# REHABILITATION OF COASTAL WETLAND FORESTS DEGRADED THROUGH THEIR CONVERSION TO SHRIMP FARMS

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**Abstract**—International demand for shrimp has stimulated large-scale conversion of mangrove and other coastal wetlands into brackish water aquaculture ponds. Poor site selection, coupled with poor management and over-intensive development of individual sites, has led to nonsustainable production and often, wholesale abandonment of ponds. This has been followed by further conversion of wetlands in an attempt to maintain aquaculture production, incomes, and employment. This has also often proved nonsustainable. The net result is that extensive areas of formerly biologically rich and productive wetland forest are lying idle. In limited cases, natural regeneration of wetlands is taking place, and there are sporadic attempts to stimulate regeneration. However, the drive to convert further wetlands is far greater than efforts at rehabilitation. The development of alternative, sustainable uses of former wetland forests is examined as a means of reducing the pressures to convert further areas of wetland forest.

## INTRODUCTION

Burgeoning human populations with inherent needs for food and income continue to drive the settlement and exploitation of coastal regions. Some 20 percent of the human population (over 1 billion people) live within 30 km of the coast (Gommes and others 1998). In tropical developing countries, approximately 90 percent of fishery landings come from shallow coastal waters and provide for 40 to 90 percent of national animal protein consumption (Holdgate 1993). In Asia, it has been estimated that one billion people depend exclusively on fish for their protein requirements (Anon. 1985). Population densities in excess of 1,000 people per square kilometer are commonplace in rural areas of developing countries in Asia, the Pacific, Central America, and the Caribbean (Lundin and Linden 1993). Such population densities place adverse pressures on coastal zones, which are used for settlement, transport, waste disposal, agriculture, forestry, aquaculture, and fishing. In many cases, the sustainable levels of exploitation in fisheries, harvest of mangroves, or the use of the assimilative capacity of wetlands to deal with sewage has long been exceeded. Competition for and overuse of renewable resources have been identified as a major problem in many regions. There are also mounting conflicts between different forms of resources development that reduce the effectiveness of investment and threaten the sustainability of resource production. For example, logging and mining activities in upland areas of Southeast Asia have brought short-term and localized economic benefits to the communities involved. At the same time, they have caused major environmental damage and imposed negative economic impacts that damaged capture fisheries, aquaculture, and tourism interests in lowland areas (Chou and others 1991, Hodgeson and Dixon 1988).

We are therefore facing a very serious challenge in most coastal regions where rapid growth in coastal populations, rapid urbanization, competition for land and water resources, and pollution are undermining the potential of coastal zones to sustain social and economic development objectives. One such objective is sustainable protein production through wise fisheries management and the development of aquaculture. However, throughout the world, coastal ecosystems believed to play a significant role in supporting fisheries and aquaculture are being lost or severely degraded. Coastal wetland forests play such a role but are not being effectively conserved. For example, estimates suggest that 70 percent of Thailand's mangrove has been converted to industrial sites, agriculture, and shrimp ponds. A policy to encourage the conversion of mangrove and other coastal ecosystems into shrimp ponds was stimulated by the reduction of open-access fishing areas as a result of the declaration of Exclusive Economic Zones by countries bordering the Gulf of Thailand. The policy aimed to relieve unemployment among fishermen and to increase fisheries production. However, little or no account was taken of the impact of the loss of mangrove in terms of decreasing support of capture fisheries or aquaculture. This lack of attention to such a basic issue may undermine the benefits derived from aquaculture when good planning and management could avoid a conflict of interests between forestry, aquaculture, and capture fisheries.

With the mounting pressures on coastal areas and resources, it is increasingly important to strive for the sustainable use of ecosystems and the renewable natural resources they generate. However, this takes sophisticated development planning and careful management of development activities. In the case of shrimp-pond based aquaculture development, we are facing two distinct sets of issues affecting the sustainability of production. The first is the adverse impact of other forms of development on aquaculture; the second is the poor siting and management of the aquaculture units.

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Aquaculture has a legitimate right of access to and use of coastal resources as well as a right not to be adversely affected by the poor planning and management of other forms of coastal development. These issues have been addressed in a comprehensive manner in recent reports of the Working Group on Environmental Interactions of Mariculture (ICES 1995, 1996, 1997, 1998, 1999). The second set of issues has been addressed by FAO (Barg 1992) and numerous other technical groups and individual experts. For example, as early as 1981, Juliano and others (1981) were able to demonstrate that production from shrimp ponds in the Philippines could be doubled through marginal improvements in the management of ponds using existing knowledge, thus reducing the need to expand the area of mangrove converted to aquaculture.

