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Minireview

Restoration and management of mangrove systems — a lesson for and from the East African region

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The restoration of mangroves has received a lot of attention world wide for several reasons. Firstly, the long ignored ecological and environmental values of mangrove forests have been documented for many mangrove areas in the world. Secondly, there is a high subsistence dependence on natural resources from mangrove forests. In addition, large losses of mangroves have occurred throughout the world leading to coastal erosion, decline of fishery resources and other environmental consequences, some of which in need of urgent attention. Finally, governments throughout the world are showing commitments towards sustainable use of mangrove areas. This paper outlines the activities of mangrove restoration and management around the world with particular emphasis on Eastern Africa. As noted here, extensive research has been carried out on the ecology, structure and functioning of the mangrove ecosystem. However, the findings have not been interpreted in a management framework, thus mangrove forests around the world continue to be over-exploited, converted to aquaculture ponds, and polluted. We strongly argue that links between research and sustainable management of mangrove ecosystems should be established.

Introduction

Webster's English dictionary (1998) defines restoration as 'an act of putting or bringing back into a former, normal, or unimpaired state or condition'. In terms of ecology, restoration will seldom mean returning an ecosystem to its initial state but will more often mean bringing it back to a state of effectiveness. A practical definition of restoration is given by Morrison (1990): 'Restoration is the re-introduction and re-establishment of community-like groupings of native species to sites which can reasonably be expected to sustain them, with the resultant vegetation demonstrating aesthetic and dynamic characteristics of the natural communities on which they are based.' Field (1998b) distinguished between rehabilitation — 'the partial or full replacement of the ecosystem's structural and functional characteristics', and restoration — 'the act of bringing an ecosystem back to its original condition'.

The need to restore a particular ecosystem implies that such an ecosystem has been altered or degraded in a way that conflicts with the defined management or conservation objectives. Before a restoration project is undertaken it is essential that goals be defined. Restoration goals and objectives may vary from region to region. The primary goal of many wetland restoration projects is the re-establishment of habitat and functions that have been or would otherwise be lost (Morrison 1990). Other objectives are: landscape enhancement, sustainable production of natural resources and protection of coastal areas (Field 1996). Restoration provides an opportunity to improve or enhance the landscape and increase environmental quality. It is particularly useful in densely populated areas or in areas of industrial development where rehabilitation can enhance the environment even if no tangible benefit may be obtained from such an exercise. In these cases, the goal of restoration will be to preserve, enhance or maintain the original functioning of the system (Morrison 1990), or, at least, its conjectured original functioning.

Global conservation status of mangroves

Mangrove ecosystems or 'mangals' (MacNae 1968) occur world wide on tropical and sub-tropical coastlines (Chapman 1976, Tomlinson 1986). For centuries, mangrove ecosystems have provided goods and services both on the community, as well as national and global levels (Hamilton and Snedaker 1984, Stafford-Deitsch 1996, Dahdouh-Guebas *et al.* 2000, Kairo and Kivyatu 2000, Dahdouh-Guebas and Koedam 2001). Many of these services are still offered and include collection of building materials and fuel-wood, gathering of shells to produce lime and wild honey collection (Table 1). Mangroves also filter land run-off (Thom 1967) and control coastal erosion (Davis 1940).

Mangrove forests have been estimated to have occupied 75% of the tropical coasts world wide (McGill 1959, Chapman 1976), but anthropogenic pressures have reduced the global range of these forests to less than 50% of the original total cover (Saenger *et al.* 1983, WCMC 1994, Spalding *et al.* 1997). These losses have largely been attributed to anthropogenic pressures such as over-harvesting for timber and fuel-wood production (Walsh 1974, Hussein 1995, Semesi 1998), reclamation for aquaculture and salt-pond construction (Terchunian *et al.* 1986, Primavera 1994), mining, pollution and damming of rivers that alter water salinity levels (Lewis 1990, Wolanski 1992). Oil spills have impacted mangroves dramatically in the Caribbean (Ellison and Farnsworth 1996), but little documentation exists for other parts of the world (Burns *et al.* 1994).

