Shrimp Farming and the Environment

Thematic Review on
Coastal Wetland Habitats
and Shrimp Aquaculture

A Consortium Program of:

NACA

WWF

THEMATIC REVIEW ON COASTAL WETLAND HABITATS AND SHRIMP AQUACULTURE

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Preparation of this document

The research reported in this paper was prepared under the World Bank/NACA/WWF/FAO Consortium Program on Shrimp Farming and the Environment. Due to the strong interest globally in shrimp farming and issues that have arisen from its development, the consortium program was initiated to analyze and share experiences on the better management of shrimp aquaculture in coastal areas. It is based on the recommendations of the FAO Bangkok Technical Consultation on Policies for Sustainable Shrimp Culture[1], a World Bank review on Shrimp Farming and the Environment[2], and an April 1999 meeting on shrimp management practices hosted by NACA and WWF in Bangkok, Thailand. The objectives of the consortium program are: (a) Generate a better understanding of key issues involved in sustainable shrimp aquaculture; (b) Encourage a debate and discussion around these issues that leads to consensus among stakeholders regarding key issues; (c) Identify better management strategies for sustainable shrimp aquaculture; (d) Evaluate the cost for adoption of such strategies as well as other potential barriers to their adoption; (e) Create a framework to review and evaluate successes and failures in sustainable shrimp aquaculture which can inform policy debate on management strategies for sustainable shrimp aquaculture; and (f) Identify future development activities and assistance required for the implementation of better management strategies that would support the development of a more sustainable shrimp culture industry. This paper represents one of the case studies from the Consortium Program.

The program was initiated in August 1999 and comprises complementary case studies on different aspects of shrimp aquaculture. The case studies provide wide geographical coverage of major shrimp producing countries in Asia and Latin America, as well as Africa, and studies and reviews of a global nature. The subject matter is broad, from farm level management practice, poverty issues, integration of shrimp aquaculture into coastal area management, shrimp health management and policy and legal issues. The case studies together provide an unique and important insight into the global status of shrimp aquaculture and management practices. The reports from the Consortium Program are available as web versions (http://www.enaca.org/shrimp) or in a limited number of hard copies.

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[1] FAO. 1998. Report of the Bangkok FAO Technical Consultation on Policies for Sustainable Shrimp Culture. Bangkok, Thailand, 8-11 December 1997. FAO Fisheries Report No. 572. Rome. 31p.

[2] World Bank. 1998. Report on Shrimp Farming and the Environment – Can Shrimp Farming be Undertaken Sustainability? A Discussion Paper designed to assist in the development of Sustainable Shrimp Aquaculture. World Bank. Draft.

Abstract

Interactions between coastal wetland habitats, particularly mangroves, and shrimp aquaculture, have received considerable attention in recent years. The review begins by documenting the status of shrimp aquaculture in relation to mangrove forest ecosystems. The environmental, social and economic impacts of shrimp farming are discussed, with examples covering both the negative and positive aspects of the sector.

The main section of the review considers interventions and other activities to improve the sustainability of shrimp farming in the context of coastal zone management and the protection of mangrove ecosystems. Over the past decade, understanding of the relationship between shrimp farming and the environment have led to various efforts to mitigate the negative impacts of aquaculture on coastal habitats. These include: zoning schemes to confine aquaculture outside wetland conservation areas; changes in farm management practices; introduction of new legislation to protect the environment (e.g. controls on farm effluent discharge); initiation of dialog among shrimp farmers through forums such as farmers societies and associations, and dialogues with non-governmental sectors, increased research and development efforts.

The effectiveness of these interventions is considered here in the light of experience based on case studies. A format for the case studies was prepared at a workshop held in Bangkok, Thailand on 14th – 16th February 2000. The expert group invited to the workshop also identified a list of potential case studies for this thematic review and considered how information from each case study should be incorporated into the synthesis. The case study analyses highlight the effectiveness of efforts made, the underlying reasons for successes or failure, their strengths and weaknesses, and identify where research and other further efforts are most required. The 14 case studies used to support this synthesis are provided in a separate Annex. Some of the case studies are based on country level experiences; others are more specific to a particular locality where there is a record of good environmental management related to shrimp farming.

This review document, together with the case studies, attempts to cover the following major questions and issues related to shrimp farming and coastal wetland habitats:

- What are the major interactions between shrimp farming and coastal wetlands? Is it possible to estimate the mangrove habitat damage from the industry/sector in terms of direct and indirect economic loss, employment, social implications, etc.?
- What strategies are being used to rehabilitate both shrimp ponds and coastal wetlands? Which strategies are most compatible/complementary? What are the major issues and what can be learned from these experiences? Is it possible to develop a set of 'best practice' guidelines for the rehabilitation of coastal wetlands and shrimp ponds?
- What are the experiences regarding the management of clusters of farms/ponds, to mitigate impacts and ameliorate environmental conditions at the medium scale? In particular, what are the experiences regarding management of water flows/cycles in larger wetland bodies?
- What are the experiences regarding co-existence of shrimp/aquaculture production areas and wetland nature reserves and multiple use conservation parks? What are the links to community management and the sustainable multiple use of resources under such schemes?
- What are the social, economic, and institutional issues to consider? How can pond and wetland habitat rehabilitation efforts be best integrated into coastal area management programmes?
- What farming systems, technologies and management practices should be considered for aquaculture in coastal mangrove and other wetland habitats? How successful have mixed aquaculture-silviculture farming systems been? What lessons can be learned regarding the scope for further interventions to promote the coexistence of shrimp aquaculture and coastal wetlands?
- What are the options for promoting coastal (aquatic) polyculture systems, in combination with mangroves and other coastal wetlands?
- What is known about the biodiversity in areas that have been fully or partially denuded of

- mangroves, and similar areas where mangroves are still intact?
- Are there any working models demonstrating that coastal aquaculture, especially shrimp farming, can exist within rather than supplanting the mangrove forest area?
- What are the key issues and needs for further development of best practices for shrimp aquaculture development in coastal habitats?

Contents

Introduction

General Background

World aquaculture production continues to grow rapidly. In 2000, global aquaculture production reached 45.71 million metric tonnes, with a value of US$ 56.47 billion. Although crustaceans represented only 3.6% of total production by weight, they comprised 16.6% of total global aquaculture by (farm gate) value in 2000. The annual percent rate of growth (APR) of the shrimp farming sector has been significantly higher than other food production sectors , although in terms of growth, shrimp production has decreased to more modest levels over the last decade (averaging 5%) relative to the double-digit growth rates which were observed during the 1970's (23%) and 1980's (25%). The rapid expansion in shrimp farming, fuelled by high profitability and strong demand mainly from affluent consumers in importing countries, has provided a number of developing countries in Asia and Latin America with substantial foreign currency earnings from shrimp exports.

In both Asia and Latin America, shrimp farming has emerged as a main source of employment and income for hundreds of thousands of people. Additional employment and income is generated by associated industries e.g. feed mills, ice plants, drug and chemical suppliers, as well as in shrimp processing and distribution, including retailing and exporting. Estimates for the main shrimp producing countries puts the total employment generated by shrimp farming at around 2 million people (Singh 1999). Thailand and Indonesia alone have about 400,000 people directly employed in shrimp farming, with significant economic benefits for the rural economies in these and other shrimp producing countries. As a specific example, Singh (1999) noted that the lowest paid category of shrimp farm worker in Mexico earned an average salary in 1996 equal to 1.22 times the average annual income for that year in the country. Returns from shrimp farming continue to be high, benefiting small-scale farmers and communities, as well as larger-scale entrepreneurs. Most shrimp farming in Asia is still undertaken by small-scale farmers owning less than 5 ha of land in rural coastal areas. Because earnings from the production, export and trade of shrimp products are so significant, expansion of shrimp farming continues in Asia and Latin America, and there is growing interest in Africa, where there has been relatively limited shrimp farm development so far.

Growth of shrimp culture has also raised controversy in both the shrimp producing and shrimp importing countries. Public opinion is being influenced by high profile concerns over environmental and social impacts of shrimp culture development, food safety issues, and, more generally, the long-term sustainability of shrimp farming practices. Major issues raised include the ecological consequences of mangrove conversion to shrimp ponds; salinization of groundwater and agricultural land; pollution of coastal waters from pond effluents; biodiversity issues arising from the collection of wild shrimp seed; and social conflicts between shrimp farmers and other coastal resource users. The 10 largest producers of farmed shrimp in 2000 (accounting for over 90% of world production) are also, with the exception of China, countries with significant mangrove resources (Table 1).

Shrimp farming sustainability has come into question because of “self-pollution” when too many shrimp farms are crowded together in a single production area, and the emergence of pathogens, which have led to economically debilitating outbreaks of shrimp disease. Such problems are in part due to the over rapid expansion of shrimp farming, with insufficient attention given to appropriate site selection, farm design, to sustainable farm-level management systems, and the lack of effective regulatory and institutional support. On the larger scale, planning and co-ordination of the sector’s development, together with poor planning and management of coastal areas and their resources, generally have not kept up with the rapid (and all too often unplanned) pace of aquaculture development. Compounding this problem, several of the leading shrimp-producing countries have coastlines that support exceedingly high human populations (most notably Bangladesh, India, Indonesia, and Vietnam), creating an exceedingly complex human and natural resource management environment.