Agencies such as the World Bank and FAO are addressing basic institutional and technical issues concerning the establishment of coastal management in developing nations. However, no international organization has yet developed proactive approaches or practical guidelines for the integration of aquaculture into coastal planning and management activities in both developing and developed nations. Where integration is being attempted, it is based upon local or regional planning within individual nations (ICES Working Groups on CZM 1995). As a result, opportunities for promoting the sustainable growth and diversification of coastal aquaculture are not being fully realized, and options for future development are being foreclosed.

Despite the feasibility of greatly enhancing the sustainable production of aquaculture through integrated development planning and sound management, there has been a rapid and largely unplanned expansion of shrimp aquaculture in developing nations. As a consequence, there has been large-scale destruction of mangrove and other wetland systems with consequent impacts on human activities that are supported directly, or indirectly, by their ecosystem functions. A second consequence has been the cessation of production in extensive areas of aquaculture sites. Land is frequently lying idle, yet there is continuing pressure to convert more wetlands in an attempt to maintain aquaculture production. This trend cannot be sustained, and it is argued that rehabilitation of disused and unproductive aquaculture sites presents a positive means of bringing these lands back into some form of productive and sustainable use while reducing the pressure to convert remaining productive wetlands. This presents a major challenge to all of us involved in forestry, aquaculture, capture fisheries, and other aspects of human development in coastal regions.

## THE ISSUE OF NONSUSTAINABLE CONVERSION OF COASTAL WETLANDS TO AQUACULTURE

The actual scale of conversions of mangrove and other wetlands to aquaculture is very difficult to document. It has been estimated that over 15 million ha of mangrove had been cleared. This accounts for approximately half of the mangrove that had previously existed, and this is thought to be further decreasing at a rate of between 2 and 8 percent per year (Kunstadter and others 1985). In the Philippines, 279,000 ha of mangrove were lost between 1951 and 1988, and conversion to culture ponds accounted for approximately 50 percent of this loss (Primavera 1995).

In addition to areas converted from mangrove to shrimp ponds, other areas have been converted from salt flats, salt marshes, freshwater wetlands, fishponds, rice paddies, or agricultural lands. Frequently, ponds were built in regions already degraded by other practices and already in need of active management.

Aquaculture of marine species has been a well-established feature of coastal development for more than a thousand years in parts of Asia. An example of this is the polyculture of milkfish and shrimp in “Tambaks” (brackish water ponds) in Indonesia. Most of these systems were extensive in nature and many integrated mangrove conservation into the pond management system as both a means of enriching the food supply in the ponds and of protecting ponds from coastal storms. The traditional extensive or semi-intensive pond systems have largely given way to intensive systems, which require very careful site selection and high levels of inputs of feed and other materials to balance water chemistry and maintain the health of the cultured species. The capital investment, technical skills, and knowledge of markets required to sustain production in intensive aquaculture systems often puts them beyond the reach of most rural communities. Where they are attempted without the requisite inputs and protection from adverse external impacts, production cannot be sustained, and they become disused.

### The Scale of Disuse of Aquaculture Sites

Accurate estimates of pond disuse (in both mangrove and nonmangrove areas) are difficult to obtain because land tenure records are often unreliable and out of date, and assessments using remote sensing are hampered by the inability to discern between productive and disused ponds (Stevenson and others 1999). Unofficial estimates of pond disuse have suggested that the percentage of ponds left idle after a period in production can be as high as 70 percent (Stevenson 1997). Attempts to quantify the scale of pond disuse have been marred by the belief that an admission of pond abandonment is tantamount to an admission of management failure, and, to date, comprehensive surveys of disused shrimp ponds have not been undertaken (Stevenson and others 1999). In practice, ponds are often converted to other uses; for instance, in Thailand, some ponds have been sold for housing and industrial development, converted to salt farms or fish or crab culture operations, and some shrimp farmers have sold topsoil for construction projects (Stevenson 1997).

In Thailand, Potaros (1995) stated that 19 900 ha of shrimp farms in the five provinces of the Inner Gulf of Thailand were closed in 1990–91. A report produced by the Network of Aquaculture Centres in Asia-Pacific (NACA) indicates that in 1989 about 62 percent of farms were operating “under capacity” and another 22 percent of farms were “abandoned” in Samut Sakhon province (Office of Environmental Policy and Planning - OEPP 1994). This is supported by Briggs and Funge-Smith (1994) who reported that an area of 40 000 to 45 000 ha south of Bangkok became derelict after shrimp production collapsed in 1989–90.

