Mangrove Restoration: Do We Know Enough?

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Abstract

Mangrove restoration projects have been attempted, with mixed results, throughout the world. In this paper, I first examine goals of existing mangrove restoration projects and determine whether these goals are clear and adequate, and whether or not they account for the full range of biological diversity and ecological processes of mangrove ecosystems. Many restored mangrove forests resemble forest plantations rather than truly integrated ecosystems, but mangrove plantations can be a first step toward mangrove rehabilitation. Mangrove restoration projects that involve associated aquaculture or mariculture operations tend to be more likely to approximate the biological diversity and ecological processes of undisturbed mangrove ecosystems than are projects that focus only on the trees. These integrated restoration projects also provide a higher economic return than do silvicultural projects alone. Second, I briefly assess whether existing ecological data are sufficient to undergird successful restoration of mangal and define criteria for determining whether or not a mangrove ecosystem has been restored successfully. These criteria include characteristics of vegetation (forest) structure, levels of primary production, composition of associated animal communities, and hydrology. Finally, I suggest ways to improve mangrove restoration projects and identify key research needs required to support these efforts. Ecological theories derived from other wetland and upland systems rarely have been applied to either "basic" or "applied" mangrove forest studies, to the detriment of restoration projects, whereas lessons from restoration of the relatively species-poor mangrove ecosystems could be beneficially applied to restoration projects in other contexts. An international database of mangrove restoration projects would reduce the likelihood that unsuccessful restoration projects would be repeated elsewhere. Clear criteria for evaluating success, greater accessibility of information by managers in the developing world, intensified international cooperation, and application of relevant ecological theories will improve the success rate of mangrove restoration projects.

Key words: biological diversity, criteria for success, mangal, mangroves, rehabilitation, restoration.

Introduction

Mangrove ecosystems, or mangal, occur on sheltered tropical coastlines throughout the world (Chapman 1976; Tomlinson 1986). For clarity, I distinguish individual "mangrove" species from the wetland ecosystem "mangal"—of which they are defining features. Mangroves (*sensu* Tomlinson 1986; Duke 1992) themselves are any one of ~54–70 species in 20–27 genera and 16–19 families of woody, tropical halophytes that are obligate inhabitants of mangal. Occupying ~181,000 km^2 of these coastlines, mangal occurs in a diversity of geomorphological settings (Twilley 1995), ranging from the vast riverine and estuarine mangrove forests of southeast Asia, the Sundarbans of Bangladesh and India, and along the Orinico River of Venezuela, to isolated mangrove cays that have developed atop carbonate sands and coral rubble in the Caribbean, Micronesia, and the Andaman Islands. This variability in geomorphology is paralleled by wide variation in nutrient inputs (Twilley 1995)—from eutrophic to oligotrophic—and outputs, which can range from <30 to >80% of total NPP (Alongi 1998) and vary over two orders of magnitude in standing biomass (6.8–436 t/ha; Saenger & Snedaker 1993) and litterfall (0.3–18.7 t/ha; Saenger & Snedaker 1993). Mangal also host exceptionally diverse communities of benthic invertebrates (e.g., Rützler 1969; Bingham & Young 1996; Farnsworth & Ellison 1996) and provides refugia for upland animals whose forest habitats have been altered or destroyed (Ellison in press). The extraordinarily high rates of productivity by mangal (in many places >2t ha^{-1} year^{-1}; Alongi 1998; Kathiresan & Bingham 2000) support pelagic and benthic food webs (Odum & Heald 1975; Robertson et al. 1992) and dense assemblages of resident and migratory birds (e.g., Johnstone 1990; Klein et al. 1995). For centuries, mangal have provided a wide range of products that people use, including (but not limited to) timber and fuelwood, finfish and edible crustaceans, and bioactive compounds for tanning and medicinal purposes (Walsh 1977; Bandaranayake 1998; Kovacs 1999). Mangal also significantly reduce coastal erosion and affords coastal communities substantial protection from tropical cyclonic storms (UNESCO 1979).

