In review, Proceedings of the Mangrove Valuation Workshop, Universiti Sains Malaysia, Penang, 4-8 April, 2001. Beijer International Institute of Ecological Economics, Stockholm, Sweden.

Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration

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ABSTRACT

Mangrove Restoration - costs and measures of successful ecological restoration. Roy R. "Robin" Lewis III, President, Lewis Environmental Services, Inc. P.O. Box 5430, Salt Springs, Florida, USA, 32134-5430.

The costs to successfully restore both the vegetative cover and ecological functions of a mangrove forest have been reported to range from USD$225/ha to USD$216,000/ha. Unpublished data would indicate that the even higher costs, as much as USD$500,000/ha, has been spent on individual projects. These are obviously cost prohibitive amounts for most countries seeking to restore damaged mangroves. I divide the types of mangrove restoration projects into three categories: (1) planting alone, (2) hydrologic restoration, with and without planting, and (3) excavation or fill, with and without planting. The first type, planting only, although inexpensive (e.g.: USD$100-200/ha) usually does not succeed due to a failure to appreciate the physiological tolerances of mangroves to tidal inundation. Even if it works, the result is often replacement of one productive marine habitat, like seagrass meadows with mangroves, a questionable trade-off. The second type, hydrologic restoration, can be done for similar costs, and with proper planning has a high success rate. Successful restoration of abandoned shrimp aquaculture ponds is an example of this method. Planting should only be done if natural recolonization fails, and can double the cost of a project. Scientific data indicates that using this method, ecological functions are quickly restored, with fish populations typically reaching reference site diversity and densities within 5 years. The third type, excavation and fill, is the most

expensive due to the high costs of large scale earthmoving. It is only a viable option in more developed countries, and may not be a cost-effective means of restoration except under limited circumstances.

1. Introduction

Restoration of existing areas of damaged, routinely harvested or destroyed mangrove forests have been recently estimated to cost between USD$3,000/ha and USD$510,000/ha (Spurgeon 1998). Unfortunately these estimates are primarily derived from a single secondary source and are referred to as "…costs for planting mangroves…" (page 374 in Spurgeon 1998)(emphasis added). As noted by Turner and Lewis (1997) and Lewis (1999), hydrologic restoration without planting is often preferred as planting of mangroves often fails due to what Lewis and Marshall (1998) refer to as the "gardening" approach to mangrove restoration. This approach emphasizes planting of mangroves without first investigating the reason why mangroves are not present in the first place. This can be the most expensive approach to restoration since any investment is wasted when planted seeds or seedlings fail to survive. Natural recolonization of areas with restored hydrology, such as reconnected abandoned shrimp aquaculture ponds, occurs quite rapidly if mangrove forests are present in the vicinity and natural production of propagules is sufficient (Stevenson et al. 1999).

In consulting the original literature on mangrove restoration (Watson 1928, Noakes 1951, Chapman 1976, Lewis 1982, Hamilton and Snedaker 1984, Lewis 1990a, Lewis 1990b, Crewz and Lewis 1991, Cintron-Molero 1992, Saenger and Siddiqi 1993, Siddiqi et al. 1993, Field 1996, Lewis 1999 and Lewis and Streever 2000) one finds few discussions of the costs of restoration. Because of this historical lack of data on cost effective restoration, and "lessons learned", many myths about mangrove restoration persist. The tiny two page paper entitled "Mangrove mythology" (Snedaker 1987) is one of the few classics in "myth busting." In it, Jane Snedaker proposes a true or false test with five questions. These are:

1. Mangroves require salt water to develop and grow.
2. Mangroves extend shorelines.
3. Mangroves build up land.
4. The red mangrove [*Rhizophora* spp.] is the most valuable species.
5. Some mangrove forest types are more important than others.

How would you answer? In fact, all are common myths, and all are false!

Much of what is "known" about mangroves and in particular mangrove restoration, is based upon such myths. It is not surprising then that attempts to restore mangroves often fail to achieve the stated goals or fail completely. Similar myths about the value, both intrinsic and of direct impact to economic activities of man still persist. As recently as March 30, 2000, the Jakarta Post reported that 80,000 ha of "wasteland" (actually mangroves) had been converted to the "..worlds largest integrated shrimp farm…" at Lampang, Sumatra (front page).

We will attempt to shed some light on additional myths mangroves and discuss the real costs and benefits of mangrove restoration, and how to minimize the first while maximizing the second. As noted by Spurgeon (1998)

> If coastal habitat rehabilitation/creation is to be widely implemented, greater attempts should be made to find ways of reducing the overall costs of such initiatives; devise means of increasing the rate at which benefits accrue; and to identify mechanisms for appropriating the environmental benefits (p. 382).