Yap (1997) reports that nearly all of the 54 912 ha of shrimp ponds in the Philippines were abandoned, and another 83 000 ha of brackish water ponds were “idle”. Reports from NGOs in the Philippines in late 1997 stating that pond disuse is common in the Philippines have supported this, although pond operators have frequently returned to traditional forms of milkfish [*Chanos chanos* (Forsskal)] culture after shrimp production has ceased (Stevenson and others 1999).

The disuse or abandonment of coastal aquaculture sites has been reported elsewhere but not quantified. Extensive areas of disused shrimp ponds are thought to exist in Bangladesh, China, Malaysia, and Colombia (Stevenson 1997) and, more recently, Mexico.

### Causes of Disuse and Abandonment of Ponds

There are numerous reasons for the cessation of production in shrimp ponds. Examples include:

- poor site selection (reported in Sri Lanka by Jayasinghe 1995);
- flooding due to poor catchment management as well as from storm surges where the buffer function of mangrove has been lost due to their removal;
- predation by nontarget species in the ponds, e.g., birds and other animals;
- poor cohesivity of soils, which causes the pond walls to collapse;
- acidification of soils and water as a result of the exposure of potential Acid Sulfate Soils (reported in Vietnam by Tuan 1996, in Cambodia by Sreng 1996);
- contamination of pond water from agricultural wastes (noted in Indonesia as a result of a shortage of fresh water and problems of water quality by Burbridge pers. obs. 1997); and
- diseases resulting from a lack of hygiene, which can be rapidly transmitted among ponds through poor water management, for example, reported in India as a result of white spot disease (Sammut and Mohan 1996), in Sri Lanka (Jayasinghe 1995), in the Philippines (Ogburn and Ogburn 1994), and in Taiwan (Stevenson and others 1999).

Briggs and Funge-Smith (1994) were among the first to highlight the problem of poor hygiene and diseases in a report to the British Overseas Development Agency (now the Department for International Development, DFID). Hambrey (1996) reported that chronic disease and water-quality problems have caused ‘significant’ pond abandonment. For instance, disease problems have caused abandonment in India, (Sammut and Mohan 1996), the Philippines (Yap 1997), and Thailand (Macintosh 1996). Poor water quality and poor site selection have caused production failure in Sri Lanka (Jayasinghe 1995) and Indonesia, and problems with Acid Sulfate Soils (A.S.S.) have caused abandonment in Vietnam (Tuan 1996) and Cambodia (Sreng 1996). These problems often lead to financial difficulty, causing farmers to either sell or abandon their farms (Fegan 1996). Ponds may also be abandoned due to a drop in profits or yields (Flaherty and Karnjanakesorn 1995), or political intervention, such as the revoking of leases or license agreements (Stevenson and others 1999).

Where the development of coastal aquaculture has not been well planned and managed, it undermines the potential for coastal zones to sustain economic and social development. This raises the question of whether it would be better to rehabilitate these areas and restore the original ecosystem, or to find a means of modifying the aquaculture system to allow it to be more productive and sustainable. There are good arguments for both alternatives. On one hand, the rehabilitation of the original ecosystem may help to rejuvenate coastal capture fisheries stocks and the income of fishermen, improve biodiversity, ecotourism, and reduce salinization of soils and groundwater, which adversely affect agriculture and domestic water supplies. However, it must be realized that rehabilitation will cost money, will take considerable time, and may not be welcomed by local people who may see little benefit for themselves.

On the other hand, developing more productive use of unsuccessful aquaculture sites could allow the original developers to achieve a reasonable return on their investment and could provide opportunities to diversify and expand local employment. Mixed aquaculture systems may help improve the food security of rural communities and reduce organic pollution loads from other forms of development, including more intensive aquaculture. One example might be the change from nonprofitable intensive or semi-intensive shrimp culture to a less intensive polyculture system or an integrated aquaculture-agriculture forestry system.

These and other alternatives will vary from place to place depending on environmental, social, and economic conditions. At this meeting, it would be useful to discuss how to develop a system to identify and evaluate opportunities to put nonproductive and idle aquaculture sites into a more productive use that helps to meet sustainable development objectives at both a local and national level. In the following paragraphs, factors that influence options for rehabilitating disused aquaculture sites are set out.

## OPTIONS FOR THE REHABILITATION OF DISUSED OR ABANDONED AQUACULTURE PONDS OR BOTH

The term restoration has been adopted in recent studies to mean any activity that aims to return a system to a pre-existing condition, whether or not this was pristine (sensu Lewis 1990b). Whereas, the term rehabilitation is used to denote any activity that aims to convert a degraded system to a stable alternative use, which is designed to meet a particular management objective (Stevenson and others 1999). The term rehabilitation is used here to describe a continuum of management options for altering the state of the ponds to some alternative condition where human activities can be sustained. This can include the reinstatement of a wetland forest ecosystem such as a mangrove, where uses foreclosed through the conversion of the wetland can be regained and benefit a range of different interests. For example, mangrove forests have been restored to meet commercial purposes such as silviculture (Watson 1928), for restoring fisheries habitat (Aksornkoea 1997, Lewis 1992), for sustainable multiple community use purposes, or for shoreline protection purposes. None of these are mutually exclusive.

