two major issues (i) identifying and addressing the causes of degradation to prevent further degradation of the existing mangroves and (ii) developing a detailed practical guideline for the executors of plans for the restoration of already-degraded mangroves. We argue that (i) ecological knowledge is the most important factor for the success of mangrove restoration and traditional ecological knowledge can help substitute the baseline information gaps that exit in Southeast Asian mangroves, (ii) anthropogenic influence can be addressed by ensuring sustained community participation and (iii) sustained community participation can be encouraged by economic considerations for the livelihood and sustenance of coastal communities.

Causes of mangrove degradation in the tropics

Tropical mangroves are shrinking rapidly, due to five major causes: (i) conversion to shrimp/aquaculture farms (e.g. Bangladesh: Hossain et al. 2001; Gain 2002; Thailand: Spalding et al. 1997; Hinrichsen 1998; Barbier 2000; Barbier et al. 2002; Barbier and Cox 2002; the Philippines: Primavera 1995, 2005; Walters 2004; Indonesia: Spalding et al. 1997; Hussain et al. 1999; Vietnam: EJF 2003; Ecuador: Lacerda et al. 2002; Honduras: DeWalt et al. 1996) (ii) conversion to sea salt farms (Prokant and Reeves 2007), (iii) conversion to agriculture (Biswas et al. 2007), (iv) natural calamities (Dahadough-Guebas et al. 2005a, b) and (v) infrastructure development and hydrological diversion. These degradations can be grouped under two broad headings: human-induced degradation and natural disturbance-related degradation. The combined effect of the two often causes a devastating impact as explained below with a hypothetical diagram (Fig. 2)

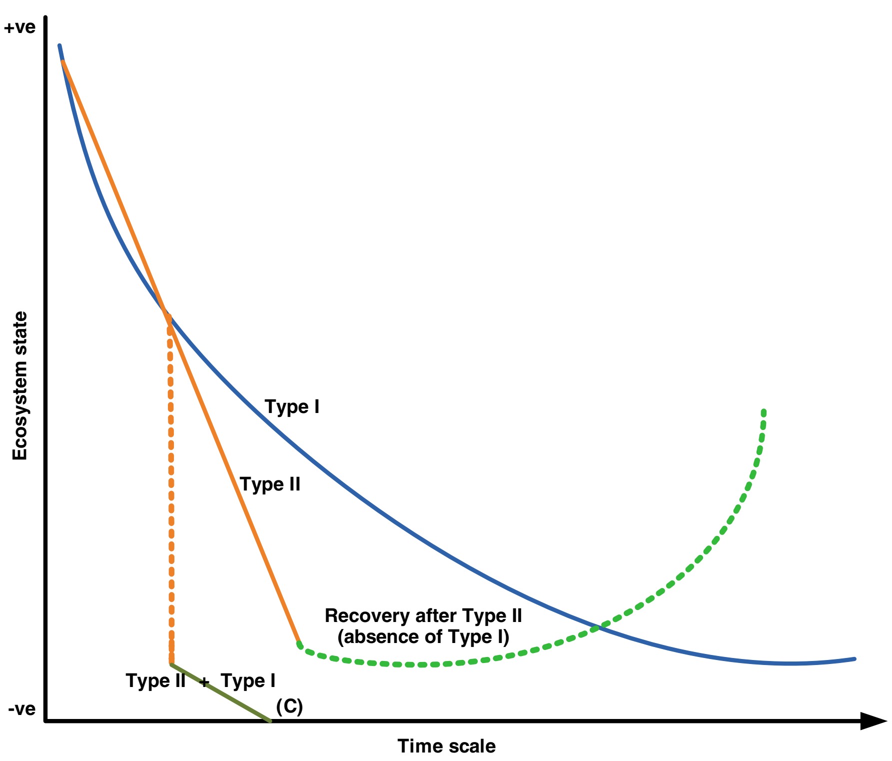

Fig. 2 Hypothetical relationships between disturbance type and recovery pattern in mangrove ecosystem. Three scenarios hypothesized: (A) *Type I* disturbances facilitate degradation of mangroves. (B) *Type II* can be massive and overnight degradation of whole or part of a mangrove forest. However, if there is no *Type I* disturbance natural recovery rate may be high following *Type II* degradation. (C) In the third scenario, a mangrove forest first degraded by *Type II* (sharp degradation) followed by *Type I* leaving limited chance for recovery

Human-induced degradation of mangroves and mangrove habitats can be defined as *Type I* degradation and may occur in two forms: (i) conversion of the newly accreted lands where mangroves develop naturally into land for human use and (ii) conversion of productive mangrove forests to other types of anthropogenic land management. The newly accreted lands in Southeast Asia have been increasingly converted into agricultural lands and shrimp and salt farms, while the productive mangrove areas are being converted to shrimp farms and for agricultural use (e.g. Walters 2004). Economic pressure from increasing populations in tropical coastal areas, where the livelihood of coastal communities is directly related to mangroves, is considered to be the dominant driving force behind *Type I* mangrove degradation (Fig. 2). Natural calamities such as tropical cyclones, tidal surges and tsunamis are accelerating the degradation of coastal mangroves. This type can be called *Type II* degradation. Climate change is thought to be the driving force behind the increasing frequency and intensity of these sorts of natural calamities causing *Type II* degradation (Fig. 2).

The mangrove restoration paradigm

Depending on the type of degradation, mangrove restorations may be of two major types: (i) restoration of mangroves following anthropogenic degradation (*Type I*) and (ii) restoration of mangroves following natural disturbances (*Type II*). For *Type II* degradation, mangrove recovery relies on ecological principles (i.e., secondary succession). However, the rate of recovery can be increased by planned restoration initiatives. *Type I* restoration is more complicated and challenging. Reliance on only ecological issues is not sufficient. It requires a holistic approach, by integrating social and economic issues of coastal communities along with ecological issues of the mangroves.