Background to the Thematic Review

A program entitled ***Shrimp Farming and the Environment***, consisting of case studies in a number of shrimp farming countries and several thematic reviews, has been jointly financed and executed by a consortium of the World Bank, NACA, WWF, and FAO. The program is based on the outcome of an April 1999 expert meeting in Bangkok (NACA/WWF 1999), recommendations of the World Bank review on shrimp aquaculture and the environment, and other ongoing initiatives and recommendations, including the FAO Bangkok consultation held in December 1997 (FAO 1997). The program activities are generally directed towards implementation of the Code of Conduct for Responsible Fisheries, with the following goals:

1. Generate a better understanding of key issues involved in sustainable shrimp aquaculture;
2. Encourage a debate and discussion around these issues that leads to consensus among stakeholders regarding key issues;
3. Identify better management strategies for sustainable shrimp aquaculture;
4. Evaluate the cost for adoption of such strategies as well as other potential barriers to their adoption;
5. Create a framework to review and evaluate successes and failures in shrimp aquaculture which can inform policy debate on management strategies for sustainable shrimp aquaculture; and
6. Identify future development activities and assistance required for the implementation of improved management strategies that would support the development of a more sustainable shrimp aquaculture industry.

Table 1. The top 25 producers of farmed shrimp in 2000 by weight and value. Source: FAO (2002).

Country/Territory	Production(MT)	Production (,000 US$)
Thailand	299,700	2,125,384
China	217,994	1,307,964
Indonesia	138,023	847,429
India	52,771	393,938
Vietnam	69,433	319,392
Ecuador	50,110	300,660
Philippines	41,811	271,385
Bangladesh	58,183	199,901
Mexico	33,480	194,184
Brazil	25,000	175,000
Malaysia	15,895	124,577
Colombia	11,390	91,120
Sri Lanka	6,970	78,342
Taiwan, Province of China	7,237	60,483
Honduras	8,500	59,500
Venezuela	8,200	34,030
Australia	2,799	27,557
Madagascar	4,800	24,000
Nicaragua	5,411	17,423
USA	2,163	14,513
Belize	2,648	12,710
New Caledonia	1,723	12,061
Costa Rica	1.350	11,475
Panama	1,212	6,399
Peru	512	3,741

Approach Taken

The interactions between coastal wetland habitats, particularly mangroves, and shrimp aquaculture, have received considerable attention in recent years. The review begins by documenting the status of shrimp aquaculture in relation to mangrove forest ecosystems. Environmental, social and economic impacts of shrimp farming are discussed, with examples covering both the negative and positive aspects of the sector.

The main section of the review considers interventions and other activities to improve the sustainability of shrimp farming in the context of coastal zone management and the protection of wetland ecosystems, with an emphasis on coastal mangroves. Over the past decade, understanding of the relationship between shrimp farming and the environment have led to various efforts to mitigate the negative impacts of aquaculture on coastal habitats. These include: zoning schemes to confine aquaculture outside wetland conservation areas; changes in farm management practices; introduction of new legislation to protect the environment (e.g. controls on farm effluent discharge); initiation of dialog among shrimp farmers through forums such as farmers societies and associations, and dialogues with non-governmental sectors, increased research and development efforts.

The effectiveness of these interventions is considered here in the light of experience based on case studies. A format for the case studies was prepared at a workshop held in Bangkok, Thailand on 14th-16th February 2000. The expert group invited to the workshop also identified a list of potential case studies for this thematic review and considered how information from each case study should be incorporated into the synthesis. The case study analyses highlight the effectiveness of efforts made, the underlying reasons for successes or failure, their strengths and weaknesses, and identify where research and other further efforts are most required. The case studies used to support this synthesis are provided in separate Annexes[3]. Some of the case studies are based on country level experiences; others are more specific to a particular locality where there is a record of good environmental management related to shrimp farming.

Invited specialists then prepared the selected case studies. After editing, these studies were used as the key reference material for this synthesis report, which was written by a team of four experts, Roy R. "Robin" Lewis III, Barry Clough, Michael Phillips and Donald Macintosh. James Machin, Jesper Clausen Sunil Pednaker, Thomas Nielsen and others provided additional contributions. An editors' meeting was held in NACA during October 2000 to discuss the draft review, and to prepare jointly the Executive Summary and recommendations sections. The draft report was peer reviewed, before being submitted to the World Bank in draft form in February 2001. Michael Phillips and Robin Lewis made a final update and edit prior to publishing in September 2003.

Scope and Objectives of the Thematic Review

This synthesis does not provide a general review of mangroves, as there are already a considerable number of excellent publications on the subject. We would refer interested readers to "Mangrove Ecology, Silviculture and Conservations by Peter Saenger (2002) for the latest scientific discussion of most of the backgroud information on mangrove forests. The review focuses on shrimp aquaculture, but also includes references to other forms of aquaculture where relevant, namely integration (silvo-fisheries) polyculture (e.g. shrimp with finfish), rotation (e.g. mud crab alternated with shrimp) and diversification (e.g. shrimp ponds converted to milkfish ponds) (see case studies based on experiences of integrated aquaculturre in Indonesia and Vietnam). There is a strong focus on (a) farm level management practices of coastal aquaculture, including the role of codes of conduct and practice for shrimp farming; (b) on policy towards mangroves and aquaculture development; and (c) on mangrove restoration/rehabilitation. Frequent

[3] Annexes are available on the Shrimp Farming and the Environment web site at www.enaca.org

reference is made in the review to specific ‘practical examples’ under these three headings, which are provided by the case studies in separate Annexes.

The review, together with the case studies, attempts to cover the following major questions and issues related to shrimp farming and coastal wetland habitats:

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In discussing the overall or development objectives of the Thematic Review, the planning meeting in February 2000 recommended that management strategies to be discussed in the review, and the overall thrust regarding best practices for shrimp aquaculture development, should be directed towards the following developmental objective, or ‘guiding principles’:

“To promote coastal aquaculture in an environmentally responsible manner, adopting the principles of co-existence of mangroves and aquaculture, of supporting the livelihood needs of local communities, and of promoting a net increase in mangrove area where this is a policy of the country concerned.”

The review is therefore presented with this development objective in mind.

Problem Analysis

Functions and Attributes of Mangroves

The natural history and ecology of mangrove ecosystems have interested scientists for decades (e.g. Carter 1957; Macnae 1968; Tomlinson 1986; Hogarth 1999), while their contributions to forestry, fisheries and aquaculture production are also well documented (Watson 1928; Schuster 1952; Odum and Heald 1972; Martosubroto and Naamin 1977; Turner 1977; Gan 1995, Saenger 2002). However it is really only within the past 10 years or so that the many functions, attributes and values of mangroves have become more widely recognised and appreciated (Tables 2 and 3).

Table 2. Summary of the uses, functions and attributes of mangroves.

Uses	Functions	Attributes
Forestry	Flood mitigation	Biological diversity value
Agriculture	Prevention of intrusion of saline waters	Socio-economic values
Salt production	Storm protection	Cultural Value
Food, drugs, beverages	Sediment trapping	Historic value
Fuelwood, charcoal	Toxicant removal	Aesthetic value
Fishing/aquaculture materials	Groundwater recharge	Wilderness value
Household items	Erosion control	Educational value
Textile and leather production	Nutrient export	Research value
Agriculture	Wildlife habitat	
Construction materials	Fish/shellfish habitats	
Water supply	Protection of offshore habitats	
Wildlife protection	(Coral reefs, sea-grass beds)	
Recreation/tourism		
Research site		
Education site		
Transport routes		

Source: Modified from Macintosh 1997.

Mangroves are opportunistic colonisers of intertidal areas along tropical and subtropical coasts. Within their climatic range, the local hydrological regime is the key factor influencing the establishment, structure and growth of mangrove forests. Mangroves flourish on sheltered tropical shores, especially where large river systems deposit alluvial sediments and coastal salinities are moderated by high freshwater discharge. The overall hydrological regime depends on many factors, including the geomorphical setting, local topography, sediment type, tidal amplitude, waves, currents, rainfall, freshwater flows (both riverine and subsurface) and catchment hydrology (Kjerfve, 1990). At the same time, the presence of mangroves affects the hydrological regime by modifying tidal flows and velocities, influencing sedimentation and erosion patterns, and reducing the impact of waves along the coast (Wolanski et al, 1992). Thus, mangrove systems are highly dynamic, both in the short term, and over the longer-term.

Although the environmental, biological and economic attributes of mangrove forests are now more widely appreciated, they are usually difficult to quantify accurately (for reviews and analysis of the relevant literature see Saenger et al, 1983; Hutchings and Saenger, 1987; Robertson and Alongi, 1992; FAO, 1994; Wilkinson et al, 1994; White and Cruz-Trinidad, 1998). One reason for this is that mangrove systems are very diverse. Their diversity results from the wide range of climatic, hydrological and edaphic (soil) conditions in which mangroves grow, and the varying nature and intensity of human impacts to which they are exposed. Consequently, the structure and productivity of mangrove systems, and their linkages to both upland terrestrial and seaward aquatic ecosystems, is highly variable (Robertson and Alongi, 1992; Saenger and Snedaker 1993). It is therefore almost impossible to define a 'typical' mangrove community or ecosystem, even for coastal areas that are relatively undisturbed by human activities. These features of mangrove ecosystems have an important bearing on the policy and management issues affecting aquaculture development.

Nevertheless, there are a number of core ecological functions that are common to most mangrove forests, the best documented of which is their role as habitat (especially nursery and feeding grounds) for a wide range of benthic and pelagic aquatic species (Robertson and Duke 1990; Vance et al. 1990 and 1996), but see Sheridan and Mays (2003) for a recent review of this issue. Organic materials produced by mangroves (mainly, but not exclusively leaf litter) are the foundation for complex estuarine and nearshore food webs involving bacteria, fungi, meiofauna (animals less then 1 mm in size) and macrofauna at all levels of organisation, often culminating in commercial shrimp and fish species (e.g. Odum and Heald 1972; Singh et al. 1994; Blaber 2000). In addition, the complex root systems of mangroves provide a protective habitat for many aquatic species, such as juvenile shrimp (Thayer et al. 1987). These core functions of the mangrove ecosystem also provide significant social and economic benefits to coastal communities, mainly from artisanal and commercial fisheries that are linked directly or indirectly to mangrove-dominated estuaries and shorelines (e.g. Turner 1977; Staples et al. 1985; White and Cruz-Trinidad 1998; Blaber 2000).