Within the last hundred years or so, many mangrove forests have been managed actively. Early management focused on timber, fuelwood, and pulpwood produc-

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tion (Watson 1928; see recent reviews in Hamilton & Snedaker 1984; Japan International Association for Mangroves and International Society for Mangrove Ecosystems [JIAM/ISME] 1993; Chowdhury & Ahmed 1994; FAO 1994). More recently, mangal have been managed for cultivation of fish, shrimp, and especially tiger prawn, *Penaeus monodon* (e.g., Hong & San 1993; Chaudhuri & Choudhury 1994; Primavera 1995; de Graaf & Xuan 1998; Semesi 1998; Twilley et al. 1998), or ecotourism (Bacon 1987; Barzetti 1993; Government of West Bengal no date). Despite repeated claims that mangrove forests can be managed sustainably (e.g., Hamilton & Snedaker 1984; Chowdhury & Ahmed 1994; FAO 1994), managed (and unmanaged) mangal continues to degrade and disappear at rates comparable to those seen in tropical wet forests (~1.5%/year; Saenger et al. 1983; Ellison & Farnsworth 1996; Farnsworth & Ellison 1997). As a result, current attention is focused on conservation of the world's remaining less-impacted mangal (e.g., Clough 1993; Diop 1993; Lacerda 1993; Suman 1994) and restoration of the far more extensive degraded mangal (Field 1996*b*, 1998*a*; Kaly & Jones 1998).

There are three purposes to this review. First, I examine goals of existing mangal restoration projects and determine whether these goals are clear and adequate, and if they account for the full range of biological diversity and ecological processes of mangal. Second, I briefly assess whether existing ecological data are sufficient to undergird successful restoration of mangal. Finally, I suggest ways to improve mangal restoration projects and identify key research needs to support these efforts. Subsequent papers in this special feature document specific case studies of current, on-going mangal restoration efforts (Imbert & Rousteau 2000; McKee & Faulkner 2000; Walters 2000; see also Twilley et al. 2000).

Goals of Mangal Restoration

Prior to 1982, the only explicit rationale or goal of mangrove restoration projects was afforestation for silviculture. Up until that year, there had been little deviation from the management plans first described by Watson (1928). Lewis (1982) articulated for the first time that restoration of mangal should emphasize ecological values, animal habitats, and detrital food sources for inshore and pelagic food webs. Subsequent reviews and analyses of mangrove restoration followed Lewis' lead. For example, in 1993, the International Tropical Timber Organization recommended that mangal restoration should sustain essential environmental and ecological values, provide for the livelihood of coastal populations, and help to ensure sustainable development and national prosperity (JIAM/ISME 1993). Field (1996*b*, 1998*b*) similarly focused attention on mangal restoration for sustainable utilization, coastal protection, and ecosystem preservation. These changes in attitude regarding the goals of forest restoration efforts in mangal parallel those seen in managed upland forests (reviewed by Perry 1998), and have spurred an integration of restoration strategies among workers in different ecosystem types. In the analysis of mangrove restoration projects presented below, I use 1982, the year of Lewis' paper, as a temporal "break-point" and compare restoration efforts before and after that year.

Despite clearly changing rationales for mangal restoration, the explicit objectives of such restoration projects have varied little this century (Table 1). I reviewed published records of projects, defined by their authors as mangrove restoration projects, from 1980 through 1999. These results were combined with those of Lewis (1982), which covers the time period from the late 1800s through 1980. Both the peer-reviewed and "grey" literature were surveyed for such projects to minimize sampling bias. Twenty-seven mangrove restoration projects and five general objectives, assigned by the project authors, were identified in this review.

Among these restoration projects, silviculture is the dominant principal objective (10 of 27 projects). Coastal stabilization (6 of 27) and environmental mitigation or remediation (8 of 27) were also common objectives. Only one project identified maintenance or sustainability of fisheries as its primary objective, whereas two identified preservation of "ecosystem function" as their primary objective. Ecosystem functions of mangal were not defined for these projects, however, so assessing the success of these projects is likely to be difficult (see Criteria for Successful Restoration of Mangal, below). Many of these projects had multiple objectives (Table 2), which also can lead to difficulties in their assessments. Although Lewis (1982) called for mangrove restoration projects to move beyond a focus on silviculture, there have been no significant changes in objectives of these projects since 1982 ($\chi^2 = 2.43$; exact $p = 0.79$, G-test). Broad geographic patterns in restoration objectives also are evident (Table 2). The majority of projects, especially those in southeast Asia, continue to emphasize afforestation to generate fuelwood, charcoal, and wood chips for rayon production (Fig. 1). Rather than attempting to restore mangal, these projects explicitly

Table 1. Primary objectives of mangal restoration projects.