The conventional philosophy of ecosystem restoration is to restore the degraded ecosystem to its pre-degradation state. This raises the question: of whether it is at all possible to restore a dynamic system. Furthermore, even if it were possible to rebuild the ecosystem to its pre-degradation state, the newly restored ecosystem would remain behind its original state since changes might take place during the restoration period (i.e. it will lag in a temporal sense). Whether total restoration is possible or not remains a philosophical issue. At the root of this debate (see Temperton 2007 for details) are questions such as whether ecosystems are cohesive (Clements 1916), the sum of few parts (Gleason 1917), whether ecosystems go through alternate stable states (Sutherland 1974) or whether ecosystems start to develop in a new direction after crossing an ecological threshold (Hobbs and Norton 1996, 2004; Walters 2000). Often it is not practical to insist on total restoration of a mangrove ecosystem to its pre-disturbance state. We acknowledge that there might be a gap in the ecosystem state between a pristine (undisturbed/low intensity and frequency of natural disturbance) and a restored ecosystem (see Fig. 3). The aim of restoration should be to minimise the gap between the undisturbed (naturally disturbed) and a restored ecosystem states (see A'–D' and D'' in Fig. 3). This coincides with the restoration principle of the Society for Ecological Restoration (2002) that defines restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.”

During restoration, ecologists manipulate the structural and compositional components of an ecosystem so that it can be revitalized. In common mangrove restoration practices; structural manipulation includes planting trees and hydrological engineering. Compositional manipulation includes seeding and planting multiple species to increase species diversity and habitat recovery. The underlying assumption is that the important structural components of an ecosystem are trees, land and water. However, in Southeast Asian countries, human influence on mangrove ecosystem is so great that humans must be considered as a component. Therefore, in addition to fine-tuning the previously suggested ecological engineering principles (Lewis 2005); we suggest to incorporate the important social and economic issues of coastal communities. More specifically we emphasize ensuring community participation and facilitating the livelihood of people. In earlier participatory mangrove restoration projects, only community participations were included but limited priority was given on the issue of livelihood. As such the participations were ineffective.

Of the controlling factors in our proposed restoration framework, ecology (*sensu* ecological engineering for restoration of ecological systems) is

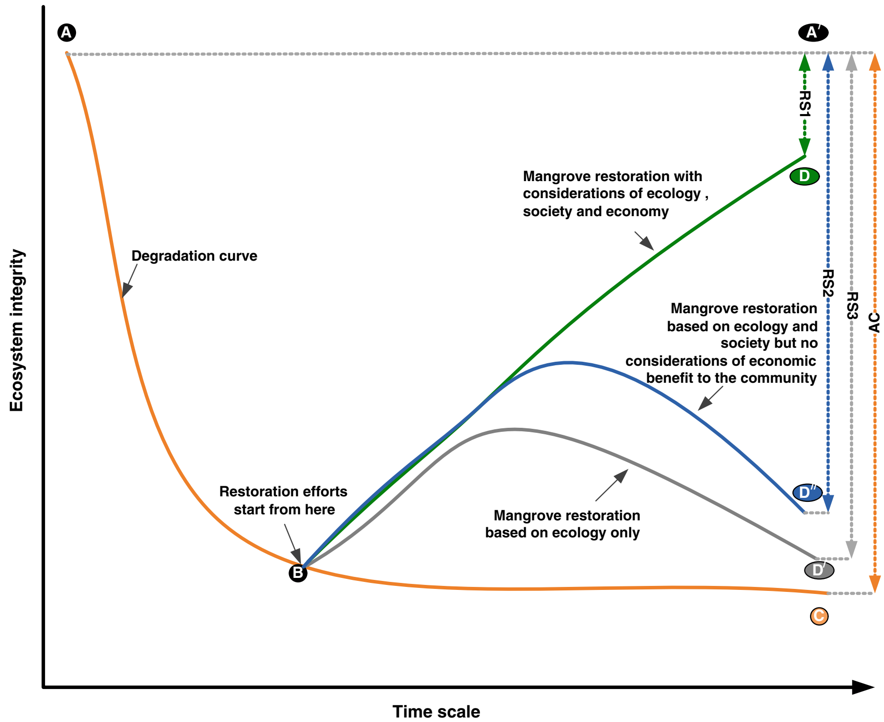

Fig. 3 A hypothesis on the concept of mangrove restoration; influenced by ecology, society and economy. We exemplified three situations. (i) Restoration considered (B–D) all three vectors and it may result a smooth upward curve. (ii) Restoration considered (B–D$^{//}$) ecology and society involvement. It may result in immediate success but since there is no consideration for financial benefit to the society (in the short term) people will go back to their previous practices and there will be again sharp degradation resulting in a humped shape Gaussian curve. (iii) Restoration based on only ecology (B–D$^{/}$), people will take few moments to realise what is going on; this time restoration efforts may yield positive result; very soon people will start to work against the project which might lead to a humped shaped curve. C reflects the status quo scenario

independently dominant. It has an upwards pulling force (i.e. ecologists try to improve the ecosystem) and any compromise on ecological principles might lead to collapse of the entire restoration effort. Society and its economy are very much inter-related and always act together instead of as isolated factors. Society pulls horizontally (i.e. they like to go as usual) and the economy keeps society either horizontally upward (when financial benefits are ensured) or downward (when there are no financial benefits). The success of restoration might show an upward pattern when both factors are considered, whereas it might be a humped shaped curve when there are no financial benefits to society (Fig. 3). It could be argued that (i) economic valuation of the ecosystem services and (ii) the development of forest area provide benefits to society (long term benefits from forest products); however these benefits alone are not sufficient to attract poor people along tropical coastlines. Indeed, some sort of immediate improved livelihood programme and establishment of a self sustaining mechanism (for sustainable financial return) can ensure society/people participation. There is always a danger that community expectation of receiving financial benefits might be raised too high, thus a very careful approach is required while providing livelihood support and developing a sustainable financial return mechanism.

The success of restoration can be expressed as a function of achieving three main objectives:

$$\text{Restoration Success(RS)} = \sum (\text{Ec}\{\text{Sc*En}\})$$

where Ec is the Success in ecological engineering, Sc the Success in society involvement, En the Success in delivering financial and other benefits to the society.

Quantification of restoration success of a complex system that is sensitive to ecological, socio-cultural and economic factors is extremely difficult and requires multifaceted studies and analyses. In a Southeast Asian context this approach is almost impractical. Alternatively, we propose an expert assessment scale of 0–10 (0 being unsuccessful and 10 being completely successful) to indicate the degree of success achieved in each of the objectives and ecosystem restoration as a whole. In this way, not only the important factors in restoration are identified, but also their degree of success is assessed.

In our proposed framework, we differentiate society involvement into a social issue and society participation and an integrated function of social and economic issues. Society involvement is a top down approach, whereas society participation is a bottom up approach. The maintenance of society participation depends on the level of society involvement in different decision making processes and their economic outcomes, i.e., the financial benefits/livelihood improvements a society receives.

$$\text{Society participation} = \sum (\text{Sc} * \text{En})$$

where Sc is the society involvement in different decision making processes, En the economic/financial benefit to the society.