2. Why restore?

Mangrove forests are coastal plant communities that are part of a larger coastal ecosystem that typically includes mud flats, seagrass meadows, tidal marshes, salt barrens and even coastal upland forests and freshwater wetlands (i.e. peatlands), freshwater streams and rivers. In more tropical climates coral reefs may also be part of this ecosystem. They are critical habitat for many species of fish and wildlife, serve as coastal fish and shellfish nursery habitat, and produce large quantities of leaf material that becomes the basis for a detritus food web (Hamilton and Snedaker 1984, Lewis et al*.* 1985). Once established, they can serve as coastal protection from hurricanes and typhoons, and riverine mangroves help remove pollutants before they enter adjacent coastal waters. In spite of these documented ecological functions, mangrove forests have been dredged and filled for decades to provide other coastal uses, like ports and housing.

It is estimated that there are 181,399 sq km of mangrove forests in the world (Spalding 1997) and major historical losses have occurred. In the Philippines the losses are estimated at 60%, Thailand 55%, Viet Nam 37% and Malaysia 12%. The total area lost in just these four countries is estimated at 7,445 sq km. Anecdotal estimates are that up to 50% of all mangroves that historically existed may have been lost to date and that current rates of loss may be as high as 1% per year.

In the United States, where much of the pioneering work on wetland restoration technology has been done (see Lewis and Streever, 2000) mangroves naturally occur in three states, Florida, Louisiana and Texas. They have been introduced in Hawaii, but probably never naturally occurred there. They are also present in the U. S. Virgin Islands, Puerto Rico and several Pacific Ocean territories.

The largest forests are in Florida, where approximately 200,000 ha remain from an estimated historical cover of 260,000 ha (Lewis et al. 1985). These forests contain three species, the red mangrove (*Rhizophora mangle*), the black mangrove (*Avicennia germinans*) and the white mangrove (*Laguncularia racemosa*). The buttonwood (*Conocarpus erectus*) is a transition zone species. In Texas, only 2,000 ha exist (Moulton et al. 1997). Louisiana mangroves are very limited, with only several hundred hectares of the cold tolerant black mangrove located around Grand Isle. Puerto Rico has just 6,410 ha of mangrove remaining from an original mangrove forest cover estimated to have been 24,310 ha (Martinez et al. 1979). 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 back to functional mangrove ecosystems (Brockmeyer et al*.* 1997). These opportunities, and a growing interest in wetland restoration, combined with strong legal requirements to replace any wetlands lost to permitted development activities have created a heightened interest in cost effective mangrove restoration.

3. Key terms and principles

Restoration or rehabilitation may be recommended when a system has been altered to such an extent that it can no longer self-correct or self-renew. Under such conditions, ecosystem homeostasis has been permanently stopped and the normal processes of secondary succession (Clements 1928) or natural recovery from damage are inhibited in some way. This concept has not been analyzed or discussed with any great detail in mangrove forests (Detweiler et al. 1976, Ball 1980, Lewis 1982 are the few exceptions) and thus restoration management has, unfortunately, emphasized planting of mangroves 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 that all ecosystems have.

Even the use of different terms and confusion in their meaning also adds to the difficulty in determining which of these projects actually succeeded in restoring a previously existing mangrove forest (ecological restoration) or converting a natural mudflat into mangroves (habitat substitution as described in Erftemeijer and Lewis 2000). For example the terms “replanting” and “reafforestation” are commonly used. “Replanting” would seem to mean planting a second time after an initial “planting”. Similarly, “reafforestation” would seem to mean planting a second time after a first effort at “afforestation”. Afforestation is a widely used term in forestry and refers to planting of trees in areas that have not previously been forested. What would be a better approach? How often are the existing stresses determined before trying to just plant? The answer to this latter question is “all too rarely.”

The term “restoration” has been adopted here to specifically mean any process that aims to return a system to a preexisting condition (whether or not this was pristine) (*sensu* Lewis 1990c and Lewis, this volume), and includes “natural restoration” or “recovery” following basic principles of secondary succession.

Ecological restoration is another important term to include in this discussion and has been defined as "the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems" (Jackson et al. 1995) and differs from simple restoration in having four key steps: (1) judgement of need; (2) an ecological approach; (3) goal setting and objective evaluation of success in meeting those goals and (4) acknowledgement of limitations in our knowledge to complete the process.