The habitat and nursery functions of mangrove systems are vital for maintaining the rich diversity of aquatic, terrestrial and avian fauna (Schodde et al. 1982; Hong and San 1993). Over hundreds of years this biodiversity has helped to sustain the social and economic well being of traditional mangrove forests dwellers and many other local people dependant on mangrove-associated fisheries. The mangrove products they use are diverse and include timber and fuelwood, bark for tanning leather, thatching materials, honey, and traditional medicines (Ong, 1982, Chan and Salleh, 1987, Hong and San, 1993). In Bangladesh, for example, almost 300,000 forest harvesters collect wood and other materials daily in the Sundarbans Reserve Forest. And it is estimated that for each harvester, there are 2.3 additional people working in direct association, plus many more employed in secondary activities (Karim, 1999).

Economic Valuation of Mangroves

An important reason why coastal ecosystems continue to be used in unsustainable ways is that their economic value is not represented adequately in decision-making. Tables 3 and 4 illustrate that many of the economic values associated with mangroves are non-market and "off-site" and therefore are not easily quantified. Only the direct supply of mangrove products is included in most economic valuations, yet this represents only part of the total value of mangroves to society.

Table 3. Summary of mangrove ecosystem value averages from around the world

Benefits of ecosystem services	Value (US$/ha/year)
Disturbance regulation	* 1,839
Waste treatment	*6,696
Habitat/refuge	169
Food production	** 466
Raw materials	* 162
Recreation	* 658
Total benefits	**3,294**

Source: White, and Cruz-Trinidad (1998).

Notes: * Disturbance regulation, waste treatment and recreation values are generally not reportedin the Philippines' context because they are indirect services which are difficult to quantify. ** The combined values for "food production" and "raw materials" (USD 628) is very close to the accepted values for mangrove fish and wood products in the Philippines.

With the growing international interest in mangrove conservation, there is an increasing scientific literature on the valuation of mangrove forests. Studies show that the on-site values of directly harvested products, such as fish, wood for charcoal and construction timbers, and tanins, are often quite low relative to the total valuation at the ecosystem level. The off-site values for fisheries can be much higher (e.g. White and Cruz-Trinidad, 1998), although such estimates involve significant uncertainty. Mangroves are also highly valued for coastal protection, the cost-savings (or avoidance costs) in reduced sea-dyke repair costs being one of the principal benefits provided by a coastal protection zone of mangroves, especially in storm-prone countries like Bangladesh and Vietnam (Macintosh, 1997). Mangroves also play a role in regulating coastal water quality, but this function is still poorly understood let alone valued. White and Cruz-Trinidad (1998) give some general estimates (Table 5), but such figures should be treated with caution as the importance of the functions listed are site specific. Economic benefits to society through "off-site" values do not always easily flow to many individuals struggling to create livelihoods in coastal systems, contributing further difficulties in management.

Table 4. The application of economic valuation to mangroves.

	On-site	**Off-site**
Marketed	Usually included in economic analysis, e.g., poles, charcoal, woodchips, crabs.	May be included in economic analysis, e.g., fish and shellfish caught in adjacent waters.
Non-marketed	Seldom included in economic analysis, e.g., medicinal uses, fish nursery areas, wildlife sanctuaries, biodiversity attributes, educational recreational and research values.	Usually ignored, e.g., nutrient flows to estuaries, buffer against storm damage, erosion control.

Modified from Dixon (1991).

On-site, non-marketed values include, species diversity values and on-site biodiversity functions, such as providing nursery areas for fish and shellfish. Similarly, the shelter and shoreline protection provided by coastal mangroves is extremely important in many countries; for example in Vietnam mangrove rehabilitation is now being promoted strongly to protect coastal areas from typhoon damage (Macintosh, 1996, 1997). Various studies have shown that the non-market value of mangroves can be significant relative to alternative uses of the land and can far exceed the direct market values from fishery and forestry products alone (Kapetsky 1986; Gonzalez 1993).

Table 5. Estimated net annual economic value (in USD/ha) of mangrove areas in the Philippines under different levels of management

Level of management	**Wood products** (value/ha)	**Fish products** (value/ha)	**Total** (Value/ha)
Mangrove plantation	156	538	694
Managed naturally regenerated	90	538	628
Unmanaged, under-stocked stands	42	538	580

Source: White and Cruz-Trinidad (1998)
Note: Wood harvest value based on average price of USD 12/m^3 of wood; fish products based on average price of USD 0.80/kg;

By undervaluing mangrove ecosystems, "development" has too often favoured their rapid conversion and loss. Mangrove conversion usually leads to short-term economic gain at the expense of greater, long-term ecological benefits and off-site values. The issue is how to decide between the true social and economic costs of mangroves and the potential gains from other uses? For example, the true net benefits of transforming mangroves to shrimp ponds should be adjusted downward to reflect the environmental costs of shrimp culture, as well as the revenues foregone from mangrove goods and services, including the non-marketed ones. Even if this analysis is done, however, the results may be equivocal because other factors such as technical skill and management capacity also affect the efficiency by which goods and services are realised. A detailed analysis of the Pagbilao mangrove forest in the Philippines concluded that even if economic efficiency is maximised, and taking into account values for biodiversity, conversion to aquaculture is still the preferred alternative (Jansesen and Padilla, 1996). The time scale over which mangrove valuation is applied may also affect the analysis and conclusions. This is well illustrated with regard to values calculated for the storm mitigation functions of mangroves. Tropical cyclones and typhoons are episodic events that may strike a particular coastline on average once annually, every 10 years, or even every 50 years (for example, Typhoon Linda which struck the Lower Mekong Delta - an area outwith the main typhoon belt - in November 1997, is considered to have been the worst storm in that region in the last century). Without mangrove protection, economic losses from coastal storm damage can be much higher, therefore the cost savings involved (i.e. storm-damage avoidance costs) will have a dramatic affect on mangrove valuations if they are factored in over a significantly long time period.

Coastal Land Use Status

The general pattern of land use activities - as they relate to mangroves and coastal aquaculture in tropical coastal areas - is shown diagrammatically in Figure 1. Historically, mangroves have been exploited or converted to various alternative forms of land use, including, salt ponds, agriculture, aquaculture, horticulture and terrestrial forestry, and urban and industrial development (see example for Thailand, Table 6). Bi-directional shifts in land use can also occur in response to economic, social or environmental pressures (Figure 1). For example, perceptions of high profits from extensive shrimp farming in the 1980's resulted in large-scale conversion of former mangrove land under agriculture, fishponds or salt production into shrimp farms. The availability of higher economic returns from land, or reduced profitability arising from shrimp disease problems, may lead to further shifts in land use. Sometimes, shrimp and fishponds are may be simply disused or abandoned when they become unprofitable, usually because of declining yields or crop failures due to diseases. These areas are generally degraded and it may be difficult to return them to a productive or useful state without some form of active rehabilitation. Land ownership and use rights complicate matters considerably; in certain cases, landowners have elected not to return disused ponds to productive capacity in anticipation of high future profits from the sale of land for urban or industrial development (approvals for land development may be generally easier to obtain if the land is considered to be unproductive or degraded). Ownership may also have been established through conversion of mangroves (public land) to a shrimp farm (private land), providing a major disincentive for rehabilitation.

Table 6. Conversion of mangrove areas in Thailand to other uses (modified from Aksornkoae, 1993)

Land-use type	Before 1980	Between 1980-1986	Total (Km^2)	% of total
Aquaculture	260.40	119.60	379.90	38.30
Mining	9.26	45.30	54.50	5.50
Salt pans	105.60	-	105.60	10.60
Others	318.70	21.33	340.00	45.60
Agriculture	-	(7.0)	-	-
Urbanisation	-	(7.4)	-	-
Industrial Sites	-	(1.8)	-	-
Harbours	-	(5.1)	-	-
Total	693.90	186.20	880.10	100

Abandonment is a likely outcome in situations where mangrove forest has been converted to shrimp ponds illegally. The different forms of mangrove conversion (particularly into aquaculture), and the effects these have had on the history of coastal land use in particular countries, and globally, are reviewed in the next section.

The history of mangrove exploitation

Causes of mangrove loss

Mangrove resource utilisation takes several forms and, in combination, these have contributed to the substantial decline in mangrove forests seen in many parts of the world in recent decades. In certain countries the loss of mangroves has already exceeded 80% by area (Table 7). The main forms of exploitation (ADB, 1992; Macintosh, 1997) arising from human utilisation of mangroves are described below:

- *Over-exploitation by traditional users, including excessive harvesting of mangrove wood and other products.*

Low levels of traditional use have little impact upon mangroves; however, as coastal populations expand and as demand for products increases, then over-harvesting and an accompanying decline in natural resource value can occur in the absence of any regulation on traditional practices, or local management initiatives. Product harvesting, if continued at unsustainable levels, can lead to a vicious circle of declining resources and livelihoods for mangrove-dependent communities. A good example is the loss of mangroves in Vietnam, which were heavily exploited for wood after the war ended in 1975 (Hong and San, 1993). In neighboring Cambodia, the once traditional use of mangrove wood for charcoal production changed rapidly from a local, subsistence level to commercial production for export to Thailand at a much higher and unsustainable rate, as trading routes opened again during the 1990's. The level of mangrove exploitation became so serious that charcoal kilns were actually destroyed by the authorities as a control measure, but as the charcoal burners have no alternative source of livelihood they may continue whatever the penalty. Mangrove losses in Africa and southern Asia have also been caused substantially by exploitation above and beyond the traditional level (Spalding et al, 1997**).**

- *Commercial mangrove wood utilisation.*

There has been widespread commercial utilisation of mangrove forests because of the high density of some mangrove woods (e.g., *Rhizophora, Ceriops*), making them good for firewood and charcoal production. Mangrove wood is also resistant to decay in saltwater, so it has been a favoured material for e.g. pilings, fishing stakes and aquaculture structures in coastal areas. In several countries in Asia, rotational felling and replanting of trees for wood production are practised as part of commercial forestry projects, the most famous of which is in the Matang forest in Perak, Malaysia where rotational cutting and planting has been practised since 1908 (Watson, 1928, Gan 1995)

- *Conversion to other natural resource uses, such as salt production, agriculture or aquaculture.*

The extent of conversion varies with population pressures, the amount of arable land available, government policies and incentives and the extent and quality of mangrove forest available. Conversion to these uses destroys the mangrove resource. In Thailand, for example, more than 48% of the mangrove area present in 1961 had already been converted to salt pans and aquaculture by the 1980s, i.e. well before the boom in intensive shrimp farming developed in the country (see Table 6).