Once again, the degree of society involvement and economic benefit to the society will determine the success of the restoration. We can use the same holistic expert assessment approach with a scale of 0-10 to quantify society participation.

Translating the paradigm into practice: a step by step guideline

We translate the mangrove restoration paradigm into a practical guideline of six major steps:

Step 1. Identify the problem area and outline the restoration goals.

Step 2. Synthesize the past and present ecosystem condition, especially its ecological structure and function and societal resource dependence on the ecosystem.

Step 3. Outline a systematic restoration plan (ecological engineering).

Step 4. Develop a community involvement and income subsidy plan (socio-economic engineering).

Step 5. Develop a detail implementation plan (layout of how to implement the various activities under different plans).

Step 6. Develop and implement a rigorous monitoring mechanism for logical adaptive management.

Identify the problem area and outline the restoration goals

First, the geographical locations of the degraded area need to be identified followed by the establishment of specific goal(s) of mangrove restoration. The goals have to be realistic (Hobbs 2007). Several questions need to be asked before setting the goal(s): is the mangrove restoration mainly for (i) coastal erosion protection and land stabilization? (ii) wood/fiber production? (iii) maintaining biological diversity and ecological processes? or (iv) integration of some or all of the above? Ellison (2000) reviewed the goals of existing mangrove restoration projects and found that out of 27 projects only two considered restoration of ecosystem functions. Most Southeast Asian mangrove restoration projects/programmes emphasised tree planting alone for forest regeneration, erosion control and coastal stabilization. However, in the true sense of restoration, functional components of the ecosystem must be identified and integrated in the restoration plan.

Ecosystem synthesis: past and present

The most important step in mangrove restoration is an analysis of past history and present conditions of the ecosystem. A clear understanding of the pre-disturbance state, current state and the dynamics of the mangrove ecosystem is essential before any intervention for restoration can take place. Three questions need to be asked: *why, when* and *how*? Figure 4 illustrates the need for basic knowledge of *ecology, society* and *economics* in mangrove restoration. During ecosystem synthesis, the aim of the restoration should not be to look for a set of easy guidelines but for a set of hard questions underpinning the long-term functioning of the ecosystem.

Assessment of the existing ecosystem conditions and its dependent community could be done either through a scientific approach or through a participatory

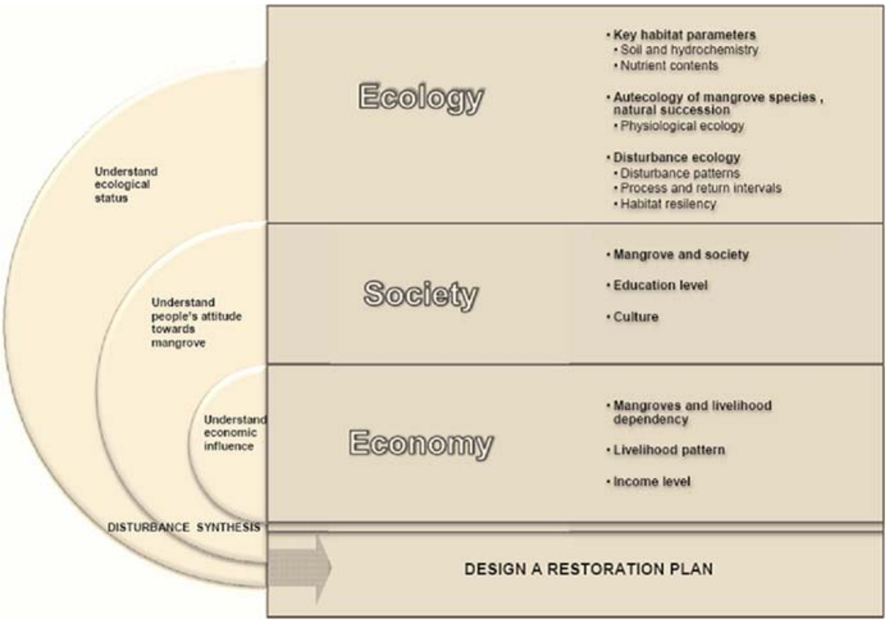

Fig. 4 Required information before initiation of a mangrove restoration project/programme

approach. For community based restoration, a participatory method is preferred. Among the participatory tools, participatory rural appraisal (PRA), rapid rural appraisal (RRA), historical mapping (HM), ven diagrams (VD), resource mapping (RM), focus group discussions (FGD), community meeting, etc, are effective. This stage involves exploring the conditions of the ecosystem and its surrounding population and developing an action plan. This stage helps the community participants and the researchers and development workers to arrive at a common understanding of the ecosystem functions and their response to management and anthropogenic interventions. A common goal of the ecosystem sustainability and meeting societal needs must be achieved by this exercise.

Development of a systematic restoration plan

A well thought out restoration plan should be prepared with local participation. The restoration plan may emphasis ecological engineering based on the findings of ecosystem assessments. In Southeast Asian countries, most often ecological knowledge of the pre-disturbed state is either absent or not well documented. Therefore, we suggest three alternatives to supplement the knowledge gaps: (i) systematic analysis of the traditional ecological knowledge of the communities adjoining the ecosystem, (ii) scaling up of the ecological knowledge from another mangrove ecosystem with similar ecological and socio-economic influence and (iii) pilot level experimentation.

The restoration plan should focus on the following.

Site selection

Site selection is critical for mangrove restoration. It is difficult to generalise sites for successful mangrove restoration since it depends on local environmental factors, sociocultural context and suitability of planting species (Kairo et al. 2001). In Southeast Asia, mangrove restoration programmes exist in three major types of sites: (i) mudflats, (ii) within shrimp farms and (iii) raised lands. Shrimp farms and raised land offer very few options for site selection but selecting a site near a bank of running water is encouraged (IUCN 2005). It is generally not a good idea to target mudflats for restoration, except in cases where these are accreting and/or where these are formally the sites of natural mangroves. Special considerations are required for mudflat selection where erosion and deposition is frequent (Erftemeijer and Lewis 2000) and ideal restoration sites must be on the deposition site. Within the deposition site, substrates should be stable mudflats as fresh depositions can be washed away by tidal actions before plant establishment.