Ecological restoration of mangrove forests has only received attention very recently (Lewis 1999). The wide range of types of projects previously considered to be restoration, as outlined in Field (1996), reflect the many aims of classic restoration which may include replanting mangroves for future harvest as wood products. Ecological restoration does not include future exploitation that may degrade, even temporarily, the ecological functions of a mangrove forest. Ecological restoration also includes a view of the proposed plant and animal community to be restored as part of a larger ecosystem with other ecological communities that also have functions to be protected or restored as mentioned above. Salt flats and mud flats, which, despite appearances, do have seasonal wildlife and fisheries values (Lewis 1990a) are particularly vulnerable to characterization as "low value habitats" and have historically been converted to mangroves with the intention of increasing their ecological "value". This increasingly is being questioned as a good ecological management practice (Erftemeijer and Lewis 2000).

It is also important to understand that mangrove forests occur in a wide variety of hydrologic and climatic conditions that result in broad array of mangrove community types (Figure 1). In Florida, Lewis et al. (1985) have identified at least four variations on the original classic mangrove zonation pattern described by Davis (1940), all of which include a tidal marsh component dominated by such species as smooth cordgrass (*Spartina alterniflora*) or saltwort (*Batis maritima*) (Figure 1). Lewis (1982 a, b) describes the role that smooth cordgrass plays as a "nurse species", where it initially establishes on bare soil and facilitates primary or secondary succession to a climax community of predominantly mangroves, but with some remnant of the original tidal marsh species remaining. This has been further generalized by Crewz and Lewis (1991) (Figure 2) as the typical mangrove forest for Florida where tidal marsh components are nearly always present.

Mangrove forests have been rehabilitated to achieve a variety of goals, for instance to meet commercial purposes (silvaculture) (Watson 1928) for restoring fisheries habitat (Lewis 1992, Aksornkoea 1996), for sustainable multiple community use purposes, or for shoreline protection purposes.

It is possible to restore some of the functions of a mangrove, salt flat, or other systems even though parameters such as soil type and condition may have altered and the flora and fauna may have changed (Lewis 1992). If the goal is to return an area to a pristine pre-development condition, then the likelihood of failure is increased. However, the restoration of certain ecosystem traits and the replication of natural functions stand more chance of success (Lewis et al. 1995).

4. Choice of Restoration Techniques

It has been reported that mangrove forests around the world can self-repair or successfully undergo secondary succession over periods of 15-30 years if: 1) the normal tidal hydrology is not disrupted and 2) the availability of waterborne seeds or seedlings (propagules) of mangroves from adjacent stands is not disrupted or blocked (Watson 1928, Lewis 1982, Cintron-Molero 1992).

Because mangrove forests may recover without active restoration efforts, it has been recommended that restoration planning should first look at the potential existence of stresses such as blocked tidal inundation that might prevent secondary succession from occurring, and plan on removing that stress before attempting restoration (Hamilton and Snedaker 1985, Cintron-Molero 1992). The second step is determine by observation if natural seedling recruitment is occurring once the stress has been removed. Only if natural recovery is not occurring should the third step of considering assisting natural recovery through planting be considered.

Unfortunately, many mangrove restoration projects move immediately into planting of mangroves without determining why natural recovery has not occurred. There may even be a large capital investment in growing mangrove seedlings in a nursery before stress factors are assessed. This often results in major failures of planting efforts. For example, Sanyal (1998) has recently reported that between 1989 and 1995 9,050 ha of mangroves were planted in West Bengal, India with only a 1.52% success rate. A similar large scale project in the Philippines is reported to have attempted the restoration of 22,723 ha of mangroves primarily by direct planting on mudflats and in existing seagrass meadows (Silliman University 1996, Lewis 1999, de Leon and White 1999). Plant survival varied from 0 to 66 % in a subsample of planted sites covering 491 ha, averaging 19% in Bohol and 17% in Cebu.

On the other hand, careful data collection by Duke (1996) at an oil spill site in Panama showed that "…densities of natural recruits far exceeded both expected and observed densities of planted seedlings in both sheltered and exposed sites" (emphasis added). Soemodihardjo et al. (1996) report that only 10% of a logged area in Tembilahan, Indonesia (715 ha) needed replanting because "The rest of the logged over area…had more than 2,500 natural seedlings per ha" (emphasis added)

Lewis and Marshall (1997) have suggested five critical steps are necessary to achieve successful mangrove restoration.