There are three basic rehabilitation options. The first is to rehabilitate the pond sites so that they can be put back into sustainable shrimp production. The second is to rehabilitate the pond sites so that they can be put to some alternative, sustainable use. The third option is to restore the environmental conditions within the pond sites and the surrounding area, and to re-establish a productive wetland ecosystem (Stevenson and others 1999). Each of these options is influenced by the causes of production failure and the conditions that remain in the pond after production has ceased (Stevenson 1997). The continuum of rehabilitation options is illustrated in figure 1.

## Factors That Influence the Choice of Rehabilitation Options

The basic rationale for attempting rehabilitation is to address factors that alter a wetland or other productive coastal ecosystem 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, Watson 1928) or natural recovery from damage are inhibited in some way.

Before any restoration is attempted, the goals should be determined through an active dialogue with, and effective participation of, the local stakeholders. The stakeholders comprise both individuals or interest groups that have promoted aquaculture, as well as those who may have been influenced by the conversion of wetlands and other systems. Those with interests in aquaculture may have invested scarce capital, as well as their labor and materials, to develop what they saw as a means of improving their welfare. In the process of developing the aquaculture sites, they may have attained user rights or title to the land. They will want to see some productive outcome from restoration efforts that will help them achieve sustainable return on their investment. On the other hand, people who did not benefit from the aquaculture development may have suffered a loss of access to common property resources such as the crabs that breed and thrive in mangrove forests or fish and crustaceans that depend upon wetlands for part of their life cycle. Balancing the needs and aspirations of the different stakeholders and achieving broad agreement on the goals are critical to the sustainability of rehabilitation initiatives. The importance of this involvement of stakeholders is often overlooked, and, without local support, restoration and rehabilitation programs have little chance for long-term success (Primavera and Agbayani 1996).

It may be possible to restore the functionality of a system even though factors such as soil type and condition may have been altered with consequent effects on the flora and fauna. If the goal is to return an area to pristine condition, then the likelihood of failure is high and must be regarded as unrealistic (Stevenson and others 1999). The restoration of certain ecosystem traits and the replication of some functionality stand more chance of success (Lewis and others 1995).

The reference conditions for restoring the functions of a system also need to be examined carefully because "pre-existing conditions" may not have been pristine due to factors outside those associated with the conversion to aquaculture. Potaros (1995) reports that in Thailand, "the mangrove area that has been used for shrimp farms is often previously degraded forest so it is very difficult to assess the economic damage related directly to shrimp farming". In such cases, it is not sensible to return the area to a previously degraded condition. The goal may be to achieve a level of functionality that will allow productive alternatives to be developed and sustained. These alternatives could include mangrove timber production or development of new forms of aquaculture.

Additionally, restoration to the original habitat type may not be the best social, economic, or ecological option. For example, rather than restoring the area to a relatively common ecosystem type, it may be preferable to restore not to the original condition, but rather to a scarce type of habitat within the ecosystem (Cairns 1988, Lewis Environmental Services, Inc. and Coastal Environmental, Inc. 1996). This is also known as "out-of-kind" restoration (Stevenson and others 1999).

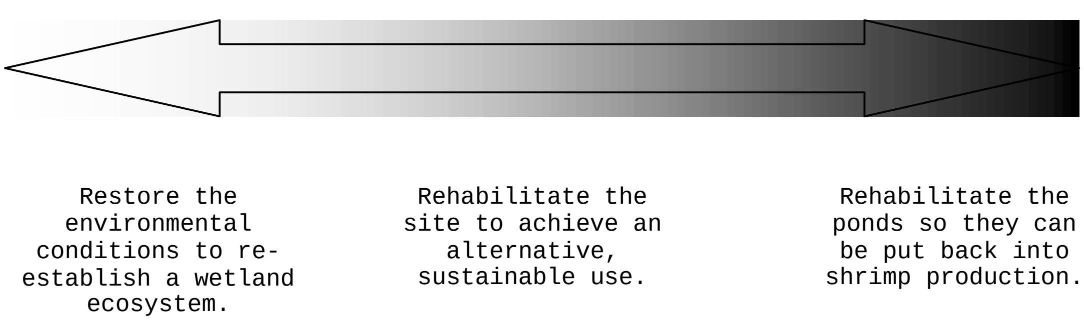


Figure 1—Diagram illustrating the continuum of options that are available for the rehabilitation of disused or abandoned aquaculture ponds.