A major threat to mangrove wetlands is their conversion to areas of aquaculture. After the development of intensive shrimp farming techniques in Taiwan in the 1970's, there was a sudden rush into modern shrimp farming in Southeast Asia (Phillips 1994), spreading to the Caribbean and Latin America (Ellison and Farnsworth 1996b). In the Indo-Western Pacific region alone, 1.2 million hectares of mangroves had been converted to aquaculture ponds by 1991 (Primavera 1995).

In eastern Africa, there are no up-to-date data available to give accurate pictures of the current condition of its mangrove forests. However, various reports (e.g. Semesi 1991, Semesi 1998, Kairo 1992, Ferguson 1993, Dahdouh-Guebas *et al*. 2000) have indicated that extensive bare lands resulting from indiscriminate cutting of the trees occur all over the region.

Travelling along the mangroves of the region, between 2°S and 27°S, one sees many examples of exploitation that have ended in disaster. For instance, there are clear cut mangrove areas at Gazi Bay (Kenya) that will never recover naturally without human intervention. In Tanga (Tanzania) and Ngomeni (Kenya), salt work ventures have created wastelands. In addition, urban and coastal development (e.g. in the Zambezi district of Mozambique) have removed large areas of mangrove forests, devastating far more land than was actually required, and therefore affecting the lives of subsistence coastal dwellers quite unnecessarily (Semesi 1998, Dahdouh-Guebas *et al*. 2000, Kairo 2001).

Shrimp farming represents a relatively new form of coastal land use that is becoming a threat in the region. Semesi (1998) cites a proposal to convert 10 000ha of the riverine mangroves of Rufiji (Tanzania) for shrimp farming. Understanding very well the ecological, social and environmental problems that are associated with industrial shrimp farming (e.g. Martosubroto and Naamin 1977, Kapetsky 1987, Baird and Quarto 1994), such a proposed conversion must be considered with a lot of precautions. The construction of shrimp ponds would result in the exposure of strongly reducing, acid-sulphate, soils and a build up of salinity levels, such that the subsequent replanting of mangroves in eventually abandoned ponds is difficult or even impossible (Stevenson *et al.* 1999, Erftemeijer and Lewis 2000).

History of mangrove restoration and management

Mangrove planting and management has a long history in Southeast Asia (e.g. Watson 1928). Perhaps the longest recorded history of mangrove management for timber is in the Sundarbans. The 6 000km^2 of mangrove forests that cover the Sundarbans region of India and Bangladesh, were managed since 1769 and detailed work-plans prepared in 1893–1894 (Chowdhury and Ahmed 1994). A parallel example is given by the 40 000ha mangroves of Matang (Malaysia) that have been managed for fuel-wood production since 1902 (Watson 1928). The operation provides significant employment to the local people, and the use of mangrove wood products for timber and charcoal makes a significant contribution to the economy of the west coast Peninsular Malaysia (Chan 1996). Matang also provides protection against coastal erosion, breeding grounds for fish, fish stakes, firewood and building materials.

More recently mangroves have been managed for integrated fish culture (Primavera 1995) and for eco-tourism (Bacon 1987). Planting mangroves has also been applied for erosion control in Florida (Teas 1977), and for experimental analysis of mangrove biology in Panama and Kenya (Rabinowitz 1978, Kairo 1995a). Beginning with the realisation of ecological roles of mangroves (Odum and Heald 1975) and the passage of laws protecting them from destruction, many small plantings for mitigating environmental damage have occurred for example in Hawaii, Burma and Fiji (Hamilton and Snedaker 1984). Mangroves have also been planted to restore a forest killed as a result of an oil spill (Duke 1995).