- *Conversion for other uses or losses due to offsite activities*

Conversion to other uses, includes activities generally unrelated to the coastal ecosystem which completely destroys the mangrove resource, such as urban or industrial development, coastal infrastructure such as ports and harbours, and coastal mining activities. There are also off-site activities unrelated to the mangrove ecosystem, which may still be detrimental, such as offshore dredging and mining, coastal oil pollution, and diversion of upstream freshwater resources for irrigation. There tends to be an increasing rate or scale of impact associated with the above and a given mangrove area can be affected by several different activities simultaneously, or over time as land use patterns change. One example, which is often overlooked, is the impact from contructing coastal roads through wetlands. The road itself may not destroy much habitat, but any mangrove forest remaining on the landward side of the road will become isolated from the normal hydrological regime and will usually die-back with time. A new road also brings settlement and other developments, usually leading to considerably more pressure on the remaining mangroves until they are heavily degraded.

Extent of Mangrove Habitat Loss

Historically, many countries have experienced a significant decline in the quantity and quality of their mangrove forests, but accurate figures for these losses are unavailable in most cases, although there is considerable anecdotal information (Saenger et al, 1983; Spalding et al, 1997). Estimates have been made in the World Mangrove Atlas (Spalding et al, 1997) and in the World Conservation Monitoring Centre data (WRI, 1996). The historical mangrove losses for Africa and Asia based on "guesstimates" of original forest cover for various countries are provided in Table 7. The extent of mangrove losses in Asia and Africa have been similar, at 61% and 55% respectively, even though coastal aquaculture in general, and especially shrimp farming, is not widespread in Africa.

Africa

The main causes of mangrove destruction in Africa stem from traditional, non-aquaculture uses. In Tanzania and Zanzibar, for example, mangrove wood has long been exploited for fuel to produce salt, lime and for processing fish; for pole wood and construction timber, especially for boat building, for charcoal production for making fish traps. Non-wood products from the mangroves include animal foder and local medicines (Semesi, 1992; Ngoile and Shunula, 1992). Areas of the Rafuji Delta mangroves in Tanzania have also been converted to rice fields and salt pans[4]. Rasowo (1992) reported an estimate that 50% of the solar salt pond area in Kenya is located on former mangrove forest. The mangroves in Nigeria are exposed to threats of destruction from urban development, coastal erosion, oil pollution, gas flaring, and subsidence aggravated by oil and gas extraction from porous subsurface layers of the Niger Delta (Ajao and Dore, 1997).

From the situation in Africa, where there has been limited shrimp farming to date, mangroves would continue to have been destroyed in many countries even without shrimp farming. Ong (1995) considers that "burgeoning populations are possibly the biggest cause of mangrove destruction and degradation".

Southern Asia

Within the southern Asia region, the mangroves of India and Bangladesh have been exploited heavily for timber, fuelwood, bark tannin, animal fodder, native medicines and food (fish, shellfish, honey, wild animals) for centuries. Population pressure has greatly increased the rate of exploitation, leading to serious degradation. In Bangladesh, there are an estimated 3 million people living in the Sunderbans, of which many are directly dependent on the Sundarbans Reserve Forest. The area of pure Sundari mangrove (*Heritiera fomes* - the main economic species and a mangrove species unique to the Sundarbans) is reported to have shrunk from 31.6 to 21.0 % between 1959 and 1983 (Chaffey et al, 1985), representing a period of exploitation before the relatively recent expansion of shrimp aquaculture in Bangladesh. Losses are continuing, despite the status of the Sunderbans in India and Bangladesh as heritage sites.

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4 That said, in 1996 a proposal for a shrimp farm in the Rufiji delta raised considerable controversy, and at the time of writing this review, was not proceeding. More details can be found on http://www.leat.or.tz/publications/foreign.investment/2.rufiji.case.study.php; and http://www.iucn.org/themes/wetlands/rufiji2.html.

Table 7: Estimated loss of original mangrove area in different regions (based on country data available in WRI, 1996)

South and Southeast Asia	Loss of original area (%)	Africa	Loss of original area (%)
Bangladesh	73	Angola	50
Brunei	17	Congo	0
India	85	Djibouti	70
Indonesia	45	Equatorial Guinea	60
Malaysia	32	Gabon	50
Myanmar	58	Guinea	60
Pakistan	78	Guinea Bassau	70
Singapore	76	Kenya	70
Thailand	87	Liberia	70
Vietnam	62	Madagascar	40
		Mozambique	60
		Somalia	70
		South Africa	50
		Tanzania	60
		Zaire	50
Unweighted average	**61**		**55**

Note: no data given for South America.

Prior to the expansion of shrimp farming from the 1980's, large tracts of coastal mangrove in Southern Asia had already been converted to rice farming (FAO, 1982). The indirect effects of agriculture on mangroves include the diversion of freshwater for irrigation, and chemical residues from agriculture entering mangroves via run-off water. The interception of freshwater is thought to have severely affected mangroves in the Indus Delta of Pakistan and the western part of the Sunderbans (Chaffey et al, 1985; Spalding et al, 1997).

Southeast Asia

Large areas of mangrove have also been removed in Southeast Asia for wood, for conversion to agriculture or salt production, coastal industrialisation and urbanisation, and in recent years conversion to coastal aquaculture ponds (e.g. Aksornkaoe, 1993). Ong (1995) suggested that the 1% loss of mangrove area per year estimated for Malaysia, probably represents a conservative average figure for losses within the Asia-Pacific region as a whole. A recent assessment (by Professor Ong, pers.comm.) of one mangrove area in Malaysia noted recent conversion in the late 1990's of mangroves to housing estates, following earlier conversions to paddy and shrimp farms. The development of housing estates on paddy and shrimp farm land (which interestingly has relatively low value compared to the land for real estate, is constrained by unwillingness of owners to sell for housing development, and of relatively "cheap" mangrove land available (administered, and undervalued by local government).

In Thailand, an estimate made by the Royal Thai Forest Department in 1993 stated that of the 'original' mangrove forest area in 1961 (372,448 ha), only 168,682 ha (or 45.3%) remained. Out of the total area in 1961, 133,812 ha (35.9%) had been converted into salt pans, mining, agriculture and infrastructure, 64,991 ha or 17.5% was occupied by coastal shrimp farms and 4,961 ha (1.35%) for community use.

It has been estimated that there were about 450,000 ha of mangroves in the Philippines in 1918, but this had declined to only 149,000 Ha by 1988, a reduction of 67%. Based on satellite imagery, about 95% of the pond area (mainly milkfish ponds), totalling 205,000 ha in 1988 was derived from mangroves (ADB unpublished). The same study also noted that the decline in mangrove area from 1952 to 1987 closely matched the increase in area of milkfish ponds (ie not shrimp), which was on average 3,600 ha per annum. It is emphasised, however, that the mangroves had also declined in terms of their biological diversity and economic value, as well as in area, due to excessive harvesting of the most valuable trees and a shift in forest structure towards younger trees as the larger trees were removed. Thus the pattern of mangrove exploitation in the Philippines has been one of selective felling for charcoal and timber extraction, followed by conversion to aquaculture. As will be discussed later, rehabilitation of abandoned milkfish and shrimp ponds is made extremely difficult in this country, because of the ownership status now conveyed to the pond owners following the conversion from mangrove to aquaculture ponds.

Central and South America

There are less complete data on the conversion of mangrove forests in Central and South America. However, there has been considerable exploitation of mangroves for wood and and charcoal and, as in Asia, mangroves have been converted for agriculture, salt production, coastal industrialisation and urbanisation, and, especially in Ecuador, for aquaculture. Since 1969, Ecuador has lost an estimated 42,000 ha of mangrove forest (CLIRSEN, 1992) or about 20% of the 1969 mangrove cover. Mangrove loss in Ecuador varies regionally. Losses in some provinces have been less than 15%, but in others they have exceeded 50% (Bodero and Robadue, 1995). A similar pattern of mangrove exploitation is thought to exist in other parts of the tropical American region, with heavily developed coastal areas most affected. The mangroves along the coastline of Sao Paulo (Brazil), for example, have been severely impacted by land fills, solid waste disposal, industrial and domestic effluents, chemicals, organic contamination and oil spills from nearby ports and oil terminals (Lamparelli, et al, 1997).

The status of shrimp aquaculture

Coastal aquaculture has been practised for several hundred years, and in some countries it has been part of the traditional livelihood for people living in mangrove areas. There are reports of early brackishwater ponds in the Mediterranean that may date back several thousand years (Phillips et al, 1992) and the brackishwater ponds in Indonesia - known as *tambaks* - date back to at least the 15th century (Schuster, 1952). In some countries, such as Vietnam, coastal ponds formed part of a process carried out over centuries whereby accreting land was gradually “reclaimed” by man from the sea, initially as impounded fisheries, and then as agricultural areas. In such systems, perhaps best termed “trapping and holding” operations, wild shrimp and other aquatic species, were carried into the pond by tidal flow, and were then harvested after a suitable interval of residence. Although such simple culture methods can still be found in Vietnam, Bangladesh, India and some other countries, shrimp aquaculture today has become a multi-billion dollar industry that has evolved various highly developed farming practices.