Some areas may not be considered suitable for restoration. In such cases, the best practical option may be to re-establish shrimp farming in a well-managed and sustainable manner. Similarly, the primary redevelopment goal of coastal managers may be to recommence shrimp farming in disused ponds.

In an area subject to storm activity, the primary goal may be to restore natural coastal protection afforded by the buffer function served by mangrove. Different goals are not necessarily mutually exclusive. Rehabilitation of a degraded mangrove can help to sustain shrimp aquaculture by acting as a buffer to storm surges and reducing flooding of ponds. It can help to provide nutrients to ponds as well as helping to assimilate wastes drained from ponds.

The choice of options can be limited by the information available on key factors that influence the costs and technical difficulties of rehabilitating ponds. For example, ponds sited in areas where Acid Sulfate Soils have been exposed to air pose difficult problems of restoring neutral soil conditions without costly liming or leaching the acids by flushing, which can impose unacceptable impacts on neighboring rivers and estuaries. There are fundamental gaps in the information available on the environmental effects of leachate from Acid Sulfate Soils and the persistence of chemicals, disinfectants, and other materials used during shrimp culture. If new and innovative treatments develop, then a variety of new alternatives may be open to the coastal manager for consideration (Stevenson and others 1999).

## FACTORS THAT INFLUENCE OPTIONS FOR THE REHABILITATION OF MANGROVE

Factors influencing the rehabilitation of mangrove were reviewed by Chapman (1976), Field (1997), Hamilton and Snedaker (1985), Lewis (1982, 1990a, 1990b), Lugo (1992), Noakes (1951), Saenger and Siddiqi (1993), Siddiqi and others (1993), and Watson (1928).

Some of the main factors that have a major influence on both the sustainability of aquaculture and the rehabilitation of disused sites include:

- the presence of Potential Acid Sulfate Soils (P.A.S.S.);
- erosion and subsidence of soils and associated increased risks of flooding;
- waterlogging of soils; and
- the presence and longevity of antimicrobials and other chemical compounds used in aquaculture operations.

There is a shortage of studies that quantify the environmental conditions in disused shrimp ponds and their effect on surrounding areas. Disused or abandoned ponds or both may represent heavily degraded environmental conditions that could prove technically difficult, expensive, and time consuming to rehabilitate. In some case, environmental changes brought about by developing ponds in inappropriate situations may be irreversible. For example, it is not possible to reverse the formation of Actual Acid Sulfate Soils (A.A.S.S.) resulting from the oxidation of Potential Acid Sulfate Soils (P.A.S.S.) caused by excavating ponds. However, it may be possible to transform A.A.S.S. to a pH neutral soil that has less acid-producing capacity.

Great care must be taken in choosing methods of dealing with A.A.S.S. Methods commonly recommended by agriculturists involve flushing the acids from the soil with copious amounts of either fresh or brackish water, for example, in Agency for Agricultural Research and Development and the Land and Water Research Group (1990). Although this may reduce the acidity in local areas, it does not address the issue of the impact of acids draining into adjacent streams, rivers, or estuaries. Field observations by one of the authors in the Mekong Delta indicated acid levels as low as pH 2.3 in canals dredged in P.A.S.S. in an attempt to reclaim Melaleuca wetland forests for agriculture. P.A.S.S. can extend over large areas and represents a very large reservoir of potential acid materials. Flushing of acids from pond sites may in the short term appear to be a viable solution. However, unless water levels are maintained above the P.A.S.S. layers, oxidation will continue with the result of continuing leaching of acids. Maintaining water levels in the soil profile can be very difficult where groundwater is being extracted to irrigate crops or to moderate salinity and temperatures in aquaculture sites.

With the clearance of trees and other vegetation to create ponds, surface erosion and subsidence and compaction of the soil profile can take place. This can have a series of knock-on effects, including increased risks of flooding from river systems as well as increased vulnerability from oceanic storm surges. These conditions are very difficult to reverse.

Additionally, it is difficult to counteract the adverse effects on surrounding areas resulting from clearance of mangrove and other wetland forest types. Lahmann and others (1987) discuss the impact of shrimp aquaculture siting in basin mangrove forests and “salitrales” (salt flats) in the southern Gulf of Guayaquil, Ecuador. The basin forests are often characterized as “unproductive” in major shrimp aquaculture countries like Thailand, but Lahmann and others (1987) point out that the local“...declining abundance of shrimp postlarva in Ecuadorian estuaries...” may at least in part be due to “...the disproportionate elimination of sources of dissolved organic matter...” and “...may be the dominant cause of the reduction in wild shrimp postlarva stocks...” (p. 242).

