# Disused Shrimp Ponds and Mangrove Rehabilitation

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## 1. Introduction

The production of shrimp (*Penaeus* spp.) by means of coastal pond systems has been a traditional practice in Asia for hundreds of years. However, advances in technology coupled with an increased international market demand for shrimp led to the development of intensive aquaculture systems that departed from traditional sustainable systems. In many instances these intensive systems were poorly planned and/or managed and have since proven to be unsustainable, with the result that large areas of "land," much of it former coastal wetlands, now lie idle and unproductive, and new sites are being developed in an effort to maintain production output (Stevenson 1997).

Although pond disuse became common in disease-hit areas as early as 1990 (and arguably much earlier in the 1980s), the matter was not given attention until much later. Briggs and Funge-Smith (1994) were among the first to highlight the matter in a report to the British Overseas Development Administration (now Department for International Development), although the significance of the problem was not fully appreciated. Other reports have emerged since then. Hambrey (1996) stated 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), Taiwan (C. Chin Chen, Personal Communication), 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 (ASS) 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 left idle due to a drop in profits or yields (Flaherty and Karnjanakesorn 1995) or political intervention (for example, the revoking of lease or license agreements). It has been suggested that some farmers have had a deliberate policy of constructing farms, as cheaply and quickly as possible, with no intention of achieving sustainability and with the explicit aim of abandoning the site after only a few crop cycles (Stevenson 1997).

Consequently, there are many areas of disused ponds that were common property resources prior to pond development, which are now unproductive and "derelict." Many pond owners and farmers are either in debt or without a livelihood (or both) and are faced with the question of what to do with disused shrimp ponds. There are three basic options. The first is to rehabilitate the pond sites so that they can be put back into sustainable shrimp production. The



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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. 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).

To date there has been no coordinated research effort into pond rehabilitation. There is however increasing recognition that active management of disused ponds is critical to restoring sustainable livelihoods in many tropical coastal communities. The rehabilitation of ponds was identified as a "priority research" area at a workshop held in late 1996 (N.A.C.A.—Network of Aquaculture Centres in Asia-Pacific 1996). Among many key researchable issues identified, the following three of note were put forward: 1) rehabilitation studies for abandoned shrimp ponds, 2) review of water/soil quality methods employed in examining effects of acid sulfate soils on shrimp pond environments, and 3) rehabilitation/re-establishment technologies for mangrove. A year earlier these would not have featured since the existence of disused ponds was largely denied at the time. There is now the scope and willingness to undertake targeted research and active management of disused ponds.

It is of crucial importance to realize that only a proportion of shrimp ponds are built in mangrove areas. Many ponds were converted from salt flats, salt marshes, freshwater wetlands, fish ponds, rice paddies, or agricultural lands. Frequently ponds were built in regions already degraded by other practices and in need of active management. More effort should be put into rehabilitating areas that were previously used for other purposes, such as rice, sugar cane, or coconut cultivation, and should examine the options for either returning ponds to their prior use or to creating alternative sustainable livelihoods. For instance, a pond that was rice paddy prior to conversion may be too saline to recommence rice growing, but it may support saline tolerant crop species such as *Casuarina, Melaleuca,* and *Eucalyptus* (Stevenson 1996). In areas with acid sulfate soils it may be possible to grow acid tolerant types of rice or sugar cane or acid tolerant crops such as pineapple, yam, and cassava. It also makes little sense to convert ponds constructed in salt flats into mangroves. True restoration would dictate restoring salt flats, which, despite appearances, do have seasonal wildlife and fisheries values (Lewis 1990a).

Many efforts are currently underway to improve the sustainability of the shrimp industry. However, until sustainability is achieved, countries will continue to see the development of disused and unproductive ponds, and continue to see degradation of the resource base on which coastal communities, particularly the "poorest of the poor," depend. Even if the shrimp industry were to achieve sustainability today, disused shrimp ponds would still remain, as would the poverty and ecological problems they create.

## 2. Scale of Disuse

Accurate estimates of pond disuse, in both mangrove and non-mangrove areas, are difficult to obtain since land tenure records are often unreliable and out of date, and assessments using remote sensing are hampered by an inability to discern between productive and disused ponds (Figure 1). 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% (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, with the exception of one uncorroborated report from the Philippines, comprehensive surveys of disused shrimp ponds have not been undertaken. The authors have received reports of mangrove restoration projects in Vietnam that have apparently incorporated pond restoration, but the scale of pond restoration or the techniques used are not known. In practice, ponds are sometimes 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).

There have been several reports from Thailand that have included estimates of the scale of pond disuse and/or abandonment (both in mangrove and non mangrove). Potaros (1995) stated that 124,374 rai (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 details that in 1989 about 62% of farms were operating "under capacity" and another 22% 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 40,000-45,000 ha south of Bangkok became derelict after shrimp production collapsed in 1989/90 (this area encompasses Samut Sakhon and probably Samut Songkhram). The authors have not conducted field studies in this area but have received reports from Thailand that this area is severely degraded and that ponds in this area have been idle for many years.

South of this region, Enright (J. Enright, Personal Communication) estimated that in late 1996 70-80% of ponds were "abandoned" in Kuiburi and Pranburi districts in Prachuap Khiri Khan Province, in the Gulf of Thailand. The authors conducted a brief survey of this area in January 1998, and at that time approximately 95% of ponds remained disused (Figure 2) The ponds at Kuiburi and Pranburi (some of which are within the boundaries of Khao Sam Roi Yot Marine National Park) exist in areas that were previously salt pan and only under water for 2 months of the year, during the monsoon months. A small number of ponds in this area were built in mangrove. The mangrove that existed along natural "khlongs" and in a narrow coastal strip is almost all gone, whether directly due to pond construction or due to alterations in the tidal flow. Ponds were reported to have been operational for 3-7 years before disease caused widespread crop failures and all culture operations ceased. The park is an important bird wintering area and a critical stop-over for migratory shorebirds en route from Siberia to Malaysia and Indonesia, and for this reason alone there is an urgent need for restoration.

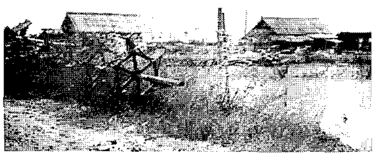

**Figure 1.** "Disused shrimp pond" or "pond in between production periods?" The paddle wheel at the side of the pond indicates that production may recommence. However the overgrown grass indicates that the paddle wheel has not been used for some time. Sathing Phra, Thailand. Photographed by Nathalie Stevenson, January 1998.