Extensive farms. These include the ‘traditional’ systems mentioned above, and other low input and low output shrimp farming methods. Extensive farming is still practised widely in Asia, using large, shallow ponds; these are commonly constructed on inter-tidal flats and mangrove areas. Some mangroves may be retained in the ponds following the concept of the original Indonesian tambaks. In both Indonesia and the Philippines polyculture of shrimp with milkfish has been the traditional practice in extensive systems. Shrimp stocking densities are low, water exchange is by tidal movement and shrimp yields are typically less than 500 kg/ha/yr, and sometimes as low as 50 kg/ha/year today. Ponds have to be built in intertidal areas for tidal water exchange and mangrove areas have been favoured locations because of their naturally abundant supplies of shrimp post-larvae (a review of traditional mangrove shrimp ponds in Southeast Asia based on trapping and holding of wild stock is given in Macintosh (1983)). Because pond yields tend to be low, many farmers have compensated for declining productivity by constructing very large ponds. Pond areas of 10-30 ha are common, but they can even be 50-100 ha. In some farms in Vietnam, farmers also retain some mangrove within their ponds to boost shrimp productivity and maintain some coastal forests (Binh *et al*, 1997).

As aquaculture has progressed, more developed countries in Asia, such as Malaysia, Thailand and Philippines, have promoted aquaculture development away from mangrove forests and/or encouraged diversification into more compatible production systems such as finfish culture in floating cages and mollusc farming. Recently, rates of decline in mangrove forest areas have slowed in Thailand, for example, as mangrove management and conservation efforts have increased, with a strong trend for new intensive shrimp farms to be located away from coastal mangrove areas. Much of the original mangrove area in Thailand converted to shrimp ponds was for large extensive culture ponds constructed during the 1980's (Tookwinas, 1996; Menasveta, 1997). In less developed countries, however, such as Bangladesh, Myanmar and Vietnam, there is still pressure to convert mangroves to extensive shrimp ponds because of their low investment cost and technical requirement, the availability of water through tidal exchange (no costs for pumping) and the perceived high profitability of extensive systems on a short-term basis.

Semi-intensive farms. Semi-intensive farming represents a broad category of shrimp culture practice usually involving at least some stocking of usually hatchery produced post larvae at moderate densities, use of feeds and fertilisers, and correspondingly higher shrimp yields. Stocking densities are around 25,000 to 100,000 post-larvae/ha. Ponds tend to be smaller (2-30 ha) and can be located both on intertidal land - which may include mangroves - and land located above the high tide mark. Tidal water exchange tends to be replaced by controlled water exchange, usually at 5-10% of pond volume per day, using mechanical pumps. Pond yields of shrimp are typically 1000-3000 kg/ha/yr. At the upper end of the production scale, there is little distinction between semi-intensive and intensive shrimp culture, but for practical interpretation Kongkeo (1990), Macintosh and Phillips (1992) and others have characterised the different levels of production as shown in Table 8.

Intensive farms. Intensive farming practices tend utilise smaller ponds with higher stocking densities (200,000 post-larvae/ha and above) and heavier feeding rates. Most intensive farming still takes place in ponds. Round ponds have also been pioneered in Hawai, Thailand and Saudi Arabia in order to improve waste removal over that of conventional ponds (Falaise and Boel, 1999). Although water exchange rates were higher in the past, there is a significant trend towards reducing water exchange in both semi-intensive and intensive shrimp farming today, mainly to prevent disease transmission (associated with shrimp viral diseases) between ponds and between farms. Yields of 5,000 to 10,000 kg/ha/yr are common in intensive culture. 'Super-intensive' shrimp farming may produce higher yields, but it is not a widespread practise. The best locations for intensive farms are above the high tide mark where ponds can be easily drained and dried between crops. Individual pond sizes are usually less than 1 ha. Intensive farming is practised primarily in the more developed Asian countries, Australia, Belize and the United States (Fast and Lester, 1995).

Shrimp culture species. The giant or black tiger shrimp (*Penaeus monodon*) is the major farmed shrimp species, contributing around 50-60% of the total global farm production; it is the dominant species farmed in all countries in Asia, except for Japan and China. The western white shrimp (*Penaeus vannamei*) is the leading species in Ecuador and most other countries in Latin America; overall makes up 25% of the world farmed shrimp production. *P. vannamei* is increasingly being grown in Asia, and already makes a significant contribution to shrimp production in China. Its contribution in 2003 is likely to be substantial. There are a number of other species which together make up the remaining production, including *Penaeus stylirostris* (grown on the Pacific coast of Latin America); *P. chinensis* (in northern China and Korea), *P. japonicus* (Australia, Japan, China and Taiwan Province); *P. penicillatus* (Taiwan Province and China) and *P. merguiensis* and *P. indicus* (extensive farms throughout Southeast and South Asia). In nature, most of these species are associated to varying degrees with mangroves. The most mangrove-associated are the banana shrimp *P. merguiensis* and the white shrimp *P. indicus*.

In 2000, 1.1 million metric tonnes were produced with a farm gate value of about US$ 6.9 billion.

Coastal land use for shrimp aquaculture

Site selection for coastal shrimp farming is governed by many factors, including climate, land elevation, water quality, type of soils and vegetation, infrastructure, legislative aspects and land availability. The result is that shrimp ponds have been constructed on many different types of land, including inter-tidal land (mangroves, mud flats and salt pans) and land above the high tide mark (rice fields, other agricultural land and saline areas). Supra-tidal sites are much more suitable for semi-intensive and (particularly) intensive aquaculture because they allow for easy drainage of ponds and drying of the pond bottom between crops. In SEAsia, locating farms on such supra-tidal land has led to conversion of agricultural land to shrimp farming, include oil palm (Malaysia), rice and rubber estate land (Thailand) and sugar plantations (Philippines).

Table 8: General characterisation of the three main levels of shrimp farming practised.

Parameter	Extensive	Semi-intensive	Intensive
Pond size	5 ha, or larger	1-5 ha	1 ha, or smaller
Stocking Density/ha	3,000-20,000	25,000-80,000	over 100,000
Water Management	tidal + pump	pump	pump with water treatment
Aeration	No	Some	yes
Fry sources	Wild or hatchery	Wild or hatchery	hatchery
Feed	natural food via pond fertilisation	Fertilisation with supplementary feed (fresh or formulated)	formulated feed
Crops/annum	1-3	2	2-2.5
Annual production	0.3-1.0 mt/ha	1-3 mt/ha	8-12 mt/ha

Source: Modified from Macintosh and Phillips (1992)

The pattern of coastal land use differs between countries. In countries with little mangrove forest, such as China, Japan and South Korea, ponds are constructed on agricultural land of low productivity, or under-utilised saline land, and in these countries shrimp farming has had virtually no (if any) impact on mangroves. In countries with significant mangrove resources, farms may be constructed on various types of land, depending on factors such as government policy, availability of non-mangrove land, population pressures and infrastructure development (e.g. road access). Land use varies from country to country, however, and even within countries, making it difficult to generalise. In some cases, land use has changed with time. In Ecuador, for example, the favoured sites for shrimp farms were originally salt pans, or "salinas". Once these sites were used up, the industry moved to less favourable areas, including mangrove habitats.

It is now increasingly recognised that mangroves do not make good sites for semi-intensive and intensive shrimp farms. Recent shrimp pond expansion has tended to be on higher land behind or away from mangrove areas. The following examples from different countries in Asia and Central and Southern America describe recent developments in coastal land use for shrimp aquaculture.

In Thailand, extensive shrimp farms were traditionally located in low lying (inter-tidal) coastal wetlands, but this preference has changed towards supra-tidal land (above the maximum tide level), where ponds are cheaper to construct and drainable, and where soils are normally more suitable for intensive culture (Menasveta, 1997). Land use for shrimp culture varies from province to province in Thailand. Recent Royal Forestry Department studies show that shrimp farms occupied 17.5% of the pre-1961 mangrove area (see Table 9) The major loss of mangroves occurred from extensive shrimp farming during the 1980's. Menasveta (1997) concluded that the trend towards intensive shrimp farming in Thailand has tended to reduce further damage to the remaining mangroves, but losses of other wetland types were not discussed.

In Indonesia, studies carried out using satellite imagery during the early 1990's showed that 56% of shrimp ponds in North Sumatra were built on what had been (in 1977) primary forest areas, 15% in secondary areas and 29% in fringe areas without forest cover (McPadden, 1993). In Java, traditional mangrove *tambak* ponds have been constructed for centuries, providing important sources of income and food for coastal people on a sustainable basis (Schuster, 1952). Although mangroves have been converted to shrimp ponds traditionally throughout Indonesia, current estimates suggest that only 5% of the total Indonesian mangrove resource has been used for coastal aquaculture ponds for the farming of shrimp and milkfish (Spalding et al, 1997).

Table 9: Utilisation of pre-1961 mangrove areas in 1993 (from: Menasveta, 1997).

Land use type	Area (ha)	(%)
Shrimp farms	64,992	17.5
Community use	4,961	1.35
Agriculture, salt farms, mining, infrastructure development	133,813	35.9
Mangrove remaining	168,683	45.3
Total	372,448	100

A comprehensive study of land use for shrimp aquaculture in Asia was undertaken through a farm level survey of around 5,000 shrimp farms in 1994 and 1995 supported by the Asian Development Bank (ADB/NACA, 1996; ADB/NACA, 1997). Table 10 summarises the percentage of farms recorded on different types of land, including mangrove, in Asian shrimp producing countries. The figures show that extensive farms account for the major loss of mangrove land. In contrast, relatively small areas of mangrove are under intensive and semi-intensive ponds. Where farms were built on mangrove areas, there is usually no information on the quality of mangrove in terms of species diversity, conservation value of the mangrove, and figures certainly include mangrove land that was degraded prior to its use for shrimp farming. The estimated 400,000 ha of ponds on ex-mangrove land from this table represent around 5.3% of the mangrove resource of 7,517,300 ha (from Spalding et al, 1997) in the 12 countries surveyed.

