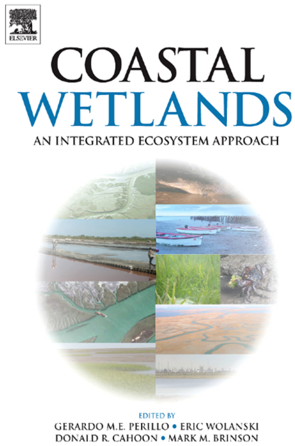

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CHAPTER 28

Methods and Criteria for Successful Mangrove Forest Restoration

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Contents

1. Introduction

Mangrove forest ecosystems currently cover 14.7 million hectares of the tropical shorelines of the world (Wilkie and Fortuna, 2003), which represents a decline from 19.8 million hectares in 1980 and 15.9 million hectares in 1990. These losses represent about 2% per year from 1980 to 1990 and 1% per year from 1990 to 2000. Therefore achieving no-net-loss of mangroves worldwide would require the successful restoration of approximately 150,000 ha/year, unless all major losses of mangroves ceased. Increasing the total area of mangroves worldwide would require an even larger scale effort.

An example of documented losses includes combined losses in the Philippines, Thailand, Vietnam, and Malaysia of 7.4 million hectares of mangroves (Spalding, 1997). These figures emphasize the magnitude of the loss, and the magnitude of the opportunities that exist to restore areas like mosquito control impoundments in Florida (Brockmeyer et al., 1997) (several tens of thousands hectares) and abandoned shrimp aquaculture ponds in Southeast Asia (Stevenson et al., 1999) (several hundreds of thousands hectares), back to functional mangrove ecosystems.

While great potential exists to reverse the loss of mangrove forests worldwide, most attempts to restore mangroves often fail completely, or fail to achieve the stated goals (Erftemeijer and Lewis, 2000; Lewis, 2000, 2005). Previously documented attempts to restore mangroves (Field, 1996, 1999) where successful, have largely concentrated on creation of plantations of mangroves consisting of just a few species, and targeted for harvesting as wood products (Kairo, 2002), or temporarily used to collect eroded soil and raise intertidal areas to usable terrestrial agricultural elevations (Saenger and Siddiqi, 1993).

Successful mangrove forest restoration requires careful analyses of a number of factors in advance of attempting actual restoration. First for a given area of mangroves or former mangroves, the existing watershed needs to be defined, and any changes to the coastal plain hydrology that may have impacted the mangroves documented. Second, careful site selection must take place factoring into account the history of the site. Third, clearly stated goals and achievable and measurable success criteria need to be defined and incorporated into a proposed monitoring program. Fourth, the restoration methodology must reflect an acknowledgement of the history of routine failure in attempts at mangrove restoration and proposed use of proven successful techniques. Finally, after the initial restoration activities are complete, the proposed monitoring program must be initiated and used to determine if the project is achieving interim measurable success to indicate whether any mid-course corrections are needed.

2. General Site Selection for Restoration

Previous research has documented the general principle that mangrove forests worldwide exist at the down slope end of coastal drainage basins (Kjerfve, 1990). At this down slope location adjacent to the sea, mangroves typically are established on a raised and sloped platform above mean sea level, and inundated approximately 30% or less of the time by tidal waters (Lewis, 2005). Kjerfve (1990) reported inundation times as short as 9% of the time for Klong Ngao on the west coast of Thailand. More frequent flooding causes stress and death of mangroves. Kjerfve (1990) suggests six key data needs prior to proceeding with looking at the hydrology of the basin and associated mangroves:

1. Size and extent of drainage basin
2. Extent and area of mangroves at the downslope (i.e., toward the sea) end of the basin
3. Topography and bathymetry of the mangrove areas
4. Hypsometric characteristics to calculate the current tidal prism of the mangrove areas
5. Rates of terrestrial input of water, sediment, and nutrients
6. Climatic water balance

These analyses will yield one or more distinct areas of mangroves with varying characteristic hydrographic patterns, including more or less natural systems, some with natural damage like recent hurricanes, typhoons, or tsunamis; and those impacted by development activities, such as dredging and filling, channelized basin flows, road construction, and restrictions to tidal exchange particularly in lagoonal mangroves.