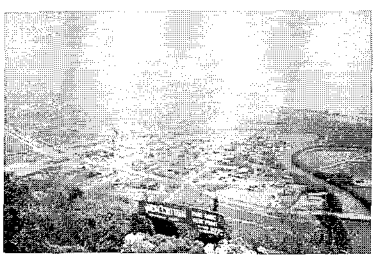

**Figure 2.** Disused shrimp ponds in Kuiburi and Pranburi Province, Thailand. Many of these ponds are in the area of Khao Sam Roi Yot Marine National Park with some occupying land within park boundaries. Photographed by Nathalie Stevenson, January 1998.

**Figure 3.** Pond construction near Sathing Phra, Thailand. Photographed by Nathalie Stevenson, January 1998.

By comparison Enright (J.Enright, Personal Communication) also estimated that 70-80% of ponds were "abandoned" in the provinces of Songkhla and Sri Thammarat; however, in January 1998 the authors (accompanied by Jim Enright) estimated that approximately 70% of ponds in these areas were either back in production or being prepared for production. Construction of new ponds was also in evidence (Figure 3). The high market price for shrimp is thought to be the main motivation for recommencing shrimp culture. Also in January 1998 the director of the Surat Thani Coastal Aquaculture Development Centre is quoted as stating that at that time 60% of shrimp ponds in Surat Thani were disused (Anuwat Rattanachote, Personal Communication, reported by Enright, Personal Communication). It is important to realize that estimates of disuse are only pertinent to the time they were formulated; the situation changes rapidly from month to month and ponds are frequently converted to other uses, and shrimp production can be recommenced at any time where the original production problems can be overcome (Stevenson 1997).

Yap (1997) reports that nearly all of the 54,912 ha of shrimp aquaculture ponds in the Philippines are presently abandoned, and that another 83,000 ha of brackish-water ponds are "idle." Reports from NGO's 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 milkfish (*Chanos chanos*) culture after shrimp production has ceased.

Pond disuse has been reported elsewhere, but not quantified. For instance, reported in India, as a result of white spot disease (Sammut and Mohan 1996); in Sri Lanka, as a result of improper site selection and poor water quality (Jayasinghe 1995); in Vietnam, as a result of acid sulfate soils (Tuan 1996; V. D. Quynh, Personal Communication); in Cambodia, as a result of acid sulfate soils and poor water circulation (Sreng 1996); in the Philippines, as a result of disease problems (Ogburn and Ogburn 1994); in Taiwan, as a result of disease (C. Chin Chen, Personal Communication), and in Indonesia as a result of disease and water quality problems (Burbridge, Personal Observation). It is also thought that there are significant areas of disused shrimp ponds in Bangladesh, China, Malaysia, Colombia (Stevenson 1997), and, more recently, Mexico.

### 3. Choice of Rehabilitation Goals

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. The term "restoration" has been adopted in this chapter to specifically mean any activity that aims to return a system to a preexisting condition (whether or not this was pristine) (*sensu* Lewis 1990b), whereas the term "rehabilitation" is applied more generally and is used to denote any activity (including restoration and habitat creation) that aims to convert a degraded system to a stable alternative.

Where production cannot be sustained, rehabilitation may be a viable alternative. Mangrove forests have been rehabilitated to achieve a variety of goals, for instance to meet commercial purposes (silviculture) (Watson 1928), for restoring fisheries habitat (Lewis 1992, Aksornkoea 1996), for sustainable multiple community use purposes, or for shoreline protection purposes.

In determining the viability of different rehabilitation options it is important to consider the preferences of stakeholders and to reach a consensus on appropriate goals so that the proposed course of action will enjoy a wide body of support. Specific issues that should be explored in coordination with local stakeholders include consideration of a need for monospecific stands of *Rhizopora* for the production of poles or charcoal and consideration of the possibility of low intensity aquaculture or silvofisheries (Fitzgerald 1997). The importance of this coordination with local stakeholders is often overlooked; without local support, rehabilitation programs have little chance for long-term success (Primavera and Agbayani 1996).

It may well be possible to restore some of the functions of a mangrove, salt flat, or other systems even though parameters such as soil type and condition, flora, and fauna may have changed. If the goal is to return an area to a pristine pre-development condition, then the likelihood of failure is virtually guaranteed. However, the restoration of certain ecosystem traits and the replication of natural functions stand more chance of success (Lewis et al. 1995). The goal must also acknowledge that "pre-existing conditions" may not have been pristine. 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, the rehabilitation goal is obviously not going to be one of returning the area to a degraded condition, but may be to convert the area to another use or to return the area to a clearly defined state somewhere between "pristine" and "degraded."

Restoration to the original habitat type may also not be the best option for the regional ecosystem. If the pre-damaged ecosystem is a small patch of a relatively common ecosystem type, then the decision may well be to restore not to the original condition, but to rehabilitate to a very 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.

In some cases, it appears that shrimp farming has been regarded as a rehabilitation activity in itself in areas that are considered unsuitable for conventional restoration. In other words the development of shrimp farming may have been regarded as the best practical option for the land at the time. Similarly, the chief goal of coastal managers may be to recommence shrimp farming in disused ponds.

For instance, in an area subject to storm activity, there may be an urgent need to restore coastal protection capacity. In such cases the primary goal would be to restore this capacity. However, if there were no such needs, and if there were sufficient mangrove already in existence in the vicinity to provide ecosystem functional support, then the most suitable goal may be to recommence shrimp farming. Alternatively, the goal may be to restore some ponds, but return others to shrimp production. However, when considering this option it is vitally important that original causes of failure and disuse are carefully evaluated. If it was thought that the chances of production success were reasonably assured, and that the original causes of production failure were unlikely to occur again, then this may be a very valid option.

The information available on ways in which to rehabilitate unproductive ponds limits the variety of potential alternative uses that they could be put to. This is especially true in ponds with acid sulfate soils. If new and innovative treatments develop, then a variety of new alternatives may be open to the coastal manger for consideration. There are fundamental gaps in the information available on the environmental persistence of chemicals that are used during shrimp culture. Before one can identify methods that ameliorate levels of chemicals, one must ascertain whether there is actually a problem. Do chemicals persist for any length of time? If so, do they have any detrimental effects on the environment? Do they limit options for rehabilitation and/or impose hazards if rehabilitation is attempted?