	Pre-1982	*Post-1982*	*Total*
Silviculture	6	4	10
Coastal stabilization	4	2	6
Fisheries	0	1	1
Mitigation	5	3	8
Ecosystem function	0	2	2

Data summarized from Lewis (1982), Field (1996a), and other references listed in footnote to Table 2.

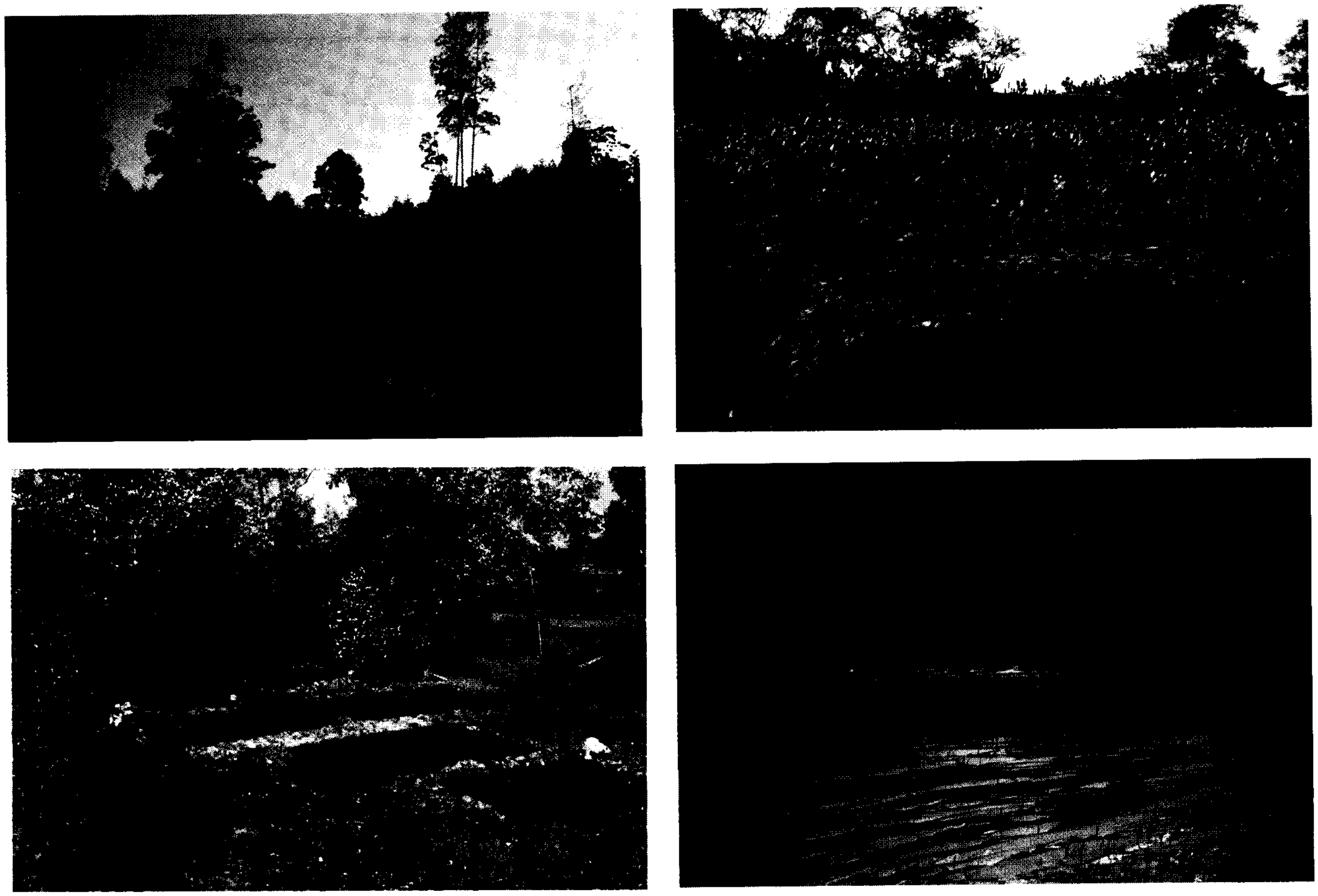

Figure 1. Examples of reforestation, restoration, and recovery of mangal. Top left: A 10- to 15-year-old stand of *Rhizophora apiculata* in Matang, Malaysia. These stands are harvested for charcoal on a 30-year rotation. Top right: A 2-year-old stand of *Bruguiera gymnorrhiza* planted for bank stabilization in the Indian Sundarbans. Bottom left: A mixed planting of mangroves surrounding small fish ponds in the Indian Sundarbans. This multi-culture is maintained by the Indian Forest Service. Bottom right: A naturally regenerating stand of *Avicennia marina* and *Sonneratia alba* in Bako National Park, Sarawak.