3. Specific Site Selection for Restoration

The general site selection process may be applied to more than one coastal drainage basin to yield a list of individual mangrove forest areas, and general characteristics of these areas. From this list, those areas showing either some current damage or significant declines in total area of mangroves from historical conditions need to be identified from a reconnaissance level examination of available maps and aerial or satellite photography. From this effort a short list of sites warranting further investigation is produced.

Each of these potential restoration sites requires a field level investigation with maps and aerial or satellite photography in hand to verify vegetation signatures, including areas of stressed, dead, or lost mangroves. There may also be areas of damaged mangroves showing secondary succession or recovery from a previous damage event. The time frame since the damage event needs to be known in order to answer the key question, which is, "does this site need management to support further recovery, or accelerate recovery, or is it likely to recover over time by itself without intervention?" Or as Saenger (2002) emphasizes, "what is the history of the site or area, or more specifically, what prior activities have led to the present conditions?"

Lewis (2005) has introduced the term "propagule limitation" to define a condition in which natural recovery is slowed or stalled due to a lack of natural mangrove propagules being available to volunteer at a damage site. Propagule limitation may be caused by a large loss of adult trees capable of producing propagules or by hydrologic restrictions or blockages (i.e., dikes), which prevent natural waterborne transport of mangrove propagules to a restoration site. Since propagules are produced at different times of the year by different species in different locations (Tomlinson, 1986), more than one site visit may be necessary in order to correctly identify a propagule limited site. Lack of propagules at a single time of year does not necessarily define a propagule limited site, and therefore careful evaluation of this parameter is important. If a damaged forest is going to recover on its own within an acceptable time frame, any attempt to introduce propagules or plant propagules or plant nursery grown mangroves is likely to be a waste of time and money. Recovery is here defined as the recolonization or planting of a restoration site and that the site's growth of plant materials to some predefined numerical level (e.g., percent cover, total basal area).Priority should be given to sites that would indeed benefit from intervention by man given always limited time and money to devote to any restoration project.

These suggestions may seem obvious, but the documentation of successful mangrove forest restoration is very limited, and more commonly former nonmangrove areas like mudflats or seagrass meadows seaward of natural mangroves or damaged areas without a properly documented history are the primary targets of well intentioned, but often faulty, mangrove restoration efforts (Field, 1996; Erftemeijer and Lewis, 2000; Lewis, 2005). The result of unsound evaluations of restoration opportunities has, unfortunately, emphasized first establishing a mangrove nursery, then planting mangroves at a casually selected site, as the primary tool in restoration, rather than first assessing the reasons for the loss of mangroves in an area and working with the natural recovery processes.

Both Brockmeyer et al. (1997) and Stevenson et al. (1999) present examples of successful mangrove restoration following reestablishment of historical tidal connections to adjacent estuaries. This is termed "hydrologic restoration" (see discussion by Turner and Lewis, 1997). In the examples discussed, volunteer mangrove and mangrove nurse-plant propagules were sufficient to allow for rapid establishment of plant cover. No planting of mangroves was required.

Lewis and Marshall (1997) suggest five critical steps are necessary to achieve ecological mangrove restoration (EMR), and these are discussed in more detail in Stevenson et al. (1999). The general approach is to emphasize hydrologic restoration opportunities without first emphasizing planting of mangroves (Turner and Lewis, 1997). These steps have been tested in training courses on mangrove restoration in the United States, Nigeria, Indonesia, Thailand, Vietnam, Sri Lanka, and India, and have been further modified with review and input by both teachers and students to include one added step as follows:

1. Understand the autecology (individual species ecology) of the mangrove species at the site, in particular the patterns of reproduction, propagule distribution, and successful seedling establishment.
2. Understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species.
3. Assess the modifications of the previous mangrove environment that occurred that currently prevent natural secondary succession.
4. Select appropriate mangrove restoration sites through application of Steps 1–3 above that are both likely to succeed in restoring a sustainable mangrove forest ecosystem, and are cost-effective given the available funds and manpower to carry out the projects, including adequate monitoring of their progress towards meeting quantitative goals established prior to restoration. This step includes resolving land ownership/use issues necessary for ensuring long-term access to and conservation of the site.
5. Design the restoration program at appropriate sites selected in Step 4 above to initially restore the appropriate hydrology and utilize natural volunteer mangrove propagule recruitment for plant establishment.
6. Only utilize actual planting of propagules, collected seedlings, or cultivated seedlings after determining through Steps 1–5 above that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth of saplings established as quantitative goals for the restoration project.

Step number 6 is still the most controversial step of EMR. If natural recruitment fails, that may mean the site has not been adequately rehabilitated to facilitate volunteer mangrove recruitment where propagule limitation does not exist. For example, if the hydrology has not been adequately restored, or at an excavated site, the final topographic grade may be too high or too low. Under these circumstances, planting will not overcome these physical limitations on plant establishment, but planting does often occur and the plants then die.

Local communities plant seedlings even after having undertaken successful EMR for a combination of three reasons: (1) lack of patience, (2) protection of the restoration site since planted areas appear to outsiders (not aware of the project) as an intentional action and provide a measure of protection for that area as it is obvious that there is human activity in the area, and (3) promotion of growth of preferred species such as *Rhizophora* over colonizers such as *Avicennia* or *Sonneratia*. Even with adequate local mangrove recruitment after EMR, planting may serve as an educational process for local communities and encourage local support for the project. It is however still important to document natural recruitment during monitoring and report the differential contribution of volunteer- and human-planted mangroves to the final estimate of plant cover.

Through the application of these six simple steps, and basic principles of ecological restoration using ecological engineering approaches, including careful cost evaluations prior to final selection of a restoration site and design of a restoration program, the opportunity for a cost-effective and successful restoration effort is maximized.

Most of the largest attempts to restore mangroves are currently taking place in Southeast Asia. While the six-step process described above has been taught as several short courses and is widely publicized in English in this part of the world, more education needs to be done in native languages, and published in native languages. The lack of large-scale translations of scientific papers about mangrove restoration into local languages is hampering adoption of the six-step process. Also, the lack of general application of the rule of law in several of these countries limits attempts to protect existing mangroves. Large-scale conversion of existing mangrove forests to aquaculture ponds is still taking place, and more recently, conversion of mangroves to what are perceived as more valuable oil palm plantations has accelerated.

Ecologists and engineers have not understood mangrove hydrology, as Kjerfve (1990) points out. Although a number of papers discuss the science of mangrove hydrology (Kjerfve, 1990; Wolanski et al., 1992; Furukawa et al., 1997, see also the review in Mazda et al., 2007), their focus has been on tidal and freshwater flows within the forests, and not the critical periods of inundation and dryness that govern the health of the forest. Kjerfve (1990) does discuss the importance of topography and argues that "...micro-topography controls the distribution of mangroves, and physical processes play a dominant role in formation and functional maintenance of mangrove ecosystems..." Hypersalinty due to year-to-year variations in rainfall can produce natural mangrove diebacks (Cintron et al., 1978), and disruption of normal freshwater flows that dilute seawater in more arid areas can kill mangroves (Perdomo et al., 1998; Medina et al., 2001), or stress mangroves to the point that they may not be able to keep up with sea-level rise through root production and the laying down of a peat layer (Snedaker, 1993).

The point of all of this is that flooding depth, duration, and frequency are critical factors in the survival of both mangrove seedlings and mature trees. Once established, mangroves can be further stressed if the tidal hydrology is changed, for example by diking (Brockmeyer et al., 1997). Both increased salinity due to reductions in freshwater availability, and flooding stress, increased anaerobic conditions, and free sulfide availability can kill or stress existing stands of mangroves, and mangroves at restoration sites (McKee, 1993).