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 prevents natural secondary succession
4. Design the restoration program to initially restore the appropriate hydrology and utilize natural volunteer mangrove propagule recruitment for plant establishment
5. Only utilize actual planting of propagules, collected seedlings or cultivated seedlings after determining through Steps 1-4 that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth of saplings established as goals for the restoration project.

These critical steps are often ignored and failure in most restoration projects can be traced to proceeding in the early stages directly to Step 5, without considering Steps 1-4. Lewis and Marshall (1997) refer to this approach as “gardening,” where simply planting mangroves is seen as all that is needed. Another common problem is the failure to understand the natural processes of secondary succession, and the value of utilizing nurse species like smooth cordgrass in situations where wave energy may be a problem. The recently introduced “encased replanting” technique (Riley 1995, Riley *et al.* 1999) for mangroves is an example of technological fix that has not been documented to work in medium to high wave energy sites in spite of the claims. Caution is advised with any “new” mangrove restoration technology that refuses to acknowledge the known and widely published science of mangrove restoration in favor of unproven technology.

The single most important factor in designing a successful mangrove restoration project is determining the normal hydrology (depth, duration and frequency of tidal flooding) of the existing natural mangrove plant communities in the area in which you wish to do restoration. The normal surrogate for costly tidal data gathering or modeling is the use of a tidal bench mark and survey of existing healthy mangroves. When this is done, a diagram similar to that in Figure 2 will result. This then becomes the construction model for your project.

5. Actual Costs of Restoration

Reported costs of mangrove restoration range from USD$ 225-216,000/ha (Teas 1977, Lewis 1981, Brockmeyer et al. 1997, Lewis 1999. These costs do not include the cost of any land purchase to provide a site for restoration. This three orders of magnitude range reflects the increases in cost associated with construction of sites. The higher costs are associated with excavation of fill, or backfilling of an excavated area, to achieve a target restored site with the same general slope, and the exact tidal elevations relative to a benchmark as the reference site, to insure that the hydrology is correct (Lewis 1990a).

Another form of this hydrologic restoration, which is much less expensive, is to reconnect impounded mangroves to normal tidal influence (Turner and Lewis 1997, Brockmeyer et al. 1997). In fact the costs quoted by Brockmeyer are the lowest published costs at USD$225/ha. Figure 3 compares this cost with similar estimates by Lewis (1999), King and Bohlen (1994)(recently updated by King 1998) and Teas (1977). These estimates range over three orders of magnitude! The key differences are: (1) the amount of soil material that needs to be excavated to restore or create the correct hydrology and; (2) the use of natural secondary succession without planting (or modifications such as hand collection and dispersal of seeds or seedlings without planting) versus costly nursery development and hand planting of young seedlings, or worst the use of very expensive 1-2 meter tall older saplings (Teas 1977).

6. Successful Ecological Restoration

Successful ecological restoration requires the successful creation or restoration by construction of tidal creeks and intertidal wetland platforms frequently inundated by tidal waters (Lewis 1999, 2000a, b). This excavation to restore the normal hydrology of the historical tidal creeks will be similar to efforts described in Roberts (1991), Whitman and Gilmore (1993) and Kurz et al. (1998). All three publications document the rapid recruitment to restored or created tidal marshes or mangrove/marsh plant communities in Florida, (the latter two publications concentrating on such projects in Tampa Bay) of 40 species of adult and juvenile fish species including red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), snook (*Centropomus undecimalis*), spot (*Leiostomus xanthurus*), black drum (*Pogonias cromis*) and tarpon (*Megalops atlanticus*).

7. Benefits

Table 1 (modified from Spurgeon 1998) lists valuations of selected mangrove benefits from four sources cited by Spurgeon (1998) (Christiansen 1982, Lal 1990, Ruitenbeek 1992 and

Gammage 1994) plus three additional sources (Nielson et al. 1998; Cabahug et al. 1986, Sathirathai (1998)).

Table 1. Valuation of selected mangrove benefits (modified from Spurgeon 1998)