Table 10: Estimated land use type for shrimp farming in 12 Asian countries, based on a farm level survey of ~5,000 farms conducted during 1995 * (ADB/NACA, 1997).

Land use type (prior to shrimp farming)	Intensive farms		Semi-intensive farms		Extensive farms	
Intertidal land	Area (ha)	%	Area (ha)	%	Area (ha)	%
Ex-mangrove	14,142	*19.0*	24,786	*18.6*	359,118	*41.9*
Non forested wetland	8,669	*11.6*	25,206	*19.0*	136,121	*15.9*
Saltpan	7,496	*10.0*	4,242	*3.2*	20,649	*2.4*
Other-intertidal	6,470	*8.7*	14,603	*11.0*	195,948	*22.9*
Supra-tidal land						
Rice farm	22,515	*30.2*	19,397	*14.6*	122,087	*14.3*
Other agriculture	8,432	*11.3*	4,603	*3.5*	8,215	*0.9*
Non-agriculture	7,397	*9.9*	36,278	*27.3*	25,601	*3.0*
Estimated total farm area	74,600	*100*	133,000	*100*	856,300	*100*

* Includes Bangladesh, Cambodia, P.R. China, India, Indonesia, R. O. Korea, Malaysia, Philippines, Sri Lanka, Taiwan Province of China, Thailand and Vietnam. The total shrimp farming area was estimated to be 1,063,900 ha in 1994.

The survey data in Table 10 show that just over 50% of intensive farming areas were located on non-mangrove land above the high tide mark. Such land is now widely recognised as being better for intensive shrimp culture, although the data show that some intensive farms are still located on less suitable intertidal land. The use of rice fields for extensive shrimp culture is due to the system of integrated rice-shrimp farming which is practised in Bangladesh, India, Myanmar and Vietnam. Many paddy farmers in these countries now follow an alternate cropping cycle, with extensive shrimp production during the dry season and rice production during the rainy season (Brennan et al, 1999).

There has also been widespread conversion of mangrove areas to shrimp farming in Latin America. However, many investors now realise that supra-tidal land provides better sites for shrimp farms, and new farms tend to be sited on this higher land. Shrimp farms in Latin America often cover several hundred hectares, so it is not unusual to find that a farm begins within the former mangrove zone but extends onto higher land. One unresolved issue, however, is the conversion of salinas or salterns, scrub mangroves and salt marshes common in the high intertidal areas behind mangroves, to shrimp aquaculture ponds. These areas are now considered as valuable seasonal wetlands, and important hydrologic connectors from watersheds to mangroves, in many parts of the world, including the Florida Everglades (Powell 1987, Lorenz et al. 2002) and wetlands in Central and South America (Lewis 1990).

It should be emphasised that even when shrimp farms are constructed on supra-tidal land, it may be necessary to build canals for intake water and effluent discharge through the mangrove, and it may be necessary to clear mangrove to construct pumping stations and service docks for shrimp farms. However, if shrimp farms are constructed outside mangrove areas, the associated infrastructure need not result in the loss of large amounts of mangrove forest. At most, areas cleared for canals and other infrastructure would not exceed 5% of the total pond area.

Some idea of the conversion of mangrove to shrimp farms in Ecuador can be obtained from statistics showing that mangrove forest reserves declined from about 204,000 ha in 1969 to 162,000 ha by 1992 (CLIRSEN, 1992). There were about 120,000 ha of shrimp ponds in Ecuador in 1992, none of which were constructed until the early 1970's. Thus, if the entire loss of mangrove had resulted from shrimp farm construction, only 35% of shrimp farms could have been constructed in mangrove areas. It is known that mangroves were converted to other uses in Ecuador (e.g. for urban expansion, timber), so the figure of 35% is an overestimate. Nevertheless, local level studies indicate that in some estuaries losses from shrimp pond construction may be higher, such as the Bolivar-Chamanga-Cojimies and Rio Chone. Mangroves in Taura and Estero Salado have also been reduced significantly by the urban expansion around Guayaquil (Bodero and Robadue, 1995). Since 1995, the land use situation has stabilised and there has been a small (2%) net gain in mangrove area overall in Ecuador (Table 11). The notable large loss of salt flats reflects the trend towards use of these high intertidal areas, as mentioned above, and raises questions about the impacts of such large scale losses of what were are considered "wastelands", as were mangroves, 4 decades ago.

There are only more limited data available from other countries. In Columbia, around 4,000 ha of mangroves are reported to have been converted to shrimp farms since 1980, representing around 1.1 % of the mangrove resource (Suman, 1994). Between 1973 and 1992, the construction of shrimp ponds around the Gulf of Fonseca region led to conversion of 4,300 ha or around 2.9% of the total resource in Honduras (Suman, 1994). During this period, mangrove land around the Gulf of Fonseca declined from 30,697ha to 23,937ha, a decline of 17% in total area (DeWalt et al, 1996). Recently, however, the mangrove area has increased as a result of improved zoning and management measures, and growth of mangroves on areas of new coastal accretion.

Table 11: Comparison of the area of mangrove and shrimp farms in Ecuador over the period 1969-1999 (in hectares).

	1969	1984	1987	1991	1995	1999
Mangroves	203,696	182,157	175,157	162,189	146,938	149,974
Shrimp Farms	-	89,368	117,728	145,998	178,071	175,255
Salt Flats	51,495	20,022	12,273	6,320	5,109	4,576

Note: The increase in mangrove area from 1995 to 1999 is due mainly to coastal accretion.

Global mangrove areas used for shrimp culture

There is no doubt that shrimp farming has contributed to the overall loss of mangroves, particularly within the last 20 years. The greatest losses have arisen from extensive culture systems that occupy large areas of intertidal land, but due to the variability and general unreliability of the available data, particularly on the status and quality of mangrove forests concerned, it is impossible to assign a reliable global figure for the losses caused by shrimp culture, let alone to assess the corresponding ecological impact world-wide. However, some indirect estimates of the scale and impact of coastal shrimp farming can be offered to help assess the global situation.

The total global mangrove resource has been estimated at 181,077 km^2 (18,107,700 ha) based largely on data collected in the 1980's (Table 12; Spalding et al, 1997). In Asia, if 37% of shrimp farm area is on ex-mangrove land, this 402,199 ha (from Table 2.10), represents 5.3% of the existing mangrove resource area of 7,517,300 ha. As the historical mangrove coverage is higher than this figure, the total regional loss from shrimp farming is certainly less than 5%. Ong (1995) gives a conservative estimate of mangrove loss from all causes as about 1% in area per year, suggesting a loss of around 75,000 ha per year, or more than 3 million ha since 1960. Figures given by WRI (1996) suggest mangrove losses in Asia of around 60% by area of the original resource (Table 7) equivalent to a total loss of 11 million ha. Taking Ong's figure, then the amount of mangrove 'converted' to shrimp ponds tentatively represents around 10-15% of the total mangrove loss since 1960. Using WRI figures for the historical losses, the percentage contribution of shrimp farming will be considerably less. Furthermore, much of this loss occurred through extensive shrimp farming practices and not from the more recent development of intensive and semi-intensive farming, as Table 10 shows. However it should also not be overlooked that specific cases involving conversion of mangroves to shrimp farming on a major scale are still occurring.

In South and Central America, shrimp farming occupied around 185,100 ha in 1995 which represents around 3.8% of the existing American mangrove resource. The 130,000 ha of shrimp ponds in Ecuador represent about 70% of the shrimp farming area in Latin America, consequently it is in Ecuador that the greatest impact on mangroves has occurred in this region. Therefore, the potential for mangrove destruction has been greater in Ecuador than in other Latin American countries. There are no data from which to estimate the percentage loss in other Latin American nations, but the evidence suggests that the percentage loss of mangrove to shrimp farming in the other countries probably does not exceed 10% of the total mangrove loss that has occurred since the 1960s.

Globally, if it is assumed that all of the 13,728 km^2 (1,372,800 ha) of ponds reported by Rosenberry (1996) were converted from mangrove land, then shrimp ponds would account for 7.6% of the present resource, representing less than 5% of the total historical resource. An analysis undertaken for the World Wide Fund for Nature (Clay, 1996) also concluded that "... the extent of mangrove destruction world-wide resulting from shrimp farming is only a tiny fraction of the total lost to date.…" the same report estimated that "Globally, shrimp farming is not responsible for even a quarter (perhaps even as little as 10%) of the mangrove clearings that have taken place since 1960." However, ten individual causes, each just 5%, results in a 50% loss of a resource. Such is the case with mangrove forests, where a multitude of culprits can be found. The fact that shrimp aquaculture, worldwide, may be but one of many such culprits does not reduce the need to manage it to reduce future losses, and hopefully restore the several hundred thousand hectares of currently documented abandoned or disused shrimp aquaculture ponds back to functioning mangrove ecosystems.