In East Africa, information on earlier mangrove plantation practices is scanty. Reference is made to mangrove planting in Lamu, Kenya, after the trees were clear-felled during the First World War (1914–1918) by Smith and McKenzie

Table 1: Valuation of mangroves

Community level	National level	Global level
Timber and firewood	Timber production	Conservation
Fodder for animals	Charcoal production	Education
Traditional medicine	Shrimp and crab industries	Preservation of biodiversity
Food	Mangrove silviculture	Indicator of climate change
Local employment	Trade	
Recreation	Ecotourism	
Shell collection	Education	
Erosion control	Water quality management	
Protection from storm damage	Coastal and estuary protection	

(*Sources*: Hamilton and Snedaker 1984, Stafford-Deitsch 1996, Dahdouh-Guebas et al. 2000, Kairo 2001)

Company (Rawlins 1957, Roberts and Ruara 1967). In Tanzania, attempts to replant mangroves in the abandoned saltpans of Tanga district failed probably because of environmental factors (e.g. soil salinity and acidification) as well as poor species selection (Semesi and Howell 1992).

A review of the available literature on mangrove plantation establishments shows mixed successes of restoration efforts (Ellison 2000), even though it has been said that mangrove wetlands are easy to restore and create (e.g. FAO 1994). Whereas the lost mangrove plant species can be returned (Kairo 1995a), a restored forest may or may not function as the original pre-disturbed system (McKee and Faulkner 2000, Bosire 1999, Bosire *et al*. submitted a, b). This is especially true where there is no natural model, simple or complex, on which to base the recreated mangrove stand (Field 1998a, Dahdouh-Guebas 2001). If a mangrove forest is disturbed by logging it is unlikely that the forest will regenerate to function as the pre-disturbed state, since the species mix, soil type, stocking rates and numbers of animals will certainly have changed.

Factors affecting restoration success

It was note above that mangrove forests are threatened ecosystems. The reasons for their destruction range from human induced stresses such as over-exploitation of the resources, land reclamation for fish farming and pollution effects (cited above). Mangroves have also died because of natural disasters (Jimenez 1985). Frequently the mangrove stands are permanently destroyed, but under some conditions the forests regenerate or can be restored. In very rare cases, new areas can also be created for mangrove growth (Saenger and Siddique 1993). When contemplating mangrove rehabilitation, special attention must be paid to soil stability and flooding regime (Pulver 1976), site elevation (Hoffman *et al*. 1985), salinity and fresh water runoff (Jeminez 1990), tidal and wave energy (Lewis 1992, Field 1996), propagule availability (Loyche 1989, Kairo 1995a, 2001), propagule predation (Dahdouh-Guebas *et al.* 1997, 1998, Dahdouh-Guebas 2001), spacing and thinning of mangroves (FAO 1985, Kairo 2001), weed eradication (Saenger and Siddique 1993), nursery techniques (Siddique *et al*. 1993), monitoring (Lewis 1990), community participation (Kairo 1995b) and total cost of restoration measures (Field 1998a).

It is difficult to generalise planting sites for successful mangrove restoration, as this will depend on local environmental conditions and the species to be planted. It is generally agreed that the hydrologic regime is the single most important overall site condition governing the survival and subsequent growth of the mangrove seedlings (Field 1996, 1998b). It is important that mangrove plantings be carried out on low energy areas where coastal erosion is minimal (Kairo 1995a).

Knowledge of mangrove species zonation is essential in determining suitable areas for different species. Rabinowitz (1978), while commenting on the distribution patterns of mangroves, noted that species zonation in mangroves was as a result of environmental tolerance and physiological preferences of the individual species. Each species of mangrove has a specific range of tolerance of environmental variables (e.g. salinities, tidal flooding, shading, elevation of the land etc.) that restricts it to the zones in which it preferably resides. For example *Sonneratia alba* Sm. will occur on the seaward fringe because it cannot tolerate wide fluctuations in salt concentrations, while *Ceriops tagal* (Perr.) C. B. Robinson and *Avicennia marina* (Forsk.) Vierh. can tolerate high salinity levels found on the landward side of the intertidal areas. For this reason, *Sonneratia* should be planted in low, muddy areas closer to the sea. In the marginal dry landward side, species like *Ceriops* and *Avicennia* may be planted (Kairo 1995a, Kairo 2001).