seek to establish forest plantations, usually monocultures of *Rhizophora apiculata* or low-diversity polycultures (Table 3) that can be rotationally harvested. Because of the economic importance of mangroves, there is broad expertise available to establish mangrove forest plantations. These forest plantations can be considered to be a first step on the road to a more mature mangal, but this successional sequence will only be realized if the plantations are left unharvested. This model has been used for successful rehabilitation of mangal (*sensu* Field 1998*b*) in Vietnam, where areal spraying of defoliants by the United States during the Vietnam (Second Indochina) War (1962–1971) destroyed >100,000 ha of mangal (Hong & San 1993).

Only mangal restoration projects in the Neotropics have placed a value on ecosystem function, and Neotropical projects are also more likely to value mangal for wildlife protection. These differences may reflect the absence of timberable stands of mangroves in the Caribbean, or a different set of political priorities in the Neotropics engendered by the dominance of the United States in the region.

Similarly, there have been no significant changes in the species richness of trees used in mangal restoration projects since 1982 compared with earlier times, nor is there a difference in the species richness of these projects in the vastly more species-rich Indo-West Pacific mangal relative to that in the relatively species-poor Atlantic, Caribbean, and Eastern Pacific (Fig. 2). Even in the latter biogeographic region, restoration projects rarely use the full complement of available species (4–8, depending on location). Methods for planting individual mangrove species are well known and well developed (reviewed by FAO 1994; Field 1996*a*). Although these methods have remained virtually unchanged since first described by Watson (1928), they are continually rediscovered in field trials conducted worldwide as a prerequisite to restoration efforts (e.g., Getter

Table 2. Geographic distribution of objectives of mangal restoration.

	Number of Projects	Forest Products	Fisheries	Coastal Protection & Stabilization	Waste Treatment	Mitigation	Wildlife Habitat	Ecosystem Function	Source[a]
Southeast Asia									
Indonesia	1	X							1
Vietnam	1	X		X	X		X		2, 3
Malaysia	2	X	X	X					4, 5
Thailand	2	X				X			6, 7
Philippines	2	X		X					8, 9
Australia	1			X					10
Indian subcontinent									
India	1	X	X	X					11
Pakistan	2		X						12, 13
Bangladesh	2	X		X			X		14
Africa									
West Africa	1	X		X					15
Neotropics									
Panama	1					X			16
Columbia	1							X	17
U.S.A.	5						X	X	18–20
Cuba	1	X	X	X					21
Caribbean Is.	3					X	X		22

Sites in Southeast Asia and Australia are grouped within the Indo-West Pacific (IWP) of Figure 2, whereas those in West Africa and the Neotropics are in the Atlantic, Caribbean, and Eastern Pacific (ACEP) of Figure 2.

[a]Sources: 1, Soemodihardjo et al. 1996; 2, Hong 1996; 3, Tri et al. 1998; 4, Chan et al. 1988; 5, Chan 1996; 6, Aksornkoae 1996; 7, Komiyama et al. 1996; 8, Cabahug et al. 1987; 9, Walters 1997; 10, Saenger 1996; 11, Untwale 1996; 12, Qureshi 1990; 13, Qureshi 1996; 14, Siddiqi & Khan 1996; 15, Saenger & Bellan 1995; 16, Duke 1996; 17, Bohorquez 1996; 18, Lewis 1982; 19, Snedaker & Biber 1996; 20, McKee & Faulkner 2000; 21, Padron 1996; 22, Bacon 1993.

et al. 1984; Kogo et al. 1987; Qureshi 1990; Siddiqi et al. 1993). In general, these planting methods focus on only a few species (primarily *Rhizophora apiculata*, *Rhizophora mucronata*, *Avicennia marina*, and *Sonneratia apetala* in the Paleotropics; *Rhizophora mangle* in the Neotropics; Field 1996*a*) and are sufficient for afforestation, not ecosystem restoration. These methods reflect the perception that all mangrove species are functionally equivalent within a mangal managed for forest products (Soemodihardjo et al. 1996) or bank stabilization (Saenger 1996). On a smaller scale, Walters (2000) found that local fisherfolk and fishpond owners also tended to plant monocultures because they were easier to plant and maintain than polycultures found in the same region of the Phillippines.