## 4. Mangrove restoration

### *4.1 General Principles*

Restoration of existing areas of damaged, routinely harvested, or destroyed mangrove forests has been previously discussed by 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), and Field (1996).

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). Mangroves can also be established through afforestation on unvegetated intertidal flats and other areas 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. Planting may also reduce the valuable support these normally unvegetated areas provide to submerged aquatic vegetation such as seagrass meadows (Phillips and McRoy 1980).

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). The second step is to 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.

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." 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."

*4.2 Restoration of Disused Ponds to Mangrove Forests*

There have been surprisingly few reports on attempts to restore aquaculture ponds back to mangroves. There are anecdotal reports of up to 13,000 ha of ponds restored in Thailand and several thousand ha in Vietnam have been seen by the authors, but no well documented data or reports have been found by the authors. It is significant to note that Field (1996), in compiling and editing reports on mangrove restoration from thirteen 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 (1996), in which mangroves were restored between existing shrimp aquaculture ponds in Pattani Province, Thailand. In several areas in Thailand, mangroves have been planted in bund walls and in areas adjacent to ponds in order to stabilize sediments and to improve water quality. The success of such endeavors is unknown.

General reference to the restoration of abandoned shrimp ponds in the literature includes Sidall et al. (1985) who states 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." With reference to general aquaculture related degradation in mangroves, Ishwaran (1996) states that, given the importance of mangroves, there is a need to rehabilitate degraded areas through planting and the introduction of environmentally friendly aquaculture technology.

Lahmann et al. (1987) discuss the impact of shrimp aquaculture siting in basin mangrove forests and "salitrales" (salt flats) in southern Ecuador, where at the time a 16% reduction in mangrove forest cover in the southern Gulf of Guayaquil due to shrimp pond construction had been reported through 1982. Quantitative data were collected within mangroves adjacent to shrimp ponds. They make the important point that while the activities are concentrated in the basin forests dominated by *Laguncularia* and *Avicennia*, the access provided by the ponds subjects the adjacent forests to selective harvesting of larger trees, including species of *Rhizophora*, thus producing forests with a low standing crop of trees. These basin forests are often characterized as "unproductive" in major shrimp aquaculture countries like Thailand, but Lahmann et al. (1987) point out that the local ". . . declining abundance of shrimp postlarva in Ecuadorean 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."

One of the authors (Lewis) has been examining the issue of pond restoration at field sites in Central America and the Philippines. Data on only the site in Central America has been fully developed and was recently presented at a meeting in Cuba (Lewis and Marshall 1997). Figures 4 through 7 show the study area on the Pacific coast of Central America. The site is a 20-year-old shrimp aquaculture facility that has had several owners and lay idle for approximately 5 years prior to its present owners purchasing it in 1987. It is significant that the owners have fully cooperated with the research effort, but only on the condition that the exact location not be revealed. They are concerned that the fact that some of the ponds have reverted back to mangroves might be interpreted by some as grounds to restore active ponds in the same manner. This fear may be part of the reason why reports of successful restoration are so rare.

The forests adjacent to the facility contain six species of mangroves: *Rhizophora mangle*, *R. racemosa*, *Avicennia bicolor*, *A. germinans*, *Pellicera rhizophora,* and *Laguncularia racemosa*. Two sites were chosen for quantitative sampling with two 5-m by 5-m plots established at each (four plots total). The first site (shown in Figure 4) was a 4-ha disused pond where the outboard dike had breached soon after the facility was purchased by the present owners in 1987. That breach is visible as location "A" in Figure 5. The owners decided not to repair the breach and to allow the pond to revegetate on its own in order to provide additional erosion protection from storm waves for the remainder of the ponds. The two plots were established at locations "B" and "C" in Figure 5. Location "C" is shown at ground level in Figure 7.

The two control plots were established at location "D" in Figure 5, with care taken not to place them in areas where mangrove pole cutting was visible. This is a remnant natural tidal stream with mangroves on both sides. All plots were sampled by measuring the diameter at breast height (DBH) of all mangroves over 2 m in height and recording the species. Measurements were then converted to basal area per tree, summed for each plot and reported as basal area in square meters per ha. All data are summarized in Table 1. As can be seen from the data, both the experimental and control areas contain the same species complement, with the same four mangrove species represented in each. These data indicate that, at this location, mangrove can naturally recolonize disused shrimp ponds and achieve a basal area equivalent to 64.2% of the natural undisturbed forest in 10 years. The stem density, as expected, is greater in the experimental plots, since the trees are younger and therefore more dense but smaller in average size.

**Table 1.** Summary data from plots in pond number 1 (under experimental rehabilitation) and mangrove forest control area.

| Site | Type | *Species* | Density ($m^2$/ha) | Relative density (%) | Basal area ($m^2$/ha) | Canopy height (m) |
|---|---|---|---|---|---|---|
| Plot 1 | Experimental | *Laguncularia racemosa* | 22,000 | 94.8 | 23.1 | 4 |
| | | *Rhizophora mangle* | 1,200 | 5.2 | 1.22 | 4 |
| Plot 2 | Experimental | *Rhizophora racemosa* | 2,800 | 38.8 | 7.04 | 10 |
| | | *Laguncularia racemosa* | 2,400 | 33.3 | 1.92 | 10 |
| | | *Avicennia bocolor* | 1,200 | 16.7 | 1.83 | 5 |
| | | *Rhizophora mangle* | 800 | 11.2 | 0.93 | 10 |
| | MEANS | | 15,200 | | 18.33 | |
| Plot 3 | Control | *Rhizophora racemosa* | 2,000 | 41.7 | 3.2 | 13 |
| | | *Laguncularia racemosa* | 1,600 | 33.3 | 9.5 | 8 |
| | | *Rhizophora mangle* | 800 | 16.7 | 0.6 | 10 |
| | | *Avicennia bocolor* | 400 | 8.3 | 13.72 | 12 |
| Plot 4 | Control | *Rhizophora racemosa* | 4,000 | 43.5 | 4.27 | 10 |
| | | *Laguncularia racemosa* | 4,000 | 43.5 | 19.51 | 8 |
| | | *Rhizophora mangle* | 800 | 8.7 | 4.27 | 12 |
| | | *Avicennia bocolor* | 400 | 4.3 | 10.64 | 10 |
| | MEANS | | 7,000 | | 28.53 | |

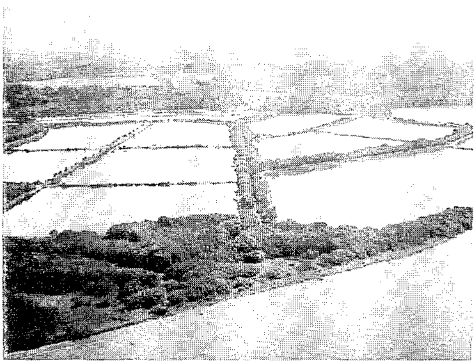

Figure 4. Aerial photograph of the study area, a commercial shrimp aquaculture facility constructed in mangroves on the Pacific coast. Photographed by Robin Lewis, September 1996.