Another essential factor in determining the success of a restoration project is the level of co-operation of the local community and their leaders. The pressure of the local population will influence the structure and functions of mangrove systems that surrounds them (Kairo 1995b, Dahdouh-Guebas *et al*. 2000). Environmental education can contribute to active involvement and greater public participation in issues related to mangrove conservation and management. When management decisions incorporate local inputs they will succeed, and political support will be greater when the public is satisfied that it has been heard and had an opportunity to become involved.

Two approaches have been used in the restoration of degraded mangrove areas. These are natural and artificial regeneration.

Natural generation

This approach uses naturally occurring mangrove propagules as the source for regeneration. The composition of the regenerated species depends on the species mix of the neighbouring population. In the family Rhizophoraceae, propagules furnished with pointed hypocotyls fall freely from the parent and plant themselves into the mud (La Rue and Muzik 1954), or they may be stranded and planted away from the parent plant (Rabinowitz 1978, Van Speybroeck 1992). Whether mangroves disperse through *self-planting* or *stranding* strategies will depend on the forest conditions (cut or not cut), tides, as well as the stability of the soils. Harvesting too many trees from the forest diminishes stability of the soil, which causes the propagules and saplings to be washed away with the tides and makes natural regeneration impossible.

In Malaysia, a country with a long history of mangrove management, it is recommended that parental mangrove trees (standards) be retained during harvesting operation to act as seed bearers for the next generation in order to promote natural regeneration. The minimum number of standards is 12 trees/ha (Tang 1978, FAO 1994) and these should be strategically retained in those areas that are poor in regeneration. In Thailand, the use of standards has been replaced by a strip clear-felling system which has been found to allow adequate regeneration (FAO 1985). The pros and cons of natural regeneration versus artificial regeneration are listed in Table 2.

Artificial Regeneration

Artificial regeneration of mangroves involves hand planting of desired propagules and saplings at the selected intertidal area. Planting of mangroves has successfully been done in Malaysia, India, Philippines and Vietnam (*cited above*). Most planting work has been done using the families Rhizophoraceae, Aviceniaceae and Sonneratiaceae.

Techniques in artificial regeneration include most commonly the use of propagules, sometimes the use of saplings (of less than 1.2m high), and rarely the use of small trees (of up to 6m high). Although these methods have remained virtually unchanged since Watson (1928), they are continuously being rediscovered world wide as the prerequisite to restoration efforts (Kogo *et al*. 1987, Qureshi 1990, Siddique *et al*. 1993, Kairo 1995a, SFFL 1997).

It is important to organise mangrove planting when propagules are in-season. Mature mangrove propagules are collected from the mother tree or litter under trees or rank on beaches. A distinct cotyledonary color in the hypocotyls of *Rhizophora* and *Ceriops* species differentiate young propagules from mature ones. In *Avicennia* species, mature propagules separate from the parent with a slight hand twist without the calyx (Kairo 1995a).

After field collection, propagules are kept in moist plastic bags for not more than three days, under natural shade, to protect them from direct sunlight. This process is known to allow seasoning of propagules, thus lowering their palatability to sesarmid crabs (Watson 1928, Kairo 1995a, Dahdouh-Guebas *et al.* 1997). Other methods of protecting propagules from crab predation are painting hypocotyls with yellow paint or placing them inside bamboo during planting (FAO 1994). Our experience in Kenya shows that as long as the moisture content is maintained, it is possible to store mangrove propagules for even six months (Kairo, personal observation). In a mangrove predation experiment, Dahdouh-Guebas *et al.* 1997) showed that, freshly collected *Rhizophora* and *Ceriops* propagules were more predated upon than those stored for eight weeks prior to planting.

Transplant saplings are collected either from the nurseries or scooped from the natural forest (wildings). It is important to protect the roots when collecting and planting saplings. This is normally achieved by scooping the saplings with root-ball diameter half the height of the sapling (Kairo 1995a).