There is evidence that mangrove forests around the world can recover from a degraded or heavily harvested condition if: (a) normal freshwater flows entering the mangrove are not disrupted, (b) the normal tidal hydrology is not disrupted, and (c) the availability of waterborne seeds or seedlings (propagules) from adjacent mangrove stands is maintained. Through afforestation, mangroves can also be established on unvegetated, intertidal flats where they would not normally grow. These areas, however, are limited in extent and often serve other ecological purposes such as feeding areas for wading birds like herons and egrets. They may also support valuable submerged aquatic vegetation like seagrass meadows that are a valuable marine habitat in their own right (Phillips and McRoy 1980).

Based on the ability of mangrove to restore itself, it has been recommended that plans for restoration should first look at the potential existence of stresses such as blocked tidal inundation, which might prevent secondary succession from occurring and to remove those stresses before attempting additional restoration (Hamilton and Snedaker 1985, Lugo 1992). The identification of stresses and evaluation of their effects on natural regeneration are not simple tasks. Studies in Panama (Duke 1996) and Indonesia (Soemodihardjo and others 1996) report successful natural regeneration of mangrove subjected to stresses from oil spills and logging, respectively. In Panama, Duke (1996) observed that "...densities of natural recruits far exceeded both expected and observed densities of planted seedlings in both sheltered and exposed sites..." (p. 228). Soemodihardjo and others (1996) report that only 10 percent of a logged area in Tembilahan, Indonesia, needed replanting because "...the rest of the logged over area...had more than 2,500 natural seedlings per hectare" (p. 109). In cases where natural recovery is not occurring through natural seedling recruitment, assisting natural recovery through planting is one option.

Unfortunately, many mangrove restoration projects move immediately into planting of mangroves without determining if natural recovery is taking place and which stresses may prevent natural regeneration and the likely effectiveness of replanting. This often results in major failures of planting efforts (Stevenson and others 1999). For example, Sanyal (1998) has recently reported that between 1989 and 1995, over 9000 ha of mangroves were planted in West Bengal, India, with only a 1.52-percent success rate. The World Bank funded Central Visayas Regional Project-I, Nearshore Fisheries Component in the Philippines that targeted 1000 ha for mangrove planting between 1984–92. An evaluation of the success of the planting in 1995–96 (Silliman University 1996) indicated only 18.4 percent of 2,927,400 mangroves planted over 492 ha had survived. Another planned 30 000-ha planting effort in the Philippines (Fisheries Sector Program, 1990–95) funded by a $150 million loan from the Asian Development Bank and the Overseas Economic Cooperation Fund of Japan was cut short after only 4792 ha were planted due to similar problems (Ablaza-Baluyut 1995).

### Restoration of Disused Aquaculture Ponds to Mangrove Forests

Detailed studies by Lewis and Marshall (1997) of pond restoration at field sites in Central America and the Philippines indicate that the most important factor in successful restoration of ponds to mangroves is the re-establishment of the tidal hydrology to the maximum extent possible. Restoration of mangroves through restoring the natural hydrology has been emphasized before by Hamilton and Snedaker (1984), Lugo (1992), and by Olsen and Arriaga (1989). Turner and Lewis (1996) also give examples of successful restoration of mangroves through restored hydrology alone.

Lewis and Marshall (1997) have suggested five critical steps to achieve successful mangrove restoration in general and pond restoration in particular:

- understand the autecology (single species ecology) of the mangrove species at the site, in particular the patterns of reproduction, propagule distribution, and successful seedling establishment;
- understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species;
- assess the modifications of the previous mangrove environment that occurred and that currently prevent natural secondary succession;
- design the restoration program to initially restore the appropriate hydrology and utilize natural volunteer mangrove propagule recruitment for plant establishment; and
- only utilize actual planting of propagules, collected seedlings, or cultivated seedlings after determining, through steps 1 through 4, that natural recruitment will not provide the quantity of successfully established seedlings, or 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 directly to step 5 without considering steps 1 through 4. Lewis and Marshall (1997) refer to this approach as "gardening", where simply planting mangroves is seen as all that is needed.

## SELECTING APPROPRIATE REHABILITATION OPTIONS

The selection of the most appropriate options for rehabilitation depends heavily upon local as well as national, economic, social, and environmental priorities. From an economic viewpoint, assessing the value of the flows of resources derived from the former ecosystem provides an important benchmark against which to assess the relative costs and benefits that can be derived from different rehabilitation options. Such benchmarks should incorporate both the tangible economic goods and services as well as the less tangible environmental goods and services provided by the wetland forest or other ecosystems before they were subjected to conversion. These environmental goods and services include flood and storm protection, sediment and toxicant removal, erosion mitigation, and nutrient export.