For these reasons, any engineering works constructed near mangrove forests, or in the watershed that drains to mangrove forests, must be designed to allow for sufficient free exchange of seawater with the adjacent ocean or estuary, and not interrupt essential upland or riverine drainage into the mangrove forest. Failure to properly account for these essential inputs and exchange of water will result in stress and possible death of the forest. Engineering works such as dikes created to make shrimp aquaculture ponds disrupt the natural hydrology and produce conditions that prevent natural recovery once these ponds are abandoned due to disease (Stevenson et al., 1999).

Use a reference mangrove site for examining normal hydrology for mangroves in your particular area. Either install tide gauges and measure the tidal hydrology of a reference mangrove forest, or use the surveyed elevation of a reference mangrove forest floor as a surrogate for hydrology, and establish those same ranges of elevations at your restoration site, or restore the same hydrology to an impounded mangrove by breaching the dikes in the right places. The "right places" are usually the mouths of historic tidal creeks. These are often visible in vertical (preferred) or oblique aerial photographs.

4. Establishing Success Criteria

Once a site is finally chosen for restoration, and a design developed, quantifiable success criteria should be established. Establishing such criteria is important to actually measure progress toward successful restoration. The first step in establishing numeric criteria for success is to prepare a brief narrative goal or set an objective (Saenger, 2002) for the project. This will define the next steps. A goal may be to establish a monotypic plantation of *Rhizophora apiculata* to be harvested after 12 years as poles. This is a typical goal of many mangrove restoration projects. It may be an acceptable goal to local stakeholders in the project such as local villages and fishermen, and harvest of wood products from locally managed forests is a typical goal (see discussion of timber production in the Matang Forest, Malaysia, by Saenger, 2002, pp. 231–234).

If on the other hand the goal is to provide fish and invertebrate habitat to restore local fisheries, a different approach to establishing success criteria is dictated. Maximizing such habitat use usually means maximizing biodiversity of the plant species, and therefore a monotypic stand of mangroves in an area that normally supports 20 or more mangrove tree species is not a logical goal. Establishment and persistence of tidal creeks to assist with entry and exit of juvenile and adult fish and invertebrates may also be needed criteria.

Once narrative success criteria are agreed upon, quantitative criteria need to then be established. For the first example above, a certain number of pole size trees per hectare could be established. Such a success criteria would also likely dictate an immediate planting program of collected propagule or nursery grown plants, rather than waiting for volunteer propagules. For the second example, to maximize biodiversity, the restoration site might be left alone and not planted immediately to allow for volunteer colonization of the largest number of different species of mangroves from propagules produced by trees adjacent to a restoration site.

The next step is to look at available information on both plantation and natural recruitment indices of success. Saenger (2002, pp. 256–270) discusses in great detail what is to be expected in terms of biomass and stem density for example from typical plantation projects. There has been much work on plantation projects where just a few species of mangroves are managed for, and thus there is a wealth of data to examine. In contrast with this, the availability of data on natural recruitment within a mixed forest is generally not available. McKee and Faulkner (2000) report on the results of sampling for density and basal area within two restored mangrove forests in Florida, USA, and compared these to two adjacent control areas. Their data show density and basal area for volunteer mangroves in the restoration areas exceeded that for planted mangroves. Proffitt and Devlin (2005) report similar results from one of the same sites sampled by McKee and Faulkner (2000) but in later years as the system matured. Lewis et al. (2005) report on the results of cover sampling over a period of 5 years within a restored mangrove forest in another location in Florida, USA. These studies help define parameters that need to be sampled and sampling methodologies, but provide limited data to apply to local situations in other parts of the world.

5. Monitoring and Reporting Success

Once success criteria have been established, and the site restored through hydrologic restoration with or without planting, monitoring, and reporting should begin. A typical monitoring schedule would consist of the following 10 reports:

1. Time Zero
2. 0 + 3 months
3. 0 + 6 months
4. 0 + 9 months
5. 0 + 12 months
6. 0 + 18 months
7. 0 + 24 months
8. 0 + 36 months
9. 0 + 48 months
10. 0 + 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.”