Mangrove monocultures and low-diversity polycultures suffer from a similar suite of pests in their establishment phase: propagule predation by sesarmid crabs and scolytid beetles, encrustation by barnacles and oysters, and herbivory by snails and macaques (references in Table 2). Furthermore, a growing body of evidence suggests that in the "sustainable" mangrove forestry operation of Matang, Malaysia, now in its third 30-year rotation, productivity has declined by ~50% (Gong & Ong 1995). These data suggest that mangrove forestry alone may not be sustainable.

Tree species richness of mangal restoration projects tends to increase with the number of objectives explicitly asserted (compare Tables 2 & 3). For example, objectives of restoration projects in Vietnam and India include: coastal stabilization (Fig. 1), provisioning of fuelwood and fodder; increase in available habitat for terrestrial and aquatic animals (Fig. 1), support of nearshore fisheries, and stable employment for local populations (Hong 1996; Untwale 1996). Mangal managed for multiple uses can also yield a significantly greater economic return, often an order of magnitude or more, than a similar-sized area mangrove forestry plantation (Thorhaug 1987; Lal 1990; Ruitenbeek 1994; Gilbert & Janssen 1998; Kaly & Jones 1998; Spurgeon 1998; Tri et al. 1998; Nickerson 1999).

Whereas the loss of plant species diversity associated with mangrove plantation creation is recognized (Chan 1996), the changes in animal species diversity in these same plantations remains unstudied. In a mangrove habitat restored by hydrological modification, changes in faunal composition and diversity were detected within 2 years after restoration had begun, but the fish and macrobenthic assemblages had not yet converged on that seen in control sites (Vose & Bell 1994). Similar numbers of species of crabs occurred in undisturbed and planted mangrove stands in Qatar, but only one species of mangrove (*A. marina*) grows there (Al-Khayat & Jones 1999). Because animals in mangal can contribute significantly to mangrove pollination (Tomlinson 1986), regulate primary productivity through herbivory (Onuf et al. 1977; Murphy 1990; Lee 1991; Farnsworth & Ellison 1991, 1993; Feller & Mathis 1997) and nutrient

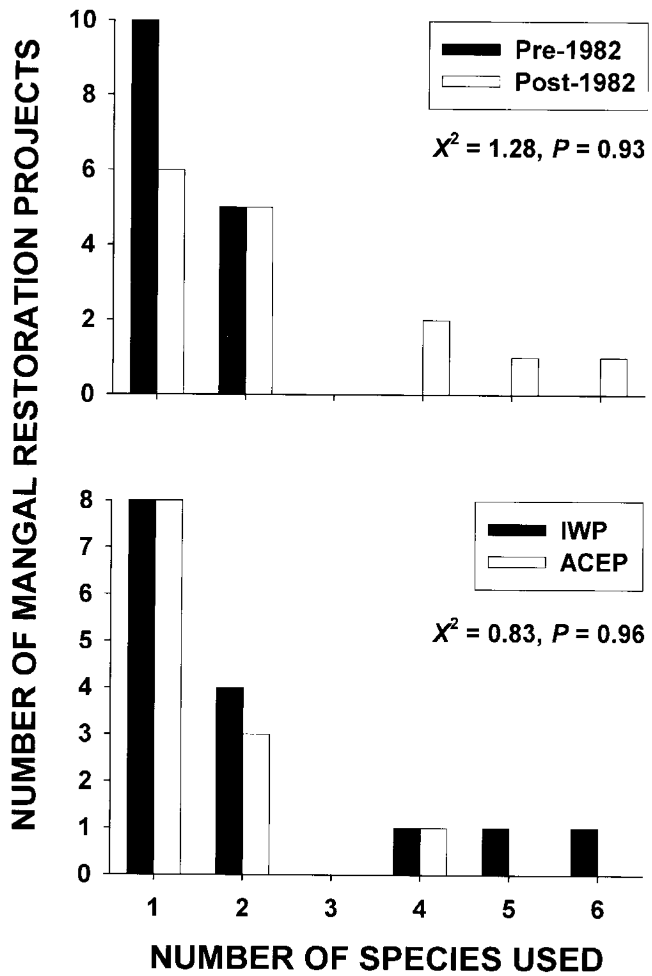

Figure 2. Species richness of mangrove restoration projects. Top: Before versus after 1982. Bottom: Restoration projects carried out in the Indo-West Pacific (IWP, which includes Southeast Asia, Australia, and India) versus in the Atlantic, Caribbean, and Eastern Pacific (ACEP, which includes West Africa, Florida, and the Neotropics).

cycling (Ellison et al. 1996), and control nutrient export through litter processing (Robertson et al. 1992; Lee 1998), it is imperative that mangal restoration projects account for the entire forest ecosystem, not just its trees.