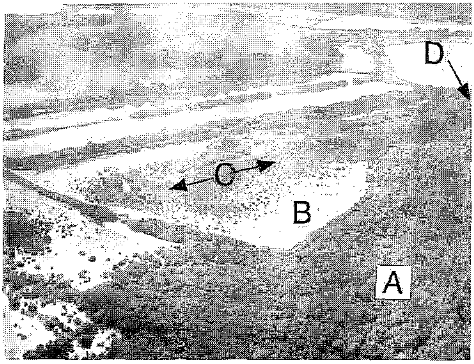


Figure 6. Aerial photograph showing pond number 2. Natural revegetation after breaching has not been as successful. "A" is an area of undisturbed mangroves, "B" is the open water unvegetated area of the pond, "C" is the naturally vegetated area of mangroves in the pond and "D" is the general location of the breach in the outer dike of this pond. Photographed by Robin Lewis, September 1996.

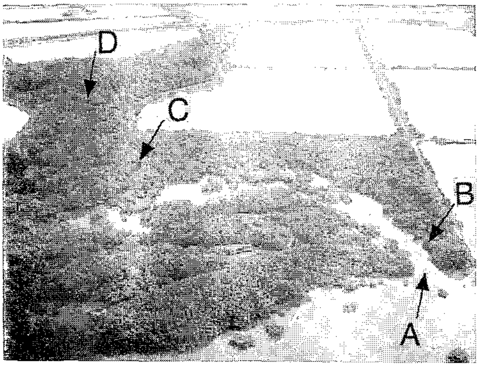


Figure 5. Aerial photograph showing pond number 1, a constructed shrimp aquaculture pond allowed to revegetate naturally with mangroves after the outer dike breached in 1987. "A" is the location of the natural breach, "B" is the location of the first sampling plot, "C" is the location of the second sampling plot, and "D" is the location of the third and fourth sampling plots. Photograph by Robin Lewis, September 1996.

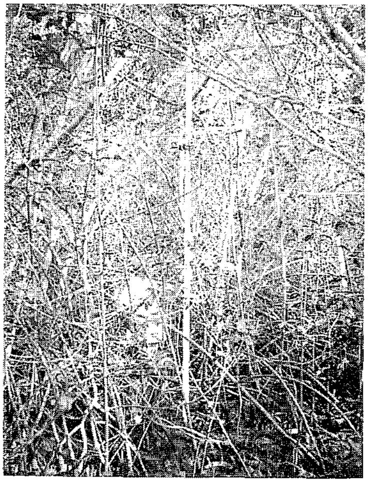

Figure 7. Ground level photograph of the mangroves in second sampling plot (naturally revegetated) inside pond number 1. The reference rod is 8 m long. The dominant species of mangrove are Rhizophora mangle and Rhizophora racemosa. Photographed by Robin Lewis, September 1996.

It is important to note that at another location on the facility, a similar but larger (25 ha) disused pond (Pond Number 2) of the same age has apparently not shown the same degree of recovery (Figure 6). The area was not quantitatively sampled due to access problems and time constraints, but it is apparent from the aerial photograph that natural recolonization has been limited to only the central area of the pond (Location "C"). Ground observations indicate that regeneration is composed almost entirely of species of *Avicennia* of low growth form. This would indicate some additional stress is present beyond that present in Pond Number 1.

Figure 8. Disused shrimp pond in Bohol, Philippines, that has no tidal reconnection (pond walls remain intact). After 15 years there has been no recolonization. Photograph by Robin Lewis, December 1997.

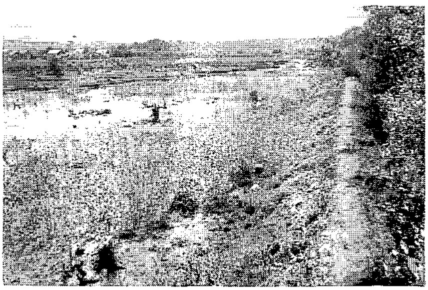

Figure 9. Breached disused shrimp pond in Bohol, Philippines, showing some recolonization of Avicennia marina after 5 years. Photographed by Robin Lewis, December 1997.

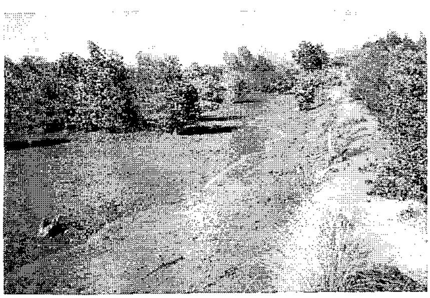

Figure 10. Breached disused shrimp pond in Bohol, Philippines, showing good recolonization of Avicennia marina after 15 years. Photographed by Robin Lewis, December 1997.

In all sites inspected to date, however, the most important factor in successful restoration of ponds back to mangroves is restoring the tidal hydrology to the maximum extent possible. The reduced species complement and restriction of natural recolonization to only the central core of Pond Number 2 were attributed to reduced tidal range and limited flooding likely caused by a restriction in the size of the natural breach (Location "D") connecting the pond to the adjacent open waters. Restoration of mangroves through restoring the natural hydrology has been emphasized before by Hamilton and Snedaker (1984), Cintron-Molero (1992), and Olsen and Arriaga (1989), who state that "where possible, mangroves should be restored through re-establishment of the natural hydrology." Turner and Lewis (1997) also give examples of successful restoration of mangroves through restored hydrology alone.