Site preparation

Mangrove restoration may require anywhere from a very limited amount to a maximum level of site preparation, depending on the specific site and restoration objectives. For example, in a mudflat very little or no site preparation is required (Erftemeijer and Lewis 2000). However, in raised land and shrimp farms, extensive ecological engineering is required so that the site can be inundated regularly (Lewis and Marshall 1997). Many stable sites may recover naturally once barriers to recovery are removed, e.g., return of natural tidal flooding to a fish pond, etc. Here, the very first question that needs to be asked is why the proposed restoration sites are not recovering naturally. Choudhury (2003) provided detailed prescriptions for hydrological engineering in the case of shrimp farm restoration. Lewis (2005) provided engineering methods for raised lands.

Species selection

Species selection in mangrove restoration is an important factor. Natural mangroves follow a distinctive zonation and during restoration; species need to be selected following natural zonation/succession. Depending on soil formation and hydrology, different species may be suitable for plantation at the same site. Choudhury (2003) developed a site-specific species matrix for Indonesian mangroves. A similar site-specific species list is not available for other tropical mangroves. For example, vegetation zonation of mangroves along the Bay of Bengal shows some kind of uniformity and species selection for mangrove plantation in this region adheres to this condition. In the mangrove plantations of Bangladesh the following site-specific species are desirable: (i) in newly formed mudflats *Sonneratia apetala* is most appropriate, (ii) newly formed sandy areas are suitable for *Avicennia officinalis*, (iii) in mature/stable lands, *Excoecaria agallocha*, *Bruguiera gymnorhiza* and *Rhizophora* are the desired species.

Seedling and propagule sources

To date, mangrove restoration mostly relies on planting. Wildings (seedlings grown in natural forests or in the wild) and seedlings grown in nurseries are the two major sources of seedlings. Walters (2000) suggested that for restoration of a diverse mangrove forest, diversity in plantation is a prerequisite. Diversity can be obtained in two ways: planting multiple species and creating a species mixture with broadcasting seed. Although explicit data and references are not available, pilot level experience from IUCN (2005) indicates that a combination of planting with seeding (broadcasting at a lower intensity) is a more efficient technique than planting alone in mudflats and raised land. The advantages of combined planting and seeding over planting are that: (i) from the very beginning a heterogeneous age class is initiated that requires minimum gap filling and (ii) it promotes other ecosystem services similar to those in a natural forest.

Level of aftercare/maintenance

After-care and maintenance requirements of mangrove plantation are site dependent. For example, in a river bank small scale gap filling (replacing dead seedlings with new ones) may be required, whereas in a shrimp farm more intensive gap filling is required since it has a limited chance of natural colonization, compared to a river bank. Protection of the plantation against grazing (especially buffalo) and fishermen (in particular those who use hand-pushed catching nets) needs to be ensured. Fishermen usually catch shrimp larvae with fishing nets along the river banks during high tide when planted seedlings are submerged, causing extensive uprooting of seedlings.

Community involvement and development plan

Community development issues should be addressed as a solution to the underlying causes of mangrove degradation. It must ensure addressing both preventive and curative measures at the same time rather than each individually. Since there are many failure stories, before initiating any community based restoration, it is necessary to survey the choice and preferences of the local people because they will be the first beneficiaries but also run the risk of becoming victims, should the project fail. Community involvement and development plan may focus on: (i) when and at what level the community will participate, (ii) what are the major issues in community livelihood and (iii) how the livelihood of adjoining communities can be improved while restoration of the mangroves progresses. The plan should specifically focus on the development of a self-sustaining mechanism, instead of depending on continuous financial support from the restoration project. At the early stages of the programme, financial support is needed, but it is desirable that over time, a self-sustaining mechanism is developed so that the community can sustain its livelihood and restoration efforts when the programme is finished.

When and at what level will the community participate?

Community participation is needed at least during three phases: (i) ecosystem synthesis/situation analysis, (ii) identification of priorities for interventions and development of restoration strategy and action plan and, (iii) participatory implementation and monitoring. First, the local community can prepare a preliminary plan of action for restoration. This plan may contain a few priority issues that are important for the community. Practical feasibility of the plan and the commitment of the community can be reassessed jointly by the project team and the community. Simultaneously, the community and the restoration workers may formulate hypotheses underlying the plan and develop methods and indicators to test them and monitor the progress and effectiveness of the plan.

How to address community livelihood issues?

Community development plans need to focus on human well-being and strengths and limitations of existing institutions. This plan might provide details on specific interventions. It may also highlight particular stress factors such as food security and provide health services. For example, in coastal areas there is a scarcity of drinking water that is correlated with many water borne diseases. A variety of institutions in the area—government, quasi-government, private sector, community groups and development organisations should be considered in the assessment of institutional strengths and limitations. Issues that emerge from the situation analysis will be prioritised and options will be derived for future action through a trade-off analysis. Prioritisation of issues follows the thematic integration of mangrove restoration and human well-being. Priorities will be based on socially determined trade-offs among the problems, opportunities for the future and the pragmatic needs to ensure successful implementation. The critical factor to sustain community participation would be such that any intervention should result in demonstrable positive impacts.

Implementation of plans

During implementation of mangrove restoration activities, three points need to be considered as a guiding principle: (i) the local community, in association with the technical experts, will plan the implementation and the role of the local community should be a positive and active one; (ii) local communities will implement the programme and monitoring should also be done by them. Capacity building may be necessary for successful implementation of such a programme; (iii) a micro-level area-specific 'restoration and community development plan' should be prepared in line with the larger plan.

Monitoring, evaluation and feedback: adaptive management

One of the most critical steps in a restoration programme is the ongoing monitoring and evaluation. The monitoring should be based on quantifiable parameters. Monitoring may include (i) technical (ecological) advances of the ecosystem and (ii) societal attitudes in support of the programme. Technical aspects can easily be quantified, whereas quantification of the social improvements needs relative scoring, considering the importance of sectoral contributions to achieve the desired goal. Technical aspects require rigorous scientific monitoring, whereas social and economic aspects can be monitored using a participatory approach. In developing tropical countries it is not always possible to maintain rigorous scientific monitoring because of technical and financial constraints. Hence, a suitable participatory monitoring system can be developed with the aid of traditional ecological knowledge. It is important that the outcomes of the monitoring and evaluations are incorporated into the restoration programme. Kolb's (1984) experimental learning model could aid in developing the monitoring system. The model suggests a systematic way of learning from experience through four major sequential steps: (i) valid or concrete experience, (ii) reflected observations, (iii) abstract generalisation and (iv) active experimentation. After initial experimentation some positive experience can be incorporated into the cyclical process and the cycle of learning might continue until restoration success is achieved (Fig. 5). The uniqueness of this model is that it will guide the restoration ecologist in a systematic way and also will serve as a bank of traditional ecological knowledge, which others can use to evaluate the success of the restoration.