Table 12: Mangrove area coverage by region

Region	Mangrove Area (sq km)
South and Southeast Asia	75,173 (41.5%)
The Americas	49,096 (27.1%)
West Africa	27,995 (15.5%)
Australasia	18,789 (10.4%)
East Africa and the Middle East	10,024 (5.5%)
Total Area	**181,077**

Source: Spalding et al. (1997)

Whilst the exact figures will never be known, the findings reviewed above confirm that shrimp culture is but one of the many causes of mangrove losses, along with population pressures, pollution, logging and conversion to agriculture, industrial and urban areas (Csavas, 1993; Macintosh and Phillips, 1992). Taking the example of Thailand, the largest producer of farmed shrimp in the world, Aksornkoae (1993) records that there have been many other reasons for the loss of mangroves in Thailand, including agriculture, salt production, mining, resettlement programmes and industrial and other infrastructure developments, as well as shrimp farming (Table 6). There are clearly areas where mangroves have been denuded by shrimp farming, but this loss has to be seen in the perspective of the overall pressure on coastal resource. Fortunately, there is increasing recognition of the problem and positive efforts are now being taken to mitigate negative impacts caused by shrimp culture. The shrimp farming industry is actually showing responsibility and initiative in advocating for a more enlightened approach to the issues concerning shrimp farming, mangroves and the environment. As a single sector with good organisational capacity in many countries, the potential for concerted action by shrimp farmers in support of the environment is strong and should be recognised and encouraged.

"Abandonment" of shrimp farms in mangrove areas

Mangrove areas are generally not ideal for intensive or semi-intensive shrimp farming, because the soils that typically support mangroves are highly organic and/or potentially acidic. Poor water and soil quality often lead to ponds being left idle and in some cases to the abandonment of entire farms (Stevenson and Burbridge, 1997, Stevenson et al. 1999). Ponds may be left idle for various reasons, but declining environmental quality leading to increased incidence of shrimp disease is commonly quoted as a cause of pond failure (although such problems are not always associated with mangroves). In other cases, ponds may be left fallow as part of the normal farming practice, to allow the soil and water quality conditions to recover between crops. The uncertain status of "abandoned" shrimp farms greatly complicates estimation of the areas of shrimp culture remaining in mangrove wetlands. Moreover, in many locations in Southeast Asia, abandoned shrimp ponds have shown at least partial return to mangrove forest through natural recolonisation, and thus the classification of such areas is problematical. The topographical, hydrological and other conditions necessary for mangrove regeneration are described in more detail later in this review. A period of about five years after shrimp farming stops may be sufficient time for shallow, extensive culture ponds to revert to mangrove provided the local hydrology is restored, and the surrounding social and institutional conditions (e.g. land use status) are favourable (see case study 13). However, if the local hydrology is not restored, by say a natural or storm caused breach in a dike, ponds may remain unproductive for decades (see Lewis et al. Case Study 13).

Environmental and socio-economic impacts of mangrove conversion

The negative impacts resulting from the decline in mangrove habitat worldwide have been widely publicised; they include losses of the various uses, functions and attributes of mangroves.

Vietnam provides one particularly severe example where the destruction of mangroves for various purposes, including defoliant spraying during the Vietnam War, and more recently logging and aquaculture, has led to major environmental and impacts (Table 13). Similar problems are now recognised to varying degrees in many other countries. Such ecological changes can have serious social and economic impacts, particularly on the livelihoods of coastal people who depend on the natural assets of mangrove resources for their livelihood. In many coastal regions of the tropics there are very limited opportunities for alternative employment and sources of food production, or when changes in land use in mangrove areas lead to coastal people being denied access to areas that they have used for their livelihoods for generations. This is a particular complaint levelled at shrimp farming in some countries (e.g., Honduras - see Tobey and Clay, 1997), but similar problems can arise from other coastal land use changes which bring traditional 'common' property and resources into private ownership, or control.

The issues involved above have been summarised succinctly by Patil and Krishnan (1998): "Sustainable shrimp farming practices require minimal disruptions to the surrounding ecosystem and coexistence with rural communities that have historical ties to the land and waters. A delicate balance is needed between promoting the development of an industry that generates large capital flows to the national economy and industrial growth in rural areas, and punishing this sector for its associated negative externalities."

The environmental, social and economic impacts associated with conversion of mangroves to shrimp culture have mostly been reported in qualitative terms. "Loss of livelihood" is a much quoted term used to describe the overall socio-economic consequences for coastal communities affected by shrimp farming or other coastal developments. Where quantitative data are available, it is difficult to know if the changes recorded are due entirely to mangrove loss, or to other factors as well. This point is well illustrated by the information provided by Hong and San (1993) on the impact of mangrove loss in the Mekong Delta (Table 13). Since 1993, the abundance of natural shrimp seed has continued to decline alarmingly and shrimp fishermen who operate large fixed bag nets in the mangrove channels of the delta estimate that their yields have declined by about 80% over the past 10 years. In can only be concluded that mangrove destruction accounts for a large, but unknown, part of the observed decline in the shrimp catch.

The social impact of shrimp farming in Nellore, India has been assessed semi-quantitatively by Patil and Krishnan (1998). They ranked the degree of severity of specific factors disrupting the well being of village communities living adjacent to groups of shrimp farms. For fishing villages, blocked access to the beach and saline well water were scored as severe or very severe impacts, while saline agricultural land and lack of, or underemployment ranked as moderately severe problems. Restrictions on fodder and fuelwood collection represented the most severe impact for farming villages. A summary of their findings is presented in Table 14.

Table 13: Environmental and socio-economic impacts related to the destruction of mangrove forests in the Mekong delta of Vietnam.

Environmental impact	Specific details
Coastal erosion	Increased coastal erosion in Tien Giang, Ben Tre, Cuu Long Bac Liue and Ca Mau provinces
Salinity intrusion	Removal of mangroves has led to increased vulnerability to storm damage and saline intrusion. In 1991, more than 2,000 ha of rice fields at Gan Gio District, Ho Chi Minh City were damaged by saline intrusion.
Shrimp post-larvae abundance	Declining availability of post-larvae has resulted in decreased yields from extensive shrimp ponds although overfishing may also be important
Mud crab (*Scylla* species) abundance	Mud crabs are an important export crop, relying on mangrove habitats. The populations are reported to be declining, a combination of over-exploitation and habitat loss.
Acidification of pond waters/soils	Removal of mangroves from extensive shrimp ponds has led to declining yields of shrimp.
Declining shrimp pond yields	Related to the decrease in shrimp larval abundance and deteriorating habitat, pond yields have decreased. From 1986 to 1988, yields from extensive shrimp ponds declined from 297 kg/ha to 153 kg/ha.

Modified from: Hong and San (1993).

Table 14: Socio-economic impacts reported from a rapid rural appraisal survey of 26 coastal villages in Nellore District of Andhra Pradesh, India located adjacent to shrimp farm development areas.

Problem category	**Percentage of villages with problems**		
	Fishing villages	**Farming villages**	**All**
Well water salinity	65	*66*	*65*
Access to beach or creek blocked	*94*	*33*	*73*
Salt intrusion into agricultural land	*65*	*89*	*73*
Un- or under-employment	*76*	*11*	*54*
Poor health	*53*	*0*	*35*
Fodder and fuelwood shortages	*12*	*89*	*38*

Modified from Patil and Krishnan (1998).

While the destruction of mangrove forests to build shrimp farms is the most obvious impact of coastal aquaculture on wetlands, other interactions should not be overlooked. Shrimp farms located within or adjacent to mangroves may impact on the ecosystem in several other ways, which are just beginning to be recognised.

Hydrological changes represent one class of potential impact. These include salinity changes caused by isolation of the mangrove from brackishwater, freshwater flooding or discharge of saline pond water into low salinity mangrove areas; and isolation from brackishwater and normal tidal inundation by construction of ponds, canals and access roads which may alter estuarine flow and local hydrology. The extensive integrated mixed farming systems used in the southern Mekong Delta are a good example of the impact of hydrological changes due in part to aquaculture (see Case Study 9). There are two main issues:

- The current practice of siting ponds along the edge of waterways, and mangroves to the rear behind the ponds results in most mangroves being surrounded by levees, thereby isolating them from normal tidal influences. Consequently, the frequency and duration of flooding is significantly reduced, resulting in reduced growth rates and poor forest development. A secondary, but equally important, effect is that most of the remaining mangroves are no longer easily accessible as habitat or nursery areas for estuarine shrimp and fish species. This may be a factor contributing to the significant decline in wild seed stocks of important commercial shrimp species like *Penaeus indicus* and *P. merguiensis,* and even the smaller, lower value *Metapenaeus* species (e.g. Clough and Johnstone, 1998).
- In Ca Mau Province of Vietnam, the level of suspended matter in waterways is high, commonly up to 0.5 g l^{-1}. This material accumulates on the pond bottom, and when the pond bottom is cleaned, it is subsequently deposited in the mangrove areas impounded within mixed farming systems (the mangroves are planted on unexcavated platforms inside the pond). Hence the land level on which mangroves are being grown is rising faster than sea level, and many mangroves are now growing in areas that are flooded too infrequently for their optimum growth.

The creation of acid sulfate soils (ASS) and the resulting loss of use of land for either aquaculture or agriculture is discussed for Indonesia in case study 10 (Sammut and Hanafie, Case Study 10). It is estimated that 102,610 ha of ASS-affected ponds, and 128,420 ha of abandoned ponds exist in Indonesia. Capacity building and training in soil management were identified as critical needs to avoid further problems.

Building levees or digging channels through or adjacent to mangroves will always lead to some change in the hydrologic regime. Sometimes this may be beneficial, for example where it leads to an improvement in tidal flushing, but usually the effect is to reduce or impede the normal tidal flushing cycle.
Another class of potential impacts involves the discharge of shrimp pond effluents. This has led to concerns about physical and chemical pollution, namely (i) smothering of mangrove roots and seedlings due to excessive sedimentation; (ii) the possible eutrophication of coastal waters; (iii) release of potentially hazardous materials from farms (mainly affecting mangrove fauna); and (iv) pathogen spread from shrimp ponds to the mangrove-associated fauna.