Our anecdotal observations of similar disused pond recolonization on the island of Bohol in the Philippines suggests that *Avicennia marina* is the initial colonizing species during years 1-5 after dikes are breached, followed by several species of *Rhizophora* and *Sonneratia* in years 5-15 (Figures 8, 9, and 10).

### *4.3 Challenges to Successful Pond Restoration*

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

1. Understand the autecology (individual species ecology) of the mangrove species at the site, in particular the patterns of reproduction, propagule distribution, and successful seedling establishment;
2. Understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species;
3. Assess the modifications of the previous mangrove environment that occurred that currently prevent natural secondary succession;
4. Design the restoration program to initially restore the appropriate hydrology and utilize natural volunteer mangrove propagule recruitment for plant establishment; and
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.

This can be demonstrated by the more common technique of collecting propagules of *Rhizophora* species and either planting them directly in the bare areas of Pond Number 2 (location "B" in Figure 5), or cultivating them in a nursery and planting them in the same location. What would be the expected outcome of these efforts? 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."

## 5. The Case for Pond Rehabilitation

The case for rehabilitation of degraded habitats largely depends on the comparative benefits derived from re-establishing the functions and flows of economic and environmental goods and services from the natural system compared to the benefits that the pond owner may realize by bringing sites back into some form of production. The more valuable the benefits to the various stakeholders, the stronger the case for rehabilitation. However many of the stakeholders who might benefit from restoring disused ponds to mangroves, such as artisanal fishers, may not be actively involved in the decision-making process that evaluates alternatives for rehabilitation. The cumulative benefits to such diffuse and often poorly represented stakeholders may in fact be very large, but they are seldom calculated. The argument is also not simply based on the perceived values of a system and the equitable use of its natural resources by different groups, but also on other factors such as the desire of a national government to earn high revenues from the export of cultivated shrimp.

One of the most obvious financial issues is the direct financial loss to the pond operator of revenue from shrimp sales (in the region of US$15,000 to US$25,000 $ha^{-1}yr^{-1}$) where pond production proves non-sustainable. There may also be the recognition that if some rehabilitation activity is not undertaken, the system may degrade further, and may actually represent a risk to neighboring habitats or land use types. This would be an economic cost. Damaged resources are often unstable and actively deteriorating, and in general if deterioration is not arrested, repair may become progressively more expensive and difficult (rehabilitation costs would be balanced against "costs avoided").

Alternatively, it may be recognized that by rehabilitating an area that has become degraded (either through shrimp culture and pond disuse or synergistic effects with these factors) and is perceived to be of low value, human pressure will be reduced on neighboring areas that are perceived to be of high value and are at risk of degradation themselves. The resulting production of useful goods and services in a rehabilitated or restored area may serve to reduce the pressure on unaltered areas, which may otherwise be at risk of exploitation.

Where ponds were converted from prior 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 people rely on subsistence agriculture or aquaculture. Where restoration to a "natural" habitat (such as mangrove) is considered inappropriate, technically very difficult, or too expensive, then rehabilitation 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. However, there is little in the literature that describes restoration to prior land use types (as opposed to habitat types).

In addition to these environmental and socio-economic arguments, there are sound economic reasons for returning an unproductive area to productive use. First there is the direct loss of revenue from shrimp production, and second, the loss of habitat that occurs as a result of pond construction results in the loss (or partial loss) of benefits from the economic and environmental goods and services that habitats normally provide. Mangroves are regarded as particularly rich in terms of the goods and services they provide and the functions they serve (Hamilton and Snedaker 1984, Burbridge 1990), 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 (for example, salt pan, marsh wetland, *Melaleuca* wetland, or mud flat).

In addition to the economic losses associated with degradation of the natural resource base, and the losses associated with the foreclosure of "options" for alternative forms of resource development, there is the loss of "non-market" values to consider. These include the functions and services provided by a habitat, such as 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 example West Bengal, Bangladesh, and some states in India, such as Andrha Pradesh), the buffering capacity and the erosion mitigation provided by mangrove is particularly important since the costs associated with the construction of artificial structures to combat erosion and to protect from storm damage can reach more than US$12,000 $m^{-1}$. 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 sea defenses and flood control structures. The benefits in such cases would be both financial in terms of costs avoided and also social in terms of the avoidance or minimization of the loss of human life and property.

Many ponds become disused or abandoned simply because they have been constructed in inappropriate locations. These can include locations where the farm density is already too high, where there is insufficient freshwater supply (shrimp optimally require brackish not fully saline water), where there is too much rainfall, or where there are unsuitable soils (for instance, very peaty or very sandy soils). Ponds have been constructed in locations regularly hit by typhoons or hurricanes (for example, India and Bangladesh) and in areas that are not normally hit by hurricanes but experience hurricanes during El Niño years (for example, along the Pacific Coast of Latin America and the United States). In September 1997, Hurricane Nora hit the Mexican shrimp farming industry and caused extensive damage to the industry. In such cases, pond rehabilitation would seem highly appropriate.

## 6. Pond Restoration

Although there have been many attempts at restoration of mangrove in degraded habitats, there are few documented cases of pond restoration. The data that do exist are often of poor quality, or else poorly disseminated and very difficult to obtain or to verify; consequently it is not possible to draw any substantive conclusions from them. Brief outlines of pond restoration efforts known to the authors are provided in this section. From the limited information available, it appears that in most cases evaluation procedures or assessment of pond condition do not take place prior to the initiation of pond restoration projects. Consequently the reasons behind either the success or failure of pond restoration projects are not known. Given the scope and technical complexity of the challenge of restoring the potentially large scale of disused and unproductive ponds, more rigorous approaches to the assessment of past and current restoration efforts must be developed.

*6.1 Haad Sai Khao, Ranong Province, Thailand*

Mangrove replanting has been successfully completed in a 2-ha disused shrimp pond in Haad Sai Khao in Ranong, Thailand. Poor productivity levels due to high acidity and poor shrimp survival caused pond operations to cease. In June 1992 the pond was replanted with four different species of mangrove to compare growth and biomass. The mangrove is reported to have grown very well, especially the *Rhizophora apiculata* and *R. mucronata* ("bai yai" and "bai lek") that have reached over 3 m tall after 4 years, according to a NACA newsletter (July-Sept 1997). The authors visited this site in January 1998 and the planted mangrove species were doing very well. Tidal inundation flows are good, and canals within the pond appear to have been dug to facilitate water flow. (More information about this project is available from Hakon Jalk at the Ranong office at 50/19 Moo 1, Tumbon Bangrin, Muang Ranong 85000, Thailand (email: tcep@loxinfo.co.th) or Donald Macintosh at CenTER Aarhus, Department of Ecology and Genetics, Institute of Biology, Building 540, Ny Munkegade, University of Aarhus, 8000 Aarhus C. Denmark.)