Example of a mangrove restoration project: the Chokoria Sundarbans, Bangladesh

The Chokoria Sundarbans are the oldest mangrove forests in the Indian sub-continent situated in the delta of the Matamuhury River, Bangladesh (latitude 21°36′–21°45′ North and longitude 91°58′–92°05′ East). It was a productive forest, supported high biodiversity (Choudhury et al. 1990) and provided a natural barrier to cyclones and storm surges. However, over the years, due to expansion of shrimp cultivation and salt farms (as a result of a shift in government policy (Biswas and Choudhury 2007) the forest has been completely degraded (see Fig. 6 for the trends of degradation). The area was characterised by the presence of many shrimp farms and salt ponds (Prokant and Reeves 2007). Unfortunately, in the absence of a functional mangrove, shrimp cultivation is not sustainable (IUCN 2005). Eventually, after a few years of cultivation, the entire industry collapsed due to poor ecological health and prevalence of diseases. Today, only a handful of shrimp farms are in operation (the number declined due to poor economic returns). Moreover, because of the loss of forest cover, these areas are now exposed to frequent cyclones and tidal surges, causing loss of lives and property. Realising the urgency of mangrove restoration, at least three different initiatives were taken by three different organizations, but these initiatives have yet to meet with significant success. Socio-political conflicts and challenges in ecological engineering (within shrimp and salt ponds) are real barriers for restoration in this area.

IUCN Bangladesh (IUCNB) started a pilot level community-based mangrove restoration programme in this area in early 2003. The goal of this programme was to develop a community-based mangrove restoration model for the entire area.

Disturbance synthesis and assessing suitability of the ecosystem rehabilitation

IUCNB started the restoration programme with a detailed synthesis of the degradation history (see box 1)

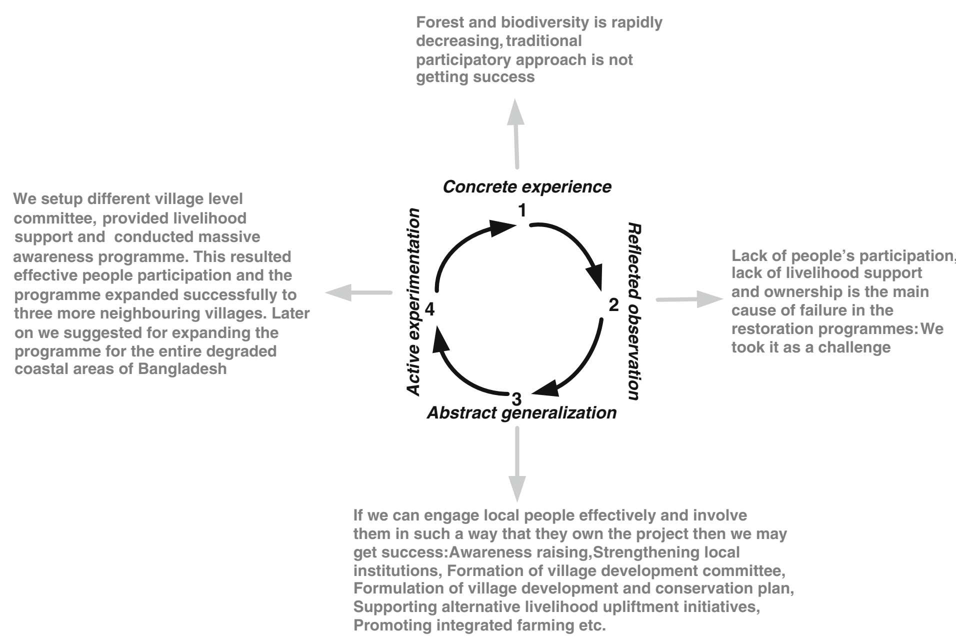

Fig. 5 A hypothetical example of adaptive management in mangrove restoration with the aid of Kolb's (1984) experiential learning model