This is a typical schedule of reporting as required by wetland mitigation projects in the United States. As noted by the data of Proffitt and Devlin (2005), however, changes in the height, density, and species composition of mangroves on a restoration site will continue over time. Eighteen years have passed since the restoration of the site described in Proffitt and Devlin (2005), and changes are still being observed. For example, the dominant species present 7 years after restoration, *Laguncularia racemosa*, experienced "reduced recruitment and apparent density-dependent mortality" through the last sampling 18 years after restoration. Longer term monitoring in forested restoration areas is recommended where resources are available. The recommended time interval after the last regular monitoring would be 5-year intervals until the time of maturity of the restored forest. Based on the work of Lewis et al. (2005) total cover by mangroves can be expected to occur rapidly (within 3–5 years), but basal area equivalency will take much longer. Ten years after hydrologic restoration Stevenson et al. (1999) report that the total basal area for all species of mangroves at hydrologically restored site in Costa Rica (abandoned shrimp aquaculture pond) was 64.2% of that of the control site. Eighteen years after restoration, Proffitt and Devlin (2005) report the total basal area of all mangrove species (42.7 m^2/ha) exceeded that of the mean of the two control areas (17.9 m^2/ha) by a factor of 2.4. They make an important note however in that they encountered a large number of saplings exceeding the 1.3 m height requirement for counting in basal area measurements, but they were less than the minimum of 2.0 cm in DBH (diameter at breast height). Normally these trees are not counted in basal area calculations (Cintron and Novelli, 1984). We believe ignoring them produces a total basal area calculation that does not represent the true value for all trees on the restoration site and recommend they do be counted and DBHs measured, but that category of trees less than 2 cm in DBH be reported separately from the other normally reported classes (i.e., $\geq$2, <10, and $\geq$10 cm) to allow for direct comparisons to other data sets like that of Stevenson et al. (1999) and McKee and Faulkner (2000).

We also recommend the establishment of either permanent, haphazard or random plots of 5 m $\times$ 5 m, at a density within the restoration area that allows for stratified sampling over the elevation gradient present within the restoration site. The Point Centered Quarter Method (Cintron and Novelli, 1984) can also be used.

6. Functionality of Restored Mangrove Forests

Lewis (2005) notes that ecological restoration of mangroves, where restored ecosystem functions are the goal, is rarely a prime goal of restoration projects, and thus is rarely monitored. Lewis (1992) notes that research on the use by fish of both restored tidal marshes and mangroves in the United States shows that fish populations in these restored plant communities are equivalent in both numbers and species composition within 3–5 years of restoration.

McKee and Faulkner (2000) examined the biogeochemical functions of two restored mangrove forests in Florida (6 and 14 years old). Soil Eh was lower at the restoration sites and pore water sulfide concentrations were significantly higher. Soil carbon and nitrogen levels were greater overall in natural soils and were correlated with soil organic matter content. They concluded that site-specific parameters such as rates of tidal flushing, topography, and salinity played a larger role in primary production and turnover rates of organic material than site age.

Bosire et al. (2008) provide a thorough review of faunal use of restored mangrove forests, including data for restoration projects in six countries (USA, Thailand, Kenya, Philippines, Qatar, and Malaysia). The data collected for these sites was very variable however, and no uniform sampling methodology or target faunal groups were the focus of the scattered research efforts. As would be expected, the conclusion of the authors was that functionality depended on what parameters were measured at a given location and generalities were very difficult to make.