*6.2 Nakorn Sri Thammarat and Phang-nga Provinces, Thailand*

Work was initiated in 1994 between overseas researchers and the Royal Thai Forestry Department. Five species were planted. The species planted included *Rhizophora apiculata, R. mucronata, Bruguiera* spp., *Avicennia marina,* and *Ceriops* spp. (Buntoon Srethasirote, Personal Communication). An area of 10 rai (1.6 ha) was planted at a density of $1 m^{-2}$ and the survival rate was said to be "good" (Buntoon Srethasirote, Personal Communication). However, the time interval at which the survival rate was estimated is unknown; the survival rate may therefore appear to be good as a result of monitoring survivorship soon after planting, rather than at an interval of a year or more. The current status of this project is not known.

*6.3 Kuiburi and Pranburi Districts, Prachuap Khiri Khan Province, Thailand*

Poor water management and high farm concentrations are thought to have led to chronic disease problems that first occurred on a wide scale in early 1993. Disease difficulties continued intermittently for the following 3 years until almost all production ceased in late 1996 (Enright, Personal Communication). Pond disuse was comprehensive (approximately 500-600 ha in this area alone) and many farmers commenced production in new areas along the Andaman coast. Many of the disused ponds were within the boundaries of Khao Sam Roi Yot Marine National Park and the immediate surrounding areas. The park is an important bird wintering area and a critical stop-over for migratory shorebirds en route from Siberia to Malaysia and Indonesia. A small area of extensive disused ponds in the park was replanted by hired labor. This replanting is reported to have been reasonably successful (J. Enright, Personal Communication). The current status of this project is not known.

Mangrove replanting work was also initiated in a 30 rai area (5 ha) of salt pan (not mangrove) in Khao Sam Roi Yot Marine National Park by the Petchaburi Regional Forestry Office (under the direction of the park) utilizing local volunteer groups of school children. Preparation work for this project began in 1994, with the first planting occurring in the dry season of 1995, with a second series of planting in 1996. *Rhizophora apiculata, R. mucronata,* and *Ceriops tagal* were planted in the salt pan in the park area, but all seedlings died, and the project was repeated after the area was scraped with a tractor in order to lower the elevation to increase tidal inundation. From site inspections in this area by the authors in January 1998, it appears that the tidal inundation was insufficient and that hypersalinity was a problem.

As pointed out by Jim Enright (Personal Communication), there were areas in the park that were much more suitable for replanting with mangrove (for instance, along the natural khlongs). The areas of salt pan that were planted experience near arid conditions during the dry season and the plots required water pumping in order to maintain the seedlings. This procedure is expensive, time consuming, and labor intensive. Similarly a nursery area at the site has been established at the high tide mark; however, it appears that there is insufficient tidal flow at the nursery and the long-term future of the project does not appear promising.

### 6.4 Samut Songkhram Province, Thailand

An experimental study of the growth and survival rate of three species of mangrove seedlings planted in a disused shrimp pond was conducted at Samut Songkhram Province and the results are presented in Table 2 (Buntoon Srethasirote, Personal Communication). The density of mangrove replanting for this experiment was 1 plant $m^{-2}$ in a test area 9 m by 9 m. No other information on this site has been obtained.

**Table 2.** Survival rate of mangrove species planted in an abandoned shrimp farm in Samut Songkhram Province, Thailand. Source: Buntoon Srethasirote, Personal Communication.

| Species | Survival Rate (after 1 yearr) | Growth Rate (after 1 year) |
|---|---|---|
| *Rhizophora apiculata* | 66.67 | 45.73 |
| *Bruguiera gymnorrhiza* | 41.33 | 44.87 |
| *Ceriops tagal* | 0% ( by 8 months) | - |

### 6.5 Benoa Gulf, Bali, Indonesia

The authors have identified information on the world wide web (Ministry of Foreign Affairs Japan 1997) that outlines a joint project between JICA (the Japanese International Co-operation Agency) and Indonesia's Department of Forestry. The project began in 1992 (current status unknown) and took place along the Benoa Gulf. The three paragraphs of information describing the "Development of Sustainable Mangrove Management Project" state that "excessively high concentrations" of shrimp were grown in ponds, and that over-usage of antibiotics led to the development of disease-resistant bacteria that rendered the ponds "unusable."

The article goes on to state that "farmers abandon these ponds and shift their operations to another area" and notes that Landsat satellite imagery clearly demonstrated the widespread damage to the mangrove forests in the region. Unfortunately the article does not provide any details of the methodologies used or the project findings and merely outlines that "experts from JICA have continued to make thorough tests of which species are suited to which locations, from sprouts through forests: now, young mangrove trees are growing in abandoned shrimp raising ponds." For 2 consecutive years the authors have tried, but failed, to obtain further information about this project. This is unfortunate since much useful and more widely applicable information might have been generated by this project.

A personal account by J.R. Clark (Personal Communication) reveals a different story behind a pond-replanting scheme in an unspecified region (perhaps Benoa Gulf) in South Bali. Shrimp culture was concentrated in a government owned mangrove area. In 1991, there were about 160 ha leased by the government to private entrepreneurs. The Governor of Bali decided to phase out all shrimp farming leases over 4 years—from 160 ha to 0 ha by 1995. Approximately 350 ha of shrimp ponds were replanted with the support of JICA and the Forestry Department who engaged in various publicity deals, such as recruiting Japanese students on vacation to plant some ponds (J.R. Clark, Personal Communication).

The replanting approach was reported as being "low tech," but the ponds themselves were "low tech," that is, crude and largely scraped out from natural sinks in the mangrove fringe. It appears that replanting simply consisted of planting seedlings in the ponds with little or no other preparation or maintenance work. It is thought that replanting started with the crudest (shallowest) ponds with the intention of progressing to more "advanced" ponds (J.R. Clark, Personal Communication). No further information on this scheme has been obtained, and the success of this project is not known.