Of particular importance are the benefits provided by mangrove in coastal protection from typhoons or hurricanes. In areas subject to strong storm activity for West Bengal, Bangladesh, and Mozambique, the removal of mangrove to form shrimp ponds has made coastal activities more vulnerable to storm surges and flooding. In some states in India, e.g., Andrha Pradesh, the buffering capacity and the erosion mitigation provided by mangrove is particularly important because the costs associated with the construction of artificial structures to combat erosion and to protect from storm damage can total more than.$12,000 (U.S.) per meter. In such areas, the case for restoration may be very strong, and the costs involved in restoration may be small when compared with the costs of constructing these artificial structures. The benefits in such cases would be both financial, in terms of costs avoided, and social, in terms of the avoidance or minimization of the loss of human life and property.

There are well-established economic techniques for undertaking such analyses. For example, see section 6 of the Mangrove Area Management Handbook (Hamilton and

Snedaker 1985). Mangroves are regarded as particularly rich in terms of the goods and services they provide (Burbridge 1990, Dixon 1989, Hamilton and Snedaker 1984) and some researchers have made estimates of the economic benefits of mangroves both in terms of fisheries and other benefits. There is less information available on the economic value of other land-use types or other habitats in tropical regions, e.g., salt pans, tidal swamp forests, Melaleuca wetlands, or mud flats.

However, well-constructed economic cases that include a full range of social as well as environmental factors for different rehabilitation options are seldom undertaken. Justifications for rehabilitation such as those by Sidall and others (1985) who state with reference to Ecuador, Panama, and the Philippines that “reclamation of abandoned ponds should be encouraged... and poorly sited or engineered ponds should be breached to promote eventual recolonization” would benefit from rigorous assessment of the benefits of different rehabilitation options. This also applies to justifications for rehabilitating general aquaculture related degradation in mangroves. For example, Ishwaran (1996) argues that given the importance of mangroves, there is a need to rehabilitate degraded areas through planting and the introduction of environmentally friendly aquaculture technology.

The case for rehabilitating disused shrimp ponds should also be viewed objectively. The direct loss of shrimp sales revenue from ponds, which fail due to poor management, can be in the region of.$15,000 to $25,000 (U.S.) per hectare per year. The costs of the system degrading further and posing a risk to neighboring habitats or land-use types should also be taken into consideration. Damaged resources are often unstable and actively deteriorating, and, in general, if deterioration is not arrested, repair may become progressively more expensive and difficult; i.e., redevelopment costs must be balanced against ‘costs avoided’ (Stevenson and others 1999).

There can be added benefits from the rehabilitation of degraded pond sites to an alternative income-generating activity. For example, by redeveloping an area that has become degraded and helping stakeholders to regain productive use of the sites, pressure will be reduced on neighboring areas, which are perceived to be of high value for conversion and are at risk of degradation. The resulting re-establishment of production of useful goods and services in a rehabilitated or restored area may serve to help maintain the flows of economic and environmental goods and services provided by undisturbed ecosystems. This will allow these systems to continue to sustain other forms of human activity, as well as meeting international obligations such as maintaining biological diversity.

Where ponds were converted from other land-use types, such as fish ponds, paddy fields, or other agricultural lands, socio-economic reasons may exist for restoring ponds to their prior uses, particularly where local reliance on subsistence agriculture or aquaculture exists. However, there is little in the literature that supports restoration to prior land-use types. Where restoration to a ‘natural’ habitat (such as mangrove) is considered inappropriate, technically very difficult, or too expensive, then restoration to prior or other land-use types may be considered. This may represent the best option in terms of economic feasibility, environmental acceptability, and maximal sustainable productivity (Stevenson and others 1999).

Where ponds have been constructed in inappropriate locations, such as those frequently hit by typhoons or hurricanes, there is a strong case for not rehabilitating ponds to alternative uses that also will be vulnerable and difficult to sustain. In cases where areas which are not normally hit by hurricanes but experience El Niño years, for instance, along the Pacific Coast of Latin America and the United States, there can be a case for rehabilitation (or even restoration) of ponds if the benefits outweigh the risks. In such cases, management practices can reduce the vulnerability of aquaculture production to periodic events.