Adequacy of Existing Data

Restoration of mangal, as opposed to a stand of mangroves, requires a more detailed understanding of species-specific physiology and population biology, and knowledge of the interspecific interactions among both plants and animals that determine their patterns of distributions and abundances and system-wide energy flow. As with research in mangrove forestry, extensive research in mangrove ecology has been conducted for decades (reviewed most recently by Robertson & Alongi 1992; Twilley 1995; Alongi 1998; Ellison & Farnsworth 2000; Kathiresan & Bingham 2000), although scant attention is paid to these studies in guidelines for mangal management and restoration (Hamilton & Snedaker 1984; FAO 1994; Field 1996*a*). For example, as noted in the preceding section, significant losses of seedlings of *R. apiculata* in forest plantations result from predation by sesarmid crabs. Smith et al. (1989) showed that propagule predation by crabs in southeast Asia and Australia is density dependent. This result suggests that species mixtures should be less prone to crab predation than monocultures, yet the existence of data on propagule predation has not been integrated into planting recommendations.

A vast number of studies exist on species patterning ("zonation"), salinity and flooding tolerances, and basic autecology of individual mangrove species (reviews in Ellison & Farnsworth 2000; Kathiresan & Bingham 2000). These data could be used much more effectively to guide the spatial placement of different species in restoration projects and could reduce the emphasis on single-species or low-diversity plantings. However, observed species zonation patterns do not represent successional sequences (Lugo 1980). Consequently, assumed successional trajectories based on zonation patterns of unmanaged mangrove forests should not be used as assessment benchmarks in mangrove restoration projects (see Parker 1997; Zedler & Callaway 1999).

Hydrologic patterns determine mangal structure and function at the ecosystem scale (Wolanski et al. 1992). Although every mangal has a different hydrologic regime, commonalities have been recognized for decades (Lugo & Snedaker 1974; Twilley 1995), and general models of mangrove hydrodynamics have been developed (e.g., Wolanski et al. 1992). Mangal restoration projects need to address hydrological modification along with attributes of forest structure (for examples, see Vose & Bell 1994; McKee & Faulkner 2000). Existing data suggest that once appropriate hydrological regimes are in place, mangrove ecosystem development proceeds along relatively smooth, directional trajectories (e.g., Thom 1982; Woodroffe et al. 1989; Colonello & Medina 1998; Lugo 1998; McKee & Faulkner 2000; Twilley et al. 2000). This observation is in notable contrast to the highly variable and nondirectional pathways seen in many other wetland restoration projects (Zedler & Callaway 1999).

Criteria for Successful Restoration of Mangal

General reviews of mangal community ecology (Ellison & Farnsworth 2000; Kathiresan & Bingham 2000) and ecosystem dynamics (Robertson & Alongi 1992; Twilley 1995) provide convincing evidence that adequate data exist to undergird mangal restoration projects. With lit-

Table 3. Number of tree species used and dominant species used in mangrove restoration projects.

	Number of Projects	Species Planted[a]	Number of Species Used	Number of Species Available
Southeast Asia				
Indonesia	1	*R. apiculata; R. mucronata; R. stylosa; B. gymnorrhiza*	4	30
Vietnam	2	*R. apiculata; R. mucronata; R. stylosa; C. decandra; B. gymnorrhiza; N. fruticans*	2, 6	20
Malaysia	2	*R. apiculata; R. mucronata*	1, 2	25
Thailand	2	*R. apiculata*	1	25
Philippines	2	*R. apiculata; R. mucronata*	1	20
Australia	1	*A. marina; Ae. corniculatum*	2	35
Indian subcontinent				
India	1	*A. marina; A. officinalis; S. caseolaris; R. apiculata; R. mucronata*	5	20
Pakistan	2	*A. marina; C. tagal; Ae. corniculatum; R. mucronata*	1	8
Bangladesh	2	*A. officinalis; S. apetala*	1, 2	25
Africa				
West Africa	1	*R. mangle*	1	4
Neotropics				
Panama	1	*R. mangle*	1	5
Columbia	1	*R. mangle*	1	6
U.S.A.	5	*R. mangle*	1	4
Cuba	1	*R. mangle; A. germinans; L. racemosa, Co. erectus*	1–4	5
Caribbean Is.	3	*R. mangle*	1	6