An important fisheries-related issue is the collection of shrimp post-larvae from mangrove areas, something that does not impact on mangroves directly, but may influence the mangrove ecosystem, and particularly its associated aquatic fauna (Tobey and Clay, 1997). The collection of wild shrimp fry is still important for some shrimp farming countries and this practise provides income for many thousands of coastal people (Silas, 1987; BOBP, 1990; Robadue, 1995; Karim, 1999). Although the ecological impact of wild shrimp post-larvae harvesting has not been quantified, there are justifiable concerns that it may be detrimental to aquatic biodiversity and fisheries recruitment (Macintosh, 1997). It is widely recognised that hatcheries would be an ecologically preferable way of supplying shrimp seed for aquaculture, even though there may be social implications in shifting from wild caught to hatchery supplied seed in certain countries. In Bangladesh, for example, Karim (1999) and more recent studies show the importance of coastal people's livelihoods on collection of shrimp seed and crab associated with Sundarbans mangroves.

Social and economic impacts

This is a complicated area, and one that has been underestimated or grossly oversimplified on many occasions by policy makers and others. Mangrove ecosystems play a vital support role to the traditional coastal communities living of the tropics and sub-tropics. The removal of mangroves can and has had wide reaching economic and social impacts (Bailey, 1988), particularly when their removal has left local communities without alternative means of livelihood. There are many examples from different parts of the world. In one study in Chantaburi district (Thailand), fishermen reported declines in catches, linked to restricted access to previously accessible mangrove areas (Sirisup, 1988). In Bangladesh, probably several million people living in coastal areas are dependent directly and indirectly on coastal mangroves and their removal and degradation in some areas has led to declining socio-economic conditions for traditional coastal fishermen. This is one of the reasons why removal of mangroves for various activities can lead to social conflicts and declining living conditions for traditional people living in mangrove areas.

On the positive side, shrimp farming in coastal areas can provide a livelihood opportunity for coastal people. The positive aspects include employment and income. The income and employment generated per area of mangroves can be substantially lower than semi-intensive or intensive shrimp aquaculture options.

Another issue relates to poverty alleviation. Shrimp aquaculture, if managed properly and with appropriate local participation, can contribute to poverty alleviation and employment among coastal peoples, providing alternatives for local people involved in overexploitation of mangrove resources. Whilst this may not always be the case in Latin America, where farms tend to be dominated by larger scale producers, in Asia small-scale farmers dominate the sector. Here coastal aquaculture can contribute to alleviation of poverty, which is the underlying cause of much mangrove destruction in developing countries (Duc, 1996).

The concepts of co-existence and sustainability

The emphasis of coastal management strategies for coastal aquaculture has to shift from the "*either* mangroves *or* shrimp" to an integrated approach which allows for "mangroves *and* shrimp" i.e. to the concept of coexistence, as incorporated in the objectives of this review (see also Barg, 1992; SEAFDEC, 1996). Shrimp farming must also be promoted in a sustainable manner. The concept of sustainable development lies at the core of the mitigation measures described later in this review.

The most widely used and accepted general definition of "sustainable development" is that by the Brundtland report (Brundtland 1987) "…development that meets the needs of the present without compromising the ability of future generation to meet their own needs". Hambrey (1998) points out that this definition might be characterised as an "inter-generational equity" definition for the term.

Another early, and similar, definition from FAO (1988) is "…the management and conservation of the natural resource base and the orientation of technological change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable".

ADB/NACA (1997) mention three additional "types' of sustainable development taken from Goodland and Daly (1996): Social sustainability (SS), Economic sustainability (EcS) and Environmental sustainability (ES). The Inter-generational equity sustainability (IS) (from Hambrey 1998 above) can be added as a fourth consideration.

The application of this concept is further clarified by the comments of Phillips, Boyd and Edwards (2001) who note, very importantly, that one must clearly define the boundaries of the system that is being described as sustainable. A single pond or group of ponds may be sustainable as long as the adjacent communities are not considered. With those included in the "boundaries", additional questions arise. Sustainable development on a macro-scale is a more difficult concept to deal with than that for a single pond or shrimp farm.

An important condition for the sustainable use of mangroves, whether for aquaculture, timber production or other uses, is that it should require no net loss of the area of mangroves in existence prior to the "sustainable" activity commencing (through restoration or creation of equivalent habitat), and the restoration back to former conditions of mangrove areas temporarily used for a defined sustainable activity. Regarding "sustainable aquaculture" New (1998) defined this as "responsible guided change for the cultivation of animals and plants in water

Institutional factors, coastal land use, tenure and enforcement

Institutional factors – policy, legal frameworks, and institutional frameworks – play an influencial role in land use changes in coastal areas, including those related to the development of shrimp and other forms of aquaculture. In general, such issues are largely ignored in many analyses, despite their importance. Institutional responsibilities and policies may suffer from conflicting mandates - this is often caused by a narrow and rigid sectoral approach to natural resources management and development. A strong institution may promote a particular sector in a manner that creates inbalance, even conflicts. Forestry and agricultural departments, for example, are strong in many developing countries for historical reasons, whereas their environmental equivalents are often much younger departments lacking in sufficient staff, other resources, and authority.

Property rights have profound consequences on the patterns of local resource use and management, and land tenure is a critical factor in how people use and manage these resources. The changes in land use over time, and willingness to participate in rehabilitation efforts are commonly related to land use rights. In the Vietnam example (Case Study 9), the interest of local people to participate in mangrove reforestation was constrained severely by the lack of land ownership conveyed upon them. As tenants with limited ownership rights, poor farmers were unwilling to invest in mangrove management, or crop diversification, and opted instead for short-term economic benefits from shrimp aquaculture.

Tobey et al (2001) mention another situation in south Sumatra where there has been some resistance among local people to the replanting of mangroves, the reason being that the status of having trees would revert the land to the government Forestry Service once the trees become productive – naturally this seems unacceptable to community members who are currently making a living in these areas.

Summary of major causes of mangrove loss

This section summarises some of the major causes of mangrove loss as revealed by the various case studies reviewed. Only a few of these causes relate specifically to aquaculture – most relate more generally to the current patterns of resource use in coastal areas which has been beyond a sustainable level throughout much of the tropics, compounded by weak policy and poor resource management capacity.

- Major coastal land use changes.
- Extensive shrimp farming in some countries.
- Uncertain land ownership and rules governing access to mangrove areas.
- Governance and institutional failure to effectively manage coastal mangrove resources, or values of mangrove resources.
- Environmental changes and shrimp disease, leading to shifting practice.
- Poor planning of coastal land use and implementation of development plans.
- Issues related to enforcement, unrealistic modes of implementation of legislation (e.g. zonation schemes).

- Lack of involvement of communities in decision-making (management, development of legislation, enforcement) Lack of understanding on why zonation is required.
- Co-ordination between different levels and different sectors of government.
- Compatibility issues, and economic returns over different time frames.
- Market forces and perceptions of high profitability versus risk from shrimp culture, based on short-term financial considerations, rather than long term economic ones.

These issues need to be dealt with through the planning process, legislative implementation mechanisms, and via farm management/private sector action, as discussed in the next section dealing with environmental mitigation measures.

Interventions and other Actions

Many possible interventions or mitigation measures can be proposed to promote the concept of co-existence of mangroves and aquaculture development. Interventions should be considered at three main stages in the development process: namely the planning (before), implementation (during) and restoration (after) stages. Mitigation can also be applied at two levels or scales, namely at the on-farm level and at the coastal zone scale.

Before **–** this is the policy, planning and development phase prior to the introduction or further development of shrimp aquaculture. Essentially this involves planning of coastal land use, aquaculture integration with wetlands, aquaculture zoning behind / in front of mangroves and other wetlands, and consideration of alternatives – polyculture, aqua-silviculture, other land uses, and community involvement in land use planning and management. These actions are considered at the coastal zone management scale.

During **–** this mainly concerns the operation and management phase. It may involve the application of more effective management practices (e.g. through applying Codes of Practice); intensification of production, use of closed culture systems, effluent management, bioremediation and other environmentally friendly options. These actions are mainly considered at the farm level, in terms of siting, construction and operational management.

After **–** this is concerned mainly with land use changes and may involve a restoration or rehabilitation phase after shrimp aquaculture has stopped; for example, because of disease problems, or after reclassification of the land area for other uses. Restoration of mangroves may apply at both the farm level and coastal zone scale (see Case Studies 9 and 11 from Vietnam, and Case Studies 12 and 13 from Thailand).

This section considers the key lessons learned from mitigation measures introduced at these different stages and levels. Mitigation can be supported by a number of other actions, especially education and awareness raising, monitoring and feedback activities, consultations and other information-sharing mechanisms, and applied research. More generally, information dissemination represents a supporting category of activities which are fundamental to the success of all the other mitigation measures and actions described here. The section concludes by reviewing the key lessons learned so far – what has been done, what works, what does not work, and why?

Policy, planning and development

Consultations conducted during the preparatory phase of the Thematic Review confirmed the need for transparency in the planning and policy process for coastal aquaculture development. A framework approach is recommended, whereby there is (a) a Planning Framework; (b) a Policy Framework; (c) a Legal and Regulatory Framework; and (d) a supporting Institutional Framework. Traditionally these have been put in place at national level, but the experiences elaborated in the case studies also emphasise the need for equivalent institutional structures and management mechanisms at local level. There are a number of countries already moving towards decentralised resource management mechanisms (e.g. Thailand) emphasising the importance of local level actions to address coastal management issues.

There is also evidence in some countries that in the absence of effective national mechanisms and/or lack of clarity of responsibilities, alliances between interested agencies can promote much more effective management. For example, in Ecuador an alliance between an NGO and the National Shrimp Farmers Association has proved effective in policing incursions by shrimp farmers into mangrove areas. The case of Ecuador is presented in associated Tables and section.

Many countries already have policies and legislation to protect mangroves and other wetlands, but these often come under different legislative and institutional responsibilities to those governing the national policy national policy towards shrimp farming. Aquaculture still comes under the fisheries legislation in some countries (FAO, 2000), whereas mangroves are usually under the legal protection of forestry, agriculture or environmental agencies. In