In a mangrove plantation experiment in Kenya, Kairo (1995b) found that the survival of the transplanted saplings or propagules was better (80–100% of 70 000 after 24 months) than for transplanted small trees (<5% after 12 months). Planting of nursery saplings gave a higher survival rate (80–100% after 24 months) compared to transplanting of wildings.

Other techniques have used aerial planting with *Rhizophora* propagules (Teas *et al*. 1976) and air-layering of *Rhizophora mangle* L., *Avicennia germinans* (L.) Stearn and *Laguncularia racemosa* Gaertn.f. (Calton and Moffler 1978).

Kairo (1995a) reported the potential of the air-layering technology in providing stock plants for transplanting without removing mangrove saplings from source area. There was a significant difference (p<0.001) in rooting success between *Sonneratia alba* (58.8%), *Lumnitzera racemosa* Willd. (36.5%) and *Xylocarpus granatum* Koenig (4.4%).

There are several advantages of using artificial regeneration: the species composition and distribution can be controlled, genetically improved stocks could be introduced and pest infestation can be controlled (Field 1998a).

Table 2: Advantages and disadvantages of natural regeneration

Advantages:
– cheaper to establish, – less subsidy is needed in terms of labour and machinery, – less soil disturbance, – saplings establish more vigorously, – origin of seed sources usually known.
Disadvantages:
– replacement may not be of the same species removed, – absence of mother trees may result in low/or no propagules supply, – genetically improved stock not easily introduced, – excessive wave action may cause poor establishment, – predation of propagules by macrobenthos (e.g. crabs, snails etc), – less control over spacing, initial stocking and composition of seedlings.

Monitoring of restored areas

Once the restoration programs have been completed, it is essential to monitor recovery processes (or lack thereof) of the plots. A summary of parameters to be monitored in a restoration project is given in Table 3. These are similar activities that would normally be taken in any forestry project.

In a restored mangrove forest in Kenya, significant differences in faunal composition and diversity were observed five years after planting (Bosire 1999, Bosire *et al*. subm. (b) in review). The density of soil-infauna taxa was significantly higher ($\chi^2_{(0.05,1df)} = 81$, p = 0.0000) in the restored system than in naked (cleared) system; and there was no significant difference ($\chi^2_{(0.05,1df)} = 2.67$, p = 0.102) in the density of soil in-fauna taxa between the restored and the natural systems (Figure 1). Though crab density was higher in the reforested areas, there was no difference in diversity of crabs between the reforested, the naked and the natural systems (Bosire *et al.* submitted b).

Conclusions

In the East African region, the major obstacles that have hitherto prevented rational uses of mangrove forests have been: the sectorial approach of mangrove resource management, lack of community inputs into management efforts, the poverty status of many indigenous coastal communities, and a lack of awareness amongst decision makers about the true values of mangroves (Semesi 1992, 1998, Kairo 2001). These management problems are compounded by inadequate knowledge of silviculture of mangroves, of multiple-use potentials of resources, and of the techniques of natural regeneration and reforestation. Apart from plantation experiments for the rehabilitation of deforested mangrove areas in Kenya (Kairo 1995a, 1995b, 2001), little effort has been made to restore degraded mangrove systems in the region.

Mangrove restoration has a big potential to increase the mangrove resources, provide employment to local population, protect fragile tropical coastlines and perhaps also to enhance biodiversity and fisheries productivity. Mangrove afforestation is proceeding at a large scale in Bangladesh, India and Vietnam principally to provide protection in typhoon-prone areas as well as to generate economic benefits to the poor coastal communities (e.g. Saenger and Siddique 1993). Artificial planting of mangroves in Asia and Pacific is promising to solve the problems of limited supply of mangrove wood products as well as maintaining the overall balance of the coastal ecosystems (FAO 1985). Although

Table 3: Activities to be monitored after the establishment of mangrove plantation (Field 1998b)