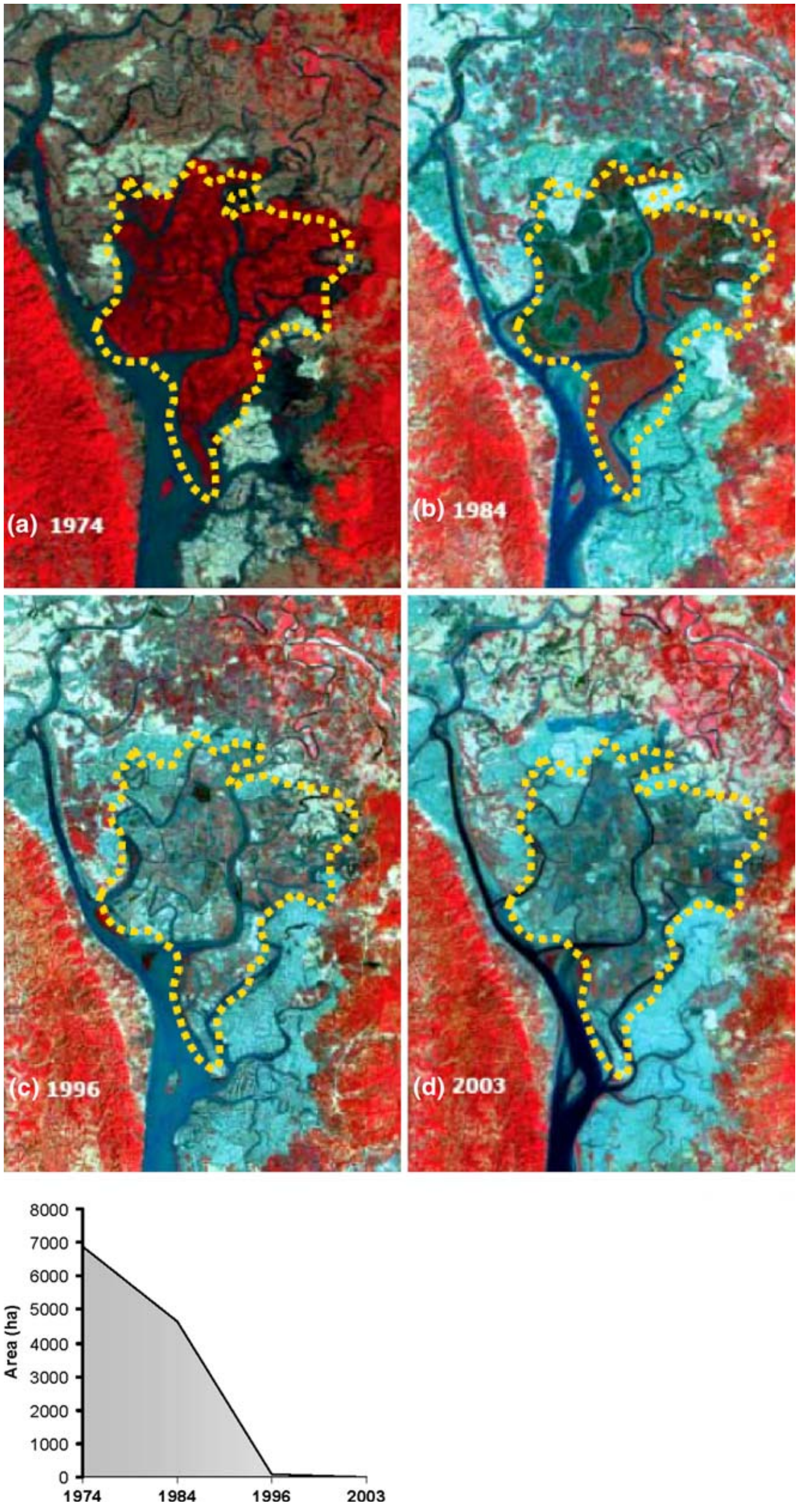

Fig. 6 Satellite images elucidate the gradual destruction of the tree cover and loss of the Chokoria Sundarbans mangrove forest over the period of 1974–2003 (modified and reorganized from IUCN Bangladesh 2005). Dotted line indicates the area of mangrove forests. Arial coverage is explained by inset graph

Box 1

Degradation of the Chokoria Sundarbans, Bangladesh – historical perspective

The first large scale exploitation of this forest was started during the First World War when a large portion of this forest was chopped down for road construction. In the 1950s, local people started to produce salt by boiling seawater with wood-fuels. In the 1960s the local inhabitants moved towards solar energy instead of wood fuel for salt production from seawater. Thus, pressure on the forest was reduced and the forest started to recover.

In 1970, a group of trespassers led by local elite cleared some areas of the forest land for dwelling. Forest Department officials took legal measures against the trespassers. However, this was the time of the liberation war of Bangladesh (1971) and it took a long time to obtain a decision from District Sub Judge Court and through the Appellate Division. In the meantime the trespassers continued their illegal activities of taking over the forestland. Through these processes part of the Chokoria Sundarban (approx. 1108.04 ha went under the control of the trespassers whose activities had destroyed the forest considerably.

In 1977, the government of Bangladesh decided to hand over some of these mangrove lands for shrimp farming. Accordingly, an area of 228 ha of reserved forestland of Chokoria Sundarbans was handed over to set up shrimp and duck farms. It was the first leasing efforts in the protected area of Chokoria Sundarbans. This encouraged the local elites to establish shrimp farms in the area. Local peoples became interested in shrimp cultivation and created political pressure to get lease more of those lands. In 1978- 1982, further 2718 ha of the reserved forest of Chokoria Sundarbans were transferred to Fisheries Department for shrimp culture. Though only 3205 hectares of forest land was officially leased out for shrimp farming, the farmers cut down the surrounding areas also and included those areas under their shrimp farms since boundaries were not clearly demarcated. Apart from this, those who had encroached gradually expand their illegal occupancy and shrimp cultivation on the forest land. The influential people encroached the remaining forest land by the end of 1990. Being gradually encroached, almost whole of the forest area have been occupied by shrimp farms, human settlement and salt farms. Forest Department has a very restricted control over the area because of intense socio-political conflicts.

At present the vegetation cover of the Chokoria Sundarbans has been stripped off completely. A small patch of natural mangrove consisted of 17 individuals of old Sundri (*Heritiera fomes*) trees and some tiger ferns are alive as remnants to witness the past of the oldest mangrove forest in Southeast Asia.

and analysis of the present state of the ecosystem, especially the hydrology and bio-physical conditions of the degraded ecosystem.

Hydrology regime

The Matamuhuri river is the main source of flowing fresh water in the area. Over the past decades a large number of shrimp and salt farms have been formed by constructing embankments along the banks of this river and its tributaries. This has interrupted the hydrology regimes, especially during normal tidal floods in this area.

Soil

Acid sulphate soils (ASSs) are common in the coastal wetlands and those of the Chokoria Sundarbans are no exception. This area undergoes extensive aquaculture during the monsoons and produces salt in the winters. Year round soil disturbances lead to oxidation of the pyrite and result in high concentrations of sulphuric acid in the soil. More than 40% of the Chokoria Sundarbans soil is predominantly ASSs (IUCN 2005).

Depending on the site, soil varies from low to extremely high salinity (Table 1). For example, inside the shrimp farms soil salinity is high, whereas outside the embankment salinity is low, which is suitable for

Table 1 Soil properties of the Chokoria Sundarbans

Sampling location	Soil chemistry			Soil nutrients			
	pH (±sd)	Salinity (±sd)	ECE (±sd)	N (±sd)	K (±sd)	P (±sd)	S (±sd)
Inside the shrimp farm	6.1 ± 0.89	22 ± 1.25	9.50 ± 1.78	0.133 ± 0.014	0.82 ± 0.16	3.06 ± 0.45	156.04 ± 2.73
Outside the shrimp farm (River bank)	6.6 ± 0.45	12 ± 2.3	19.64 ± 1.82	0.177 ± 0.015	0.12 ± 0.12	2.57 ± 0.65	589.16 ± 3.41

mangroves. Soil pH ranges from slightly acidic to neutral indicating suitability of mangrove species.

Soil nutrient contents, especially potassium (K) and sulphur (S) are high which helps growth of mangrove species. Nitrogen (N) and phosphorus (P) contents are very low, probably due to the lack of leaf litter decomposition. Given the soil nutrient contents of the Chokoria Sundarbans and that of the Sandarbans, the area is still suitable for mangroves without any treatment, when one compares the area with that of other mangrove forests.

Socio-economics

The area of the Chokoria Sundarbans is characterized by people in low to medium income groups. Very few people are in the high income group, but they influence the poor. The literacy rate is very low compared to other parts of the country. Complex socio-political conflicts are common in the coastal areas of Bangladesh, including this area. People adjoining the forests are suspicious of any outsiders, even NGOs, for at least one reason: many local people are located on encroached land and they are always in a fear of losing control of this land.