Geographic ordering follows Table 2 (Indo-West Pacific [IWP] = Southeast Asia, Australia, and India; Atlantic, Caribbean, and Eastern Pacific [ACEP] = West Africa and the Neotropics); data from sources given in Table 2. For contrast, I present the number of species available that occur locally in undisturbed mangal (species numbers after Tomlinson 1986).
[a]Genera: *A., Avicennia; Ae., Aegiceras; B., Bruguiera; C., Ceriops; Co., Conocarpus; L., Laguncularia; N., Nypa; R., Rhizophora; S., Sonneratia.*

tle effort, researchers and managers working together could use these data to assemble a set of criteria with which to assess the success of mangal restoration projects. Reviews by Loucks (1992) and Harwell et al. (1999) provide general frameworks for establishing such sets of criteria in restoration projects in any ecosystem. Such a set of criteria requires a benchmark, relatively undamaged system (Fig. 1) through which one can establish, at a minimum, targets for: tree stand structure; tree abundance, species richness, and diversity; invertebrate abundance, species richness, and diversity; primary production (biomass and litter); nutrient export; and hydrologic patterns. To date, few restoration projects in any habitat, and no mangal restoration project have accounted for all of these ecological processes, although most such restoration projects address at least one or two of them. The relative ecological simplicity of mangal makes it an ideal testing ground for general theories of restoration ecology, and lessons learned from these studies could be applied to more complex, upland habitats.

In a similar vein, mangal restoration projects should yield tangible economic benefits to local populations. As with ecological processes in mangal, economic returns from mangal have been enumerated and modeled (e.g., Cabahug et al. 1987; Thorhaug 1987; Lal 1990; Barzetti 1993; Clough 1993; JIAM/ISME 1993; Ruitenbeek 1994; Gilbert & Janssen 1998; Kaly & Jones 1998; Spurgeon 1998; Tri et al. 1998; Twilley et al. 1998; Nickerson 1999; Rivera-Monroy et al. 1999). Restoration of mangal should maximize economic benefits to multiple sectors. By this criterion, as mangrove afforestation projects for silviculture alone do not outperform restoration projects for multiple uses (Nickerson 1999), they should not be considered "successful" restoration efforts.

Restoration or Rehabilitation?

Field (1998*b*) distinguished between rehabilitation of an ecosystem—the partial or full replacement of the ecosystem's structural and functional characteristics—and total restoration of an ecosystem—the act of bringing an ecosystem back to its original condition. In this scheme, restoration is one possible end-point of a successful rehabilitation effort, but there are many others. Afforestation projects that provide forest cover and initiate a successional sequence can be seen as successful rehabilitation projects (Lugo 1992; Parrotta et al. 1997), as can multiple-use systems for high and sustainable yield (Field 1998*b*). Because there is little evidence to support the notion that mangrove silviculture alone can provide high and sustainable yield (Gong & Ong 1995), and because the rapid rotation times of mangrove plantations do not allow for development of structural and functional characteristics of a mature mangal, mangrove silviculture alone does not appear to be a good candidate for either rehabilitation or restoration of mangal. However, the wealth of well-developed techniques for mangrove plantings derived from silvicultural operations lend themselves well to rehabilitation of degraded tropical coastal lands. From Vietnam to South America, low diversity plantings have given way to higher diversity forests, provided the stand is not harvested (e.g., Hong & San 1993; Perdomo et al. 1998; Twilley et al. 2000; but see Walters 2000 for a counter-example).