For example in Thailand, crab diversity at some of the restored sites was higher than at an upper shore natural mangrove site, and both biomass and crab numbers were consistently higher in the restored sites (Macintosh et al., 2002). However, the natural site was characterized by large numbers of sesarmid crabs. Differences in the crab diversity in Thailand were thought to relate to, among other things, inundation zone and differences in the mangrove species present in the restored sites (Macintosh et al., 2002). However, in Qatar, Al-Khayat and Jones (1999) found lower species richness of crabs at restored sites compared to natural habitats of *Avicennia marina*. In Kenya, reforested stands of *Rhizophora mucronata* and *A. marina* had higher crab densities than their natural references (Bosire et al., 2004) but with similar species diversity and crab species composition compared to respective bare control with similar site history. In the Philippines the relative abundance of mud crab (*Scylla olivacea*) to two other noncommercial species was used to separate the effects of habitat from fishing pressure and recruitment limitation. A comparison of mud crab (*Scylla olivacea*) populations in restored, natural, and degraded sites in the Philippines suggested that 16-year-old restored *Rhizophora* spp. can support densities of mud crabs equivalent to that of natural mixed species mangroves (Walton et al., 2007). Mollusk diversity showed similar patterns to that of crabs in both previously mentioned studies in Qatar and Thailand, while in Kenya, no mollusks were observed in a bare site while the restored site and natural reference site within a *Sonneratia alba* forest had similar species composition, density, and diversity.

Infauna communities (i.e., polycheate worms, amphipods) showed patterns similar to those described above. Lower diversity of taxa was observed in restored versus natural sites in Qatar with the data being less clear in Thailand. Studies in Malaysia suggested that 2-year-old restored mangroves had the greatest biomass and species number followed by the control and 15-year-old stand, although species diversity was highest in the control site and lowest in the 2-year-old site (Sasekumar and Chong, 1998). In Kenya, bare sites had the lowest infauna densities and taxa richness compared to restored sites with natural reference sites having the highest densities. Taxa richness and composition were similar among respective restored and natural sites (Bosire et al., 2004), suggesting successful fauna recolonization following mangrove restoration.

Studies of mobile fauna in restored mangroves of varying ages and species composition showed variable patterns. In Qatar, lower diversity of both juvenile and adult fish was observed in restored sites compared to natural stands of *A. marina*

(Al-Khayat and Jones, 1999). Studies comparing fish and shrimp density between natural stands of *R. apiculata*, *Avicennia officinalis*, *A. marina*, and a single restored *R. apiculata* stand (5–6 years old) in the Philippines indicated that density and biomass were primarily influenced by tidal height and mangrove species (Rönnbäck et al., 1999). In *S. alba* plantations in Kenya, there were strong seasonal fluctuations of juvenile fish, showing temporal patterns to be a potentially stronger influence on fish assemblages than type of restoration site or presence of fringing mangroves (Crona and Rönnbäck, 2007). However, the spatial scale of observation is likely a much stronger factor affecting biodiversity studies of more mobile fauna compared to less mobile animal communities described above.

Since most studied restoration sites are small in size, site-specific effects on fish distribution patterns remain largely unknown. The same is true for juvenile shrimp. In Kenya one species, *Penaeus japonicus*, dominated the community, and lower species richness was observed in a restored area of *S. alba*, than in adjacent clear felled areas (Crona and Rönnbäck, 2005). Natural forests had higher root complexity and also higher abundances and more even distribution of shrimp species in terms of species composition. Similarly, in the Philippines, higher abundances of juvenile shrimp in a restored *R. apiculata* site were seemingly related to higher structural root complexity, although more inland stands of mature *Avicennia* spp. and *Rhizophora* spp. showed no such differences (Rönnbäck et al., 1999).

Lewis and Gilmore (2007) discuss fish use of both natural and restored mangrove forests and report specifically about monitoring of a successful 500 ha mangrove restoration project in Hollywood, Florida, USA, where sampled fish populations in both reference and restored sites were statistically indistinguishable within 3–5 years of restoration. They emphasize three restoration and design goals to ensure functional ecological restoration of mangrove forests:

1. Achieve plant cover similar to that in an adjacent relatively undisturbed control area of mangrove forest.
2. Establish a network of channels that mimic the shape and form of a natural tidal creek system.
3. Establish a heterogeneous landscape similar to that exhibited by local mangrove ecosystems.