### Selection of Rehabilitation Options and Their Implementation in Practice

There are limited references to the practical restoration of abandoned shrimp ponds. Given the extensive areas of mangrove converted unsuccessfully to shrimp ponds, there have been surprisingly few reports of attempts to restore aquaculture ponds back to mangroves. Anecdotal reports of up to 13 000 ha of ponds restored in Thailand and several thousand hectares in Vietnam have been noted by Stevenson and others (1999). It is significant to note that Field (1997), in compiling and editing reports on mangrove restoration from 13 countries including Thailand, Malaysia, Vietnam, Indonesia, India, Pakistan, and Bangladesh, does not report a single occasion where pond restoration was attempted. In fact, the only mention of aquaculture ponds in this work is by Aksornkoae (1997), in which mangroves were restored between existing shrimp aquaculture ponds in Pattani Province, Thailand. In several areas in Thailand (and probably elsewhere), mangrove has been planted in bund walls and in areas adjacent to ponds as part of the aquaculture management system in order to stabilize sediments and to improve water quality.

Stevenson and others (1999) observed that pond rehabilitation is an ongoing concern, and there are probably many localized efforts to either reforest ponds in former mangrove areas or to put disused ponds to alternative uses. However, the data that do exist are often of poor quality, or they are poorly disseminated and difficult to obtain or verify. Consequently, it is not possible to draw any substantive conclusions from them. The authors concluded that in most cases, evaluation procedures or assessment of pond condition do not take place prior to the initiation of pond rehabilitation projects. Therefore, the reasons behind either the success or failure of pond rehabilitation projects are not known, and there is no ‘learning curve’ or lessons learned from these endeavors. This is not a rational way to continue (Stevenson and others 1999).

## CONCLUSIONS

Aquaculture forms an important activity in many of the world’s coastal regions, and its importance as a source of income, employment, and exports is likely to continue to expand for the foreseeable future. Aquaculture of a generally nonintensive nature has been a part of coastal land and water use for many centuries in Asia, and it has proven sustainable. However, the rapid expansion of poorly planned and managed semi-intensive and intensive shrimp aquaculture has created a number of significant adverse environmental, economic, and social effects. In turn, shrimp aquaculture has often been adversely affected by impacts from other forms of human development.

The combined effects of poor standards of aquaculture development and adverse impacts on aquaculture operations have led to unnecessary destruction of coastal wetland forests, nonsustainable aquaculture production, disuse of pond sites, and even abandonment of the land and the loss of the investment of peoples' labor and capital. Reluctance on the part of the aquaculture industry and government to admit that shrimp aquaculture has often proven nonsustainable has helped to disguise the extent of unproductive shrimp farming. However, extensive areas are believed to be involved in many of the poorer developing nations such as India, the Philippines, and Indonesia.

Developing nations cannot afford to allow the extensive areas of nonsustainable, unproductive shrimp farms to remain idle if they are to meet the development needs of coastal communities, as well as national development objectives and international obligations such as the conservation of biodiversity. Substantial scientific effort is required to analyze the factors that lead to nonsustainable aquaculture and to help the 50 or more shrimp-producing nations find ways to rehabilitate unproductive, disused, and abandoned areas. This will serve both to help people to develop sustainable uses of coastal areas and resources already committed to aquaculture and to reduce pressures on remaining coastal ecosystems and the renewable resources they generate.

Options for the rehabilitation of areas that can no longer sustain shrimp production need to be identified, tested, evaluated, and demonstration projects established as a means of engaging the interest and active support of stakeholders. Efforts to improve the dialogue between donors, researchers, aquaculturists, and governmental bodies will be essential in developing workable solutions. Unfortunately, much of the research into pond rehabilitation carried out to date has been conducted without adequate site assessment, without documentation of the methodologies or approaches used, and often lacks subsequent follow up or evaluation. Those projects, which have not been successful, are rarely documented and information on them is largely anecdotal and hard to obtain. The reasons for success or failure are still largely guesswork, and we are still at the beginning of what may prove to be a steep 'learning curve.'

To reduce the length of time required to address this learning curve and avoid further unnecessary damage to wetland forests, consideration should be given by the international scientific community and donors to placing greater emphasis upon working with developing nations where these issues are acute and where poverty and lack of effective development assistance will drive people to degrade more areas through repeating mistakes of the past.

The potentially adverse effects of new aquaculture development can generally be avoided through good planning and management. To be fully successful, such plans and management arrangements must recognize that aquaculture should have equal rights of access to and use of natural resources and a good quality environment. It is suggested that Integrated Coastal Zone Management can provide a beneficial framework for the development of aquaculture where due care and attention are given to the maintenance of the functional integrity of coastal ecosystems that sustain aquaculture and other natural resource-dependent activities. It is also suggested that multiple use management of coastal ecosystems will provide a better basis for integrating aquaculture with other activities, which have a common dependence on the functions and resources provided by one or more coastal ecosystems.

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