Benefit	Value (USD$/ha/yr)	Value (USD$/ha/50 yr)	Source	Location
On-site sustainable fisheries	126	6,300	Ruitenbeek (1992)	Irian Jaya
On-site crustacean and mollusc harvests	126	6,300	Nielson (1998)	Vietnam
On-site sustainable harvest, all products	500*	12,500	Cabahug (1986)	Philippines
Fish products	538	26,900	de Leon and While	“
Vicinity fish harvests	1,071**	53,550**	Cabahug (1986)	“
Vicinity shrimp harvests	254**	12,700**	“	“
Vicinity mollusc harvests	675**	33,750**	“	“
Vicinity crab harvests	720**	36,000**	“	“
Off-site fisheries	189	9,500	Christensen (1982)	Asia
Off-site fisheries (managed)	147***	7,350***	Sathirathai (1998)	Thailand
Off-site fisheries (open)	92***	4,600***	Sathirathai (1998)	Thailand
Other products (e.g. fruits, thatch)	435	21,750	“	“
Sustainable forestry	756	37,800	Gammage (1994)	El Salvador
Charcoal	378***	18,900***	Sathirathai (1998)	Thailand
Biodiversity (capturable)	20	1,000	Ruitenbeek (1992)	Irian Jaya
Total direct use value	2,505****	125,250****	Sathirathai (1998)	Thailand
Waste assimilation	7,833	391,600	Lal (1990)	Fiji

* Page 453 in Cabahug (1986)
**Derived from Table 62-III in Cabahug (1986)(p. 455)
*** Assuming a conversion rate of 38 baht/ $USD 1
**** Mean value assuming a conversion rate as above

7. Cost/Benefit Ratios

Barbier (2000) discusses two examples where he estimates the annual benefits of mangrove associated fisheries. The first example is in Surat Thani, Thailand, where the author is working on a large scale (800 ha) mangrove restoration effort to convert abandoned shrimp aquaculture ponds back to there former condition as mangrove forests. Based upon actual costs generated by the Royal Forest Department in doing successful mangrove restoration, these forests can be restored using just hydrologic restoration for USD$200/ha, or USD$700/ha if planted. Planting is not felt to be essential for successful ecological restoration by the author, but is a form of local economic incentive and employment of currently unemployed or under employed residents.

Barbier (2000) estimates that the economic loss to the Gulf of Thailand fisheries due to removal of 1200 ha of mangroves is USD$ 100,000/yr. Restoration of a similar area of currently abandoned shrimp aquaculture ponds back to mangroves would take about three years and cost between USD$ 240,000-840,000. Without factoring in a discount rate, these figures indicate that the cost of restoration would be recovered in restored fisheries values within 2.4-8.4 years, and then would continue to be generated without additional costs in perpetuity.

8. Conclusions

Successful ecological restoration of mangrove forests is feasible, has been done on a large scale in various parts of the world and can be done cost effectively. Rational decisions can be made as to the most cost effective methods to use based upon specific site conditions and goals of a project. The benefits that can be derived from restoring a specific forest area appear, based upon this literature review, to represent a significant positive cost benefit ratio.

Lewis (2000b) however, has pointed out that the failure to adequately train, and retrain coastal managers in the basics of successful coastal habitat restoration all too often leads to projects “destined to fail, or only partially achieve their stated goals.” This would obviously result in a negative cost benefit ratio. He quotes the National Academy of Science of the United States in their report entitled “Restoring and Protecting Marine Habitat - The Role of Engineering and Technology” (National Academy of Science 1994) as stating that “the principle obstacles to wider use of coastal engineering capabilities in habitat protection, enhancement, restoration and creation are the cost and the institutional, regulatory and management barriers to using the best available technologies and practices.”

This lack of training also leads to a routine failure to look for the most cost effective means of achieving restoration goals. Cost effective here means the <u>least cost alternative</u> that achieves both successful restoration, and those target ecological and economically important functions identified as restoration goals.

It is unfortunate that much of the research into mangrove restoration that has been carried out to date has been conducted without adequate site assessment, documentation of the methodologies or approaches used and the real costs of the work. Subsequent follow-up or evaluation for success in achieving these aims is essentially non-existent. Unsuccessful (or only partially successful) projects are rarely documented. A common methodology approach of documentation should be developed for habitat restoration projects. Those involved could then begin to learn from successes and failures, act more effectively, and generate those benefits listed here in a cost effective manner. Once this kind of information reaches a wider target audience, including politicians and other decision makers, the value of preserving existing mangrove forests will be obvious, and hopefully prevent the current large scale need to restore damaged forests in the future. But at least, when restoration is considered, it won't result in unnecessary expenditures of public funds for badly designed and expensive restoration efforts.

The simple application of the five steps to successful mangrove restoration outlined by Lewis and Marshall (1997) would at least insure an analytical thought process and less use of "gardening" of mangroves as the solution to all mangrove restoration problems. Crewz and Lewis (1991) in examining the critical issues in success and failure in tidal marsh and mangrove restoration in Florida found that the hydrology, as created or restored by excavation to the correct tidal elevation, was the single most important element in project success.

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