Activities	Remarks
Monitor mangrove species that develop	Check correctness of original provenance of propagules and seed
Monitor growth as a function of time	Common parameters are: density of saplings or trees, stem diameter, tree height and volume Annual increments should be determined
Monitor growth characteristics	Include determination of stem structure, node production, phenology, fruiting and resistance to pests
Record level of failure of saplings	Provide a scientific explanation of failure
Record levels of rubbish accumulation	Note source of rubbish and steps taken to minimise the problem
Adjust density of seedlings and saplings to an optimum level	Degree of thinning, replanting or natural regeneration should be noted. Growth should be monitored
Estimate cost of restoration project	The estimation of costs should include all the undertakings including site preparation, propagule collection, nursery establishment, field transplantation etc
Monitor impact of any harvesting project	This should be part of any long-term record for restoration
Monitor characteristics of the rehabilitated mangrove ecosystem	This involves detailed measurement of fauna, flora and physical environment of the new mangrove ecosystem and comparison with similar undisturbed mangrove ecosystems

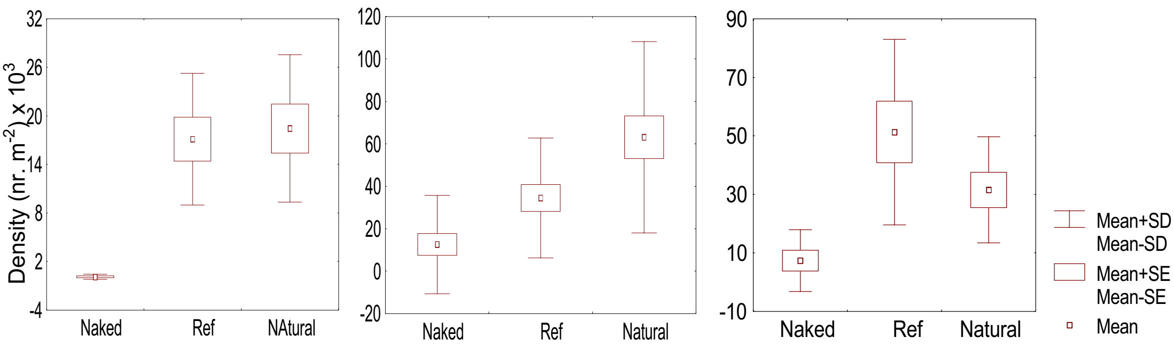

Figure 1: The density (nr. of animals m^{-2}) of sediment-infauna in a naked (cleared) system, a restored system and a natural system. left = *R. mucronata*, middle **=** *S. alba* and right = *A. marina* stands (adapted from Bosire 1999 and Bosire *et al.* subm.b)

plantation productivity has been shown to decline over many decades (e.g. Gong and Ong 1990, 1995), given the chance, restored mangroves may develop into mature forests with many of the structural and functional characteristics of mature mangrove system. In Vietnam for example, low diversity planting has given way to higher diversity forests, provided the reforested area is not harvested (Twilley *et al.* 2000).

The relationship between mangrove and fishery productivity has been documented for many areas (e.g. Lewis *et al.* 1985, Twilley *et al.* 1993, Primavera 1995, Ellison and Farnsworth 1996b, Baran and Hambrey 1988, Baran 1999, Naylor *et al.* 2000). It is routine to hear that fish and shrimps decline where mangroves have been removed (Martosubroto and Naamin 1977). Similar losses are asserted where mangroves are cleared for aquaculture, but quantification for these losses are scarce. Folke and Kautsky (1998) have used the ecological foot print concept (Wackernagel and Rees 1996) to quantify the ecosystem support area that is required to support shrimp farming in mangroves. From these calculations they suggest that a semi-intensive shrimp farm requires a mangrove area that is 35–190 times larger than the surface area of the pond. Clearly, integrated management of mangrove forestry and fisheries is urgently required. In East Africa, where the aquaculture and mariculture operations are just beginning (*cited above*), there are real opportunities to develop mangrove-friendly aquaculture that may be truly sustainable.

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