Community organisation and social mobilisation

Given the experience from other failures in rehabilitation, IUCNB emphasised community participation right from the beginning, which helped the community to realise its ownership of the programme. The whole system was transparent to the community. The underlying assumption was that people should get organised to work together if they are to live in close proximity and share common interests for community development.

During the community organising process, people from heterogeneous groups e.g. farmers, labourers, shrimp farmers, fisherman, shrimp trader, school and college teachers, representatives from local governments, local elites and other influential persons got together. Participatory Rural Appraisal (PRA) techniques were practiced extensively during the social mobilisation. Community interest for restoration of the degraded mangrove was assessed using formal and informal interviews, community meetings and discussions. During this process target groups were sensitised to their own problems of declining shrimp production and frequent exposure to natural calamities, due to the absence of mangroves. Awareness generation into the causes for the degradation of mangroves and the need for their restoration was carried out using focus group discussion (FGD) and community meetings in selected villages. During this process relevant case studies from South East Asia were presented. Beside these, the decreasing trends of shrimp production due to loss of mangroves were discussed. People were briefed on historical analyses of past natural calamities in this area such as cyclones, draughts, massive exploitation of natural resources, etc. At the end of this social mobilisation, people became organised in a common motive—the rehabilitation of the Chokoria Sundarbans.

Restoration plan

Considering the existing biophysical and socio-economic conditions of the site, an area-specific restoration and community development plan was prepared with active participation of the local community. First, the community prepared a preliminary action plan. This plan contained details of interventions/activities to be undertaken. It also identified several priority areas targeted for plantation establishment. Second, the plan was further refined considering the necessary technical, social and economic conditions. IUCNB guided people in terms of technical backstopping. The purpose of the plan was to provide a strategic framework for moving the development toward a more sustainable path.

Restoration of degraded sites

After site selection, a plantation plan was developed jointly by the community and the project team. The key components of the plan are: (i) species selection, (ii) plantation and (iii) plantation management.

Species selection

Based on the predisturbance vegetation history and existing biophysical conditions, three mangrove species were selected for plantation i.e., *Sonneratia apetala, Avicennia officinalis* and *Excoecaria agallocha*. Both, *Sonneratia apetala* and *Avicennia officinalis* are pioneer species in the natural mangroves of Bangladesh (Das and Siddiqi 1985). These species grow well on new accretions that receive regular inundation. The community people preferred *Avicennia officinalis* for plantation (since their wood value is higher) and by matching with site characteristics this species was planted on sandy sites. Some of the target sites were slightly raised where *Excoecaria agallocha* was planted. The regularly inundated river banks were planted with *Sonneratia apetala.*

Plantation

Planting was carried out during August–September. This season is physiologically optimal for mangrove plantation. For plantation, indigenous techniques were used. For example, a pointed wooden pole, 3 m long and about 10 cm in diameter, was used to make holes. Since the soil was neither too hard nor too soft this technique proved to be cost effective and efficient. The planting holes were about 25-30 cm deep and 10 cm in diameter. Seedlings with well developed taproots were manually placed in every hole up to the collar mark of the seedlings. No manure and fertilizers were used. Apart from the plantings, viviparous seeds of *Avicennia officinalis* were also broadcast seeded to initiate stand heterogeneity.

Plantation management

A community based approach was followed for plantation management. For sustainable management of the restored site, a rehabilitation and advisory committee was formed with representations from the community that included shrimp farmers, local government representatives and members of the civil society. Representatives of this community ensured protection of the plantations and they also undertook necessary gap fillings.

Results

Table 2 provides a comparative summary of mangrove restoration interventions in the area with their initial success. The pilot initiative by IUCNB restored 21 h of degraded and newly accreted land with

Table 2 Comparative restoration parameters and initial success in the restoration of the Chokoria Sundarbans

Successive interventions[a]	Ecological considerations	Social considerations	Community participations	Financial benefit to the community	Leadership in the project implementation	Rigorous monitoring	Overall success[b]
Project I (Bangladesh Forest Department)	++	–	–	–	–	+	?
Project II (Organisation for Industrial, Spiritual and Cultural Advancement)	+++	–	+	+	–	+	+/?
Project III (Unnayan Bikolpa Niti Gobeshona Kendra)	+	+	–	–	+	–	?
Project IV (IUCN Bangladesh)	+++	++	++	+	+	+	+

[a] Indicate coordinating/implementing organization. + Sign indicates positive and their frequency indicates level of considerations (+ minimum, ++ medium, and +++ maximum). – Sign indicate absence

[b] We assessed restoration success in terms of area planted and status of that plantation

mangrove species and is considered a success (IUCN 2005). However, the necessary database to assess the ecological parameters (pre- and post-restoration) was not available to identify the ecological improvements, except the area under plantation and the status of its health. The programme was planned to provide livelihood support, but due to funding limitation, support was provided at a negligible scale (IUCN 2005). The entire activity was planned and implemented on a participatory basis and involved all local resource users and stakeholders through transparent community-based planning, implementation and monitoring. It should be mentioned that after the pilot phase, there was some small scale follow up but livelihood support was not ensured. How long the community will keep its interest in this effort remains to be seen.

Discussion

Do we have sufficient ecological knowledge for mangrove restoration?

Ecology, disturbance (type and patterns) and especially hydrology are the primary considerations for mangrove restoration. Although restoration of Southeast Asian mangroves demands special attention for social and economic issues (IUCN 2005), it cannot be carried out without a good ecological understanding (Ellison 2000). Documented knowledge of mangrove ecology is very limited in Southeast Asia. Two factors may contribute to this knowledge gap: (i) because of a poor economy, investment opportunities are limited and based on basic ecological research that generates little knowledge and (ii) most of the tropical mangrove restoration projects are funded externally and have a limited time frame (1–5 years). With a few exceptions, most of these short-term projects focus on overnight solution trials rather than investing in detailed understanding and experimentation. However, these regions are extremely rich in traditional ecological knowledge. Again, the problem is a lack of documentation. Although limited, some valuable evidence is available on traditional ecological knowledge in mangrove management (Walters 1997, 2004, 2005; Dahadough-Guebas 2005a, b; Bormthanarat et al. 2007; Jayatissa et al. 2006). Rist and Dahadough-Guebas (2006) emphasised the use of science and traditional ecological knowledge in management of natural resources. This approach creates a symbiotic relationship between local communities and restoration workers. Restoration workers benefit from ecological knowledge while local communities benefit socially, culturally and economically. This enhances community participation. Once properly documented, it is likely that similar ecological knowledge can be used in other regions for mangrove restoration, provided they experience similar social and ecological conditions.