## 7. Biophysical Uncertainties

Whilst there appears to be a distinct lack of studies qualifying the environmental characteristics that remain in a pond after disuse, there has been some debate on the re-use potential of disused ponds. Some authors have commented on the condition of ponds and surrounding lands after disuse. For instance, Marsden (1994) reports with reference to Thailand that the land abandoned after shrimp culture is "salinized and polluted and has few economic uses." Similarly Landesman (1994) reports that "the bottom soil of an abandoned shrimp pond that has been used for intensive culture is usually too saline for agriculture or other uses, so that conversion of land to shrimp farming may, for practical purposes, be irreversible." However, quantitative assessment of these problems is lacking, and the debate continues.

Disused shrimp ponds in many cases represent highly degraded systems; although difficult to substantiate, intensively farmed sites and those located in acid sulfate soils may be the most severely degraded. However, it must be remembered that extensively farmed ponds generally cover a greater area than intensively farmed ponds, and may represent a problem more in terms of quantity rather than quality.

In the absence of studies quantifying the environmental effects of disused ponds, it is only possible to put forward hypotheses of alterations to physical processes that may result from the existence of significant areas of disused shrimp ponds. It is also only possible to hypothesize the effects these alterations will have on the surrounding locale. Possible alterations to physical processes may include alterations to sedimentation rates, the hydrodynamics of the area, the tidal regime, and nutrient flows (Stevenson 1996). Discontinuities in habitat arising from large areas of ponds in a locale may alter faunal movements (for example, fish and crustaceans), and therefore may affect faunal distributions. Loss of habitat may lead to a decrease in nursery and breeding grounds and may serve to decrease shoreline protection capabilities.

It is important to realize that some processes that may have occurred as a result of clearance, shrimp culture, and disuse are irreversible and that no amount of restoration effort can return certain parameters to their prior condition. For instance, the recreation of prior soil condition may be next to impossible due to the complex interactions that take place in soils and the nature of coastal soil profiles. In many mangrove areas acid sulfate soils exist in a reduced form, known as "potential acid sulfate soils," and as a result of the excavation and construction of the shrimp ponds potential acid sulfate soils become oxidized, forming actual acid sulfate soils. It is not possible to convert actual acid sulfate soils back to potential acid sulfate soils but it may be possible to transform actual acid sulfate soils to a pH neutral soil that has less acid producing capacity (J. Sammut, Personal Communication). In cases where irreversible changes have occurred, the best that could be hoped for would be a return to similar conditions or to conditions regarded as stable.

The oxidation of potential acid sulfate soils can be a serious problem. The acidic water resulting from actual acid sulfate soils destroys food resources, displaces biota, releases toxic levels of aluminum, and alters the physical and chemical properties of the water (Sammut et al. 1996). Persistent alterations to pH can lead to changes in the flora and fauna by favoring acid tolerant species. It is significant to note that during shrimp culture the effects of acid sulfate soils can be ameliorated by additions of lime, but that after abandonment such efforts cease. The management of acid sulfate soils has now become a matter of urgency because they are more difficult to treat as they age (J. Sammut, Personal Communication). However, it is not known if or to what degree moderately acid sulfate soils affect mangrove recolonization; mangrove seedlings may be sensitive to moderately acid sulfate soils, whereas mature trees may not.

As early as 1982 Ong (1982) stated that it is not known if mangroves will recolonize ponds disused as a result of acid sulfate conditions. Acid sulfate soils are a particularly difficult problem since they can persist for long periods and are expensive and time consuming to treat (J. Sammut, Personal Communication). Depending on the local conditions, and the hydrological changes made to enable shrimp culture, acidification may firstly increase, before declining, unless there are some attempts at restoration. This is supported by Sammut and Mohan (1996) who draw attention to the potential for environmental degradation and economic losses if changes in land use do not address the acidification problem. They point out that recurrent acidification interferes with ecosystem recovery, and that habitat may be degraded further as a result of acid sulfate soils.

Unfortunately, one of the issues with acid sulfate soils is that attempts to restore them may cause other problems. For example, reflooding ponds with acid sulfate soils may increase small acid events, floc out iron that may clog aquifers and smother stream beds, and extend saline water into areas it previously did not enter. Consequently, restoration activities involving acid sulfate soils management must be carefully planned, monitored, and appraised (J. Sammut, Personal Communication).

Disused ponds that are severely degraded but stable may not warrant expensive and active restoration efforts (such as planting), and merely re-instating conditions conducive to natural regeneration may prove sufficient. However, if a pond is disused in an unstable state, this may lead to further degradation of the pond and may pose a risk to nearby areas; however, to what extent this occurs is not known. Such cases may warrant the costs of active restoration, since there is a risk of further degradation if restoration is not undertaken. Restoration may therefore serve to act not only as a correction measure, but as a prevention measure (Stevenson 1996).

Disused shrimp farms may lead to further habitat degradation as a result of increased soil erosion, due to structural and compositional changes to the soil and the lack of protective cover of vegetation. This has occurred in Sri Lankan farms that have been abandoned due to improper site selection and has resulted in the creation of areas of unprotected, bare land that have been subject to soil erosion (Jayasinghe 1995).

There may be changes in biota resulting from shrimp culture operations, particularly where exotic species have been cultured or where antimicrobials and chemicals have been used throughout culture. There is much evidence to suggest that antimicrobials and disinfectants used in salmon culture alter the microbial flora of sediments underneath salmon cages. Antibacterial agents have been shown to accumulate in culture organisms and the benthos in intensive aquaculture systems, and it would seem to be likely that the use of such chemicals in shrimp ponds would have similar long-term results to those found in salmon culture. How this alters restoration prospects or alternative uses for ponds is uncertain.

A further consideration is the alteration to soils that are likely to occur as a result of the clearance of mangrove and later pond disuse in either a drained or flooded state. Changes from shrimp culture are likely to vary with farming method and culture intensity. However, the effects of clearance and disuse may include accelerated soil erosion due to increased surface run-off and subsoil surface flow; decrease in soil water storage capacity; reduction in biodiversity of soil fauna; transport of sediments, dissolved inorganic and organic constituents and principal nutrients; and depletion of soil organic matter through leaching and mineralization (Stevenson 1997).