Few studies exist on trends in biodiversity in restored mangroves, and the range in age, species, and inundation class of restored sites makes generalizations difficult. However, the co-occurrence of many animal species in both restored and comparable natural forests suggest colonization of restoration sites by both mobile and nonmobile fauna is a rapid process, and equivalent populations of mangrove fauna in both natural controls and restored mangrove sites can typically be found within 5–10 years of restoration.

7. Summary

Mangrove forest restoration has not been generally successful except where timber production was the goal and monotypic stands were established. Ecological restoration of mangrove forests, where the goal is the restoration of a mixed species forest cover and functions equivalent to that of an adjacent reference forest has not typically been a design criteria, and most restoration projects not targeting timber production, but with some general ecological goals have not been successful (Erftemeijer and Lewis, 2000; Lewis, 2005). The chosen restoration sites for many of these projects have been mudflats or seagrass beds lying seaward of the outer edge of existing mangrove forests. These sites are typically planted with nursery grown mangrove seedlings which do not survive due to frequent inundation.

Although there are relatively few studies on trends in biodiversity in restored mangroves, the co-occurrence of many animal species in both restored and comparable natural forests suggest colonization of restoration sites by both mobile and nonmobile fauna is a rapid process, with equivalent populations of mangrove fauna in both natural control areas and restored mangrove sites typically found within 5–10 years of restoration. The scientific basis for optimum design of restoration projects to meet certain established criteria, such as increased fish production or more use by wading seabirds, is however very minimal.

In the future mangrove restoration projects should be more carefully designed to ensure successful establishment of plant cover at minimal cost over large areas. This can be achieved for example by restoring hydrologic connections to impounded mangrove areas as has been done in Florida (Brockmeyer et al., 1997), Costa Rica, and the Philippines (Stevenson et al., 1999). Funding agencies typically fund mangrove restoration projects with minimal funds dedicated towards quantitative monitoring and reporting over a reasonable and ecologically based time period (5 years minimum). Both failures and successes thus go undocumented, and mistakes are repeated and lessons learned are lost. Funding agencies and governments need to realize that large amounts of limited restoration funds are now being wasted because of these shortsighted efforts, and at a minimum they should regularly review, publish, and teach the lessons learned from both past successes and failures.

These same funding agencies and governments are very loath to fund careful examination of the ecological functions of restored mangrove areas. This is somewhat understandable given the large costs of quantitative monitoring, but at a minimum attempts should be made to coordinate restoration projects with graduate training programs to provide, at likely minimal costs, opportunities to graduate students and researchers alike access to restoration sites where good research can be done for minimal costs. These efforts to date have been hampered however by the lack of application of uniform methodologies of sampling and reporting. We have made some recommendations above, but would encourage every researcher to revisit and read carefully the excellent work of Snedaker and Snedaker (1984), where uniform scientific methodologies developed by worldwide consensus for sampling flora, fauna, biochemistry, litter production, and decomposition, among other parameters, were recommended. In addition, the additional detailed work on mangrove forest hydrology of Kjerfve (1990) and Mazda et al. (2007) are essential to round out the beginning point for any mangrove restoration research program. We find most current researchers do not start with these references and then add appropriate additional scientific publications to the mix to develop a very well thought out and reviewed plan of study. The result can be data generation of little value in promoting the advancement of the science of ecological restoration of mangrove forests.

At the present time, we believe that greater success at EMR could be achieved with a four-step approach that includes:

1. General site selection for restoration sites that includes examination of multiple coastal basins that contain mangroves.
2. Specific site selection that looks at the history of changes in areal cover of mangroves and changes in hydrology at specific potential restoration sites, and targets hydrologic restoration of these sites.
3. Establishing quantitative and measurable success criteria and use uniform criteria between study sites.
4. Monitoring and reporting of progress toward achieving these success criteria, including reporting on lessons learned from both successes and failures.

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