What determines effective community participation in mangrove restoration?

Participation means different things to different people. In community-based restoration projects it is a common belief that external agencies will initiate a restoration programme for a specific time frame to develop a participatory mechanism and the community will continue when the external agencies depart. However, it is not uncommon that the whole effort collapses as soon as the external support is withdrawn. Although communities are often blamed for a lack of participation, it is rare that participatory programmes start with a thorough understanding of the driving forces behind community participation. The possible driving forces are: (i) cultural conditions (ii) economic conditions (iii) ownership in the community, (iv) transparency of the efforts and (v) pluralism. Cultural conditions integrate the choice of the people and restoration activities must be in line with their traditional culture/norms. Viability of a system will depend on the economic returns from the system. A system may be well-designed and technically sound, but it will not be sustainable if it does not yield any economic return to the community in the short-term. Apart from cultural and economic considerations, ownership feeling of the community and transparency of the entire system are prerequisites for the sustainability of a particular system. There have to be well established linkages between the driving forces. When a particular restoration effort is in line with their traditional norms/cultures, produces economic returns, the community owns the programme and entire system is transparent to all, only then will members of each community be accountable to their own roles and the restoration may be successful.

Should a mangrove restoration project put emphasis on property right issue?

This is a very complicated issue. The short answer to the above question is ‘yes’ if the intervention is targeted at policy level but ‘no’ if it is only at the field level restoration. Walters (1997) suggested that restorationists should identify and negotiate with all property right holders to reduce the likelihood of future conflicts. Most of the river banks (where mangroves grow), especially in Asia, are either government or privately owned. In case of government ownership, the local community does not have legal access to that property. Alternatively, in private hands, the owner might not be interested to share the benefits with the community. It is important to assign some kind of rights to the community so that it feels some sort of ownership and actively participate in the restoration programme. If the property right issue can be sorted out at the government policy level then it becomes easier to execute the restoration plan. However, only field level efforts that deal with property rights may end up with further conflicts. For example, Primavera (2005) in her award winning essay in Science wrote “as I write on this late June afternoon, my heart grieves amid news that a young couple,…had been shot over a fishpond dispute.” This type of situation is quite common in Southeast Asia. In the Chokoria Sundarbans of Bangladesh many lives have been lost in property right conflicts. In this region hardly any evidence is available where a mangrove restoration project deals with the property right issue successfully. Although relevant, considering the complexity of the issue, perhaps it would be more productive to treat the issue of property separately and concentrate more on effective planning and execution of the restoration plan.

How can we measure the success of a mangrove restoration programme?

The Society for Ecological Restoration(2004) listed nine attributes for a restored site: (i) similar diversity and community structure in comparison with reference sites (ii) presence of indigenous species (iii) presence of functional groups necessary for long term stability (iv) capacity of the physical environment to sustain reproducing populations (v) normal functioning (vi) integration with the landscape (vii) elimination of potential threats (viii) resilience to natural disturbance and (ix) self sustainability. For testing the success of any mangrove restoration, a long-term monitoring programme is required. The monitoring period needs to be even longer in a dynamic social environment. Most frequently, success of restoration is judged by the area under plantation/tree cover. We maintain species diversity or plant trees to maintain ecosystem functions. It should be noted that depending on ecosystems of interest and degree of disturbance, functional redundancy varies. It is quite likely that the floral assemblage of a mangrove may have a low functional redundancy, which that raises a further concern, since large scale mangrove restorations in Southeast Asia continue with few species (Saenger and Siddiqi 1993) that hardly meet the functional requirement of the ecosystem and seldom can be considered as mangrove restoration. Lewis (2005) suspected that this type of restoration can hardly qualify as a successful mangrove restoration. Interestingly, if we consider the area under tree cover the same project may qualify as a successful project. The potential for silent ecological disasters remains. As such it is important to evaluate key ecological parameters of both structural and functional components while measuring the restoration success. Ruiz-Jaen and Aide (2005) suggested three simple but effective measures for assessing restoration success: (i) species diversity—this can be measured by the presence and abundance of species, (ii) vegetation structure—this can be measured by vegetation cover and (iii) ecological process—this can be measured indirectly by measuring nutrient availability and biotic interactions. Technical and financial resources are a regulating factor for the assessment of simple to complex functional components of an ecosystem. Depending on available resources, one can chose from the above mentioned parameters to monitor restoration success.

Conclusion

The literature on the subject has stressed the importance of mangroves for their productive, protective and ecological functions. The necessity of the protective function of the mangroves has been dramatically demonstrated at the expense of hundreds of thousands of lives during the 2004 tsunami. Hence, tremendous efforts continue to stop further degradation of mangroves and at the same time restoration is carried out of degraded mangroves in a systematic and effective way. In our restoration framework, we structured most of the aspects. As well, we leave many aspects (based on local conditions) for professional/personal judgments from a mangrove restoration ecologist. A mangrove restoration team should consist of representatives of various disciplines so that the full potential of the framework can be realised.

In the first place, we emphasis social, economic and ecological factors with special considerations for Southeast Asia (high anthropogenic influence). However, in other parts of the world with less anthropogenic influence, this framework can be equally applicable after necessary amendments. For example, where mangroves are experiencing *Type II degradation* (degradation due to natural events), social and economic considerations may be less critical.

Second, local ecological knowledge has a high potential use in mangrove restoration since it may act as a symbiotic agent between a mangrove restoration ecologist and local communities. This knowledge can also advance the science and has the potential to provide a new direction. It is desirable to utilise the traditional ecological knowledge along with scientific knowledge obtained from experimentation. Traditional knowledge can also be refined through gradual development of scientific understanding.

Third, at the moment comprehensive measurement of restoration success is a challenge because of the lack of quantitative indicators. If the quantifiable indicators are developed, it will be easier to monitor the success or failure of a mangrove restoration programme by using a fuzzy inference system.

Finally, we identified the lack of documentation and research communication on mangrove ecology and mangrove restoration, especially in the developing countries of Southeast Asia. It is important to understand as well, that projects that fail generate no less knowledge than the successful projects and hence documentation of the failed projects is equally important for the benefit of new directions to solve the restoration puzzle.

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