As neatly summarized by Flaherty and Karnjanakesorn (1995), "the abandoning of aquaculture developments represents a significant challenge to the productive use of coastal areas in the future because of the limited land use prospects for vast areas of former rice fields and mangrove forest. The rehabilitation of these areas is complicated by the fact that many of the environmental conditions that once fostered the growth of mangrove forests have been removed or severely altered." When considering options for redeveloping disused ponds, it is important that the environmental parameters remaining in a pond are identified. To date little work has been conducted to elucidate the conditions found in disused ponds, or to identify what implications these biophysical uncertainties may have for future uses.

## 8. Other Considerations

There must be careful consideration of how sensible it is to suggest that an area be restored if the risk of similar degradation occurring again is high. This may seem self evident, but there are many examples of restoration failure because the socio-economic needs of local inhabitants have not been considered. Rehabilitation to a sustainable and managed use, rather than restoration (*sensu stricto*) for conservation purposes, may be a more sensible option (Stevenson 1996).

Development activity that is occurring or is likely to occur in the region or locale of abandoned shrimp ponds should also be considered. For instance, there is little point in expending time and money in restoring a disused shrimp pond if new ponds are likely to be constructed in the vicinity, particularly if construction requires the clearance of relatively healthy mangrove. It would make much better sense to attempt production in the disused ponds and thereby avoid the costs of new pond clearance and the costs of replanting in disused ponds. Similarly, there is little point in replanting disused ponds if the area is likely to be urbanized. Some shrimp farms in the Mai District, Chanthaburi Province, Thailand were originally located in degraded mangroves areas that were not regarded as potential candidates for restoration activity since urban expansion was threatening the area.

Other constraints include a general lack of technical expertise in restoring habitats and an even greater lack of experience of restoring disused shrimp ponds. A further difficulty is that in many cases large conglomerate/corporate groups either own or have use rights to pond sites but are reluctant to rehabilitate or convert these ponds since shrimp culture may be possible in these sites again in the future. At one end of the scale the most important need may be to create sustainable livelihoods for individual pond operators, but at the other end of the scale there may be a strong case to restore large expanses of ponds owned or managed by conglomerates (whether national or international) that were built in wetland areas.

Perhaps even more crucially, the preferences of the pond owners/operators themselves must be taken into account and market forces must be considered when identifying potential alternative uses, and economic feasibility must be assessed (Stevenson 1997). Tri (1996) quantified the economic benefits of mangrove rehabilitation (taking the costs of rehabilitation into account), and found that mangrove rehabilitation can be desirable and feasible from an economic perspective based entirely on the direct use benefits by local communities, and that when indirect use benefits are incorporated into the analysis, the benefits of rehabilitation far outweigh the costs.

It may be possible to create financial disincentives to habitat destruction, such that the costs of destroying or denuding a habitat might be raised to a level that matches or exceeds the cost of keeping or replacing it. However, this would not speed the rehabilitation of ponds that have been left idle historically, and consequently other means of catalyzing and funding rehabilitation or restoration activities must be found. The use of strategic incentives (whether financial or otherwise) may be essential to "creating" a motivation to restore or rehabilitate. Finally, the issue of who bears the costs of rehabilitation must be considered. This is an issue of considerable importance and subject to ongoing debate.

## 9. Conclusions

The terms "disused" or "abandoned shrimp ponds" are no-longer labels to be shunned or skirted around. The authors hope that the days where disused shrimp ponds were cited as evidence to denigrate and point accusatory fingers towards the shrimp industry are gone. Instead a real determination to tackle the issue appears to be emerging and all those involved should continue to focus on solving the issue and resist the temptation to lay blame. That is not to say that the reasons for disuse should be ignored; these are very important and should be examined as part of a logical evaluation of disused shrimp ponds.

Though difficult, and still somewhat politically sensitive, an important step may be to quantify the scale of disused shrimp ponds in the most affected of the fifty or more shrimp producing nations (in the first instance this could include Thailand, the Philippines, and India). The results will never be static but key areas of wetland habitat (for example, marsh and mangrove), other important natural habitats (for example, natural salt flats), and important cultivated areas (for example, rice paddy fields) that have been degraded by unsustainable shrimp culture should be mapped and priorities established 1) to study the physical characteristics of those areas, 2) to study the processes leading to degradation, and 3) to identify those areas most suitable for rehabilitation (Stevenson *et al.* 1998).

Alternative, desirable, and feasible uses for disused ponds that can no longer sustain shrimp production, and that are judged to be poor candidates for restoration (*sensu stricto*), should be identified, tested, evaluated, and demonstrated. The resulting information should be used to develop a rationale and practical decision support "question and answer" system that can be applied and utilized elsewhere (Stevenson *et al.* 1998).

Lewis (in review) 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." 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."

It is unfortunate that much of the research into pond rehabilitation that has been carried out to date has been conducted without adequate site assessment and without documentation of the methodologies or approaches used, and that it often lacks subsequent follow-up or evaluation. Unsuccessful (or only partially successful) projects are rarely documented and information on them is largely anecdotal and very hard to obtain. If and when documentation is found, the data collection and reporting formats are not standardized, and comparisons between data cannot therefore routinely be made. The development of "common methodologies for assessing environmental impact" is one of the recommendations made as a result of the joint Food and Agriculture Organization and Network of Aquaculture Centres in Asia-Pacific Regional Workshop in 1994 (FAO/NACA 1995). This common methodology approach should be extended to assess shrimp aquaculture, to habitat restoration projects, and to studies of disused ponds. Those involved could then begin to learn from successes or failures, act more effectively, and reach a wider target audience.

The simple application of the five steps to successful mangrove restoration outlined in this chapter would at least insure an analytical thought process and less use of "gardening" of mangroves as the solution to all mangrove restoration problems. While simply breaching dikes seems to be one solution, it is not always so easy. The location and size of breaches is important, as shown in Section 4.2, where an inadequate breach limits tidal exchange and therefore natural recovery. Successful restoration will, however, only occur when adequate training programs are in place and those involved begin to "learn from mistakes" and utilize the basic principles of adaptive management.

The good news is that more information is appearing in the literature; the admission of the existence of disused ponds is increasingly being seen as a step forward along the path towards solving the problem, and more dialogue between researchers, research groups, aquaculturists, and governmental bodies is occurring. The authors hope that this piece of work will go some way to promote dialogue and co-operation between all concerned parties and will facilitate the active management of disused shrimp ponds.

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