Lugo (1998) pointed out that the unique hydrologic and edaphic conditions of mangal make it difficult for nonmangrove species to invade tropical coastal estuaries. Consequently, competition between nonmangrove and mangrove species is rarely a problem in mangal restoration, and rehabilitation using a small or large complement of native species should be straightforward. In some cases, removal of mangrove ferns (*Acrostichum* spp.) is necessary because their large (2–3 m) canopy can impede tree seedling establishment (Srivastava et al. 1987), but once established, the mangrove canopy can suppress *Acrostichum* regeneration. The aerial roots of established trees can then entrap floating mangrove propagules, assuring the establishment of a sapling bank (Ellison & Farnsworth 1993; Hong & San 1993; Farnsworth & Ellison 1996). Where there is no mechanism for propagule retention, regeneration of any mangrove vegetation in the absence of human intervention may not occur. This is especially striking in Vietnam, where areas denuded during the Vietnam War and subsequently unplanted remain unvegetated to this day (Hong & San 1993), whereas areas where plantings have been made now support large canopies (Hong & San 1993).

In sum, lessons learned from mangrove forestry programs can be easily applied to mangal rehabilitation efforts. Rehabilitated mangal may, given the chance, develop into mature forests with many of the structural and functional characteristics of mature mangal. In these relatively simple ecological systems, complete restoration is assuredly possible.

Future Directions and Research Needs

Restoration of mangal does not appear to be especially difficult. Planting techniques developed over 70 years ago are effective and yield high establishment rates. Given the correct hydrological conditions, mangroves can grow and thrive in a variety of coastal environments, and within two decades approach the biomass, stand structure, and productivity of "natural" forests (e.g., Colonello & Medina 1998; McKee & Faulkner 2000; Twilley et al. 2000). Although it can be difficult to restore hydrological conditions in isolated, inland wetlands, it is more straightforward to restore tidal fluctuations and flushing to impounded coastal systems where mangroves could subsequently flourish (but see Zedler & Callaway [1999] for a contrasting scenario in a temperate salt marsh). Removal of impoundments and barriers is technically feasible, but may be constrained by political, social, or economic goals (such as coastal housing developments).

More importantly, it is imperative that individuals and organizations that undertake mangal restoration projects have a clear set of goals in mind, and match the implementation of their restoration project to the goals. Experience to date (summarized in Tables 1–3; Fig. 2) suggests that despite the oft-expressed goals of restoring diverse and sustainable mangrove ecosystems, the implementation routinely focuses on low-diversity forestry or, at best, coastal stabilization programs. Given enough time, these projects may develop into more mature mangal, but management for timber products will not normally allow for this development. Sociopolitical and economic constraints to further mangal restoration may be ameliorated by incorporating multiple stake holders in the planning process (e.g., Franks & Falconer 1999; Nickerson 1999) and by focusing on restoration and management programs that have multiple uses and serve multiple constituencies (Farnsworth 1998; Spurgeon 1998).

Mangal restorationists and managers, who normally work in isolated conditions in developing countries, must collaborate with each other and have access to current data and evolving concepts in mangrove ecology to improve mangal restoration programs. This idea is not new; reports issued since the early 1970s have repeatedly called for international databases, mangrove information clearing houses, and improved communication among basic researchers, managers, planters, and residents (UNESCO 1979; JIAM/ISME 1993; Field 1996*b*). The potential of the world wide web, increasingly accessible via low-technology means such as cable television, affords new hope for better communication and information sharing among parties involved in mangal restoration. Such a mangrove web would at the very least minimize the repeated rediscovery of planting methods, virtually unchanged since Watson (1928) first described them, on a project-by-project basis (Field 1996*a*, 1996*b*).

In much of the "North," restoration, mitigation, or remediation is now required whenever wetlands are disturbed or damaged as a consequence of development. It is imperative that in the "South," home to virtually all of the world's mangal, that coastal development not proceed without conscious attention to restoration. Information, expertise, and technology exist to guide and support the restoration of mangal wherever the political will exists.

Acknowledgments

Portions of this manuscript were presented at the symposium on restoring mangrove ecosystems held during the SER/IITF meeting on "Tropical Restoration for the New Millennium." I thank Jess Zimmermann for the invitation to present this paper and organize the symposium, and the other participants in the symposium—Zakir Hussain, Daniel Imbert, Karen McKee, Robert Twilley, and Brad Walters—for helpful discussions. The late Bill Niering encouraged us to develop these papers as a special feature for *Restoration Ecology.* During the last 12 years, my research on mangroves has been supported by the Center for Field Research (Earthwatch), the Smithsonian Institution, Swarthmore College, Mount Holyoke College, and the U.S. National Science Foundation. Elizabeth Farnsworth, a constant collaborator in all of these studies, critically reviewed an early draft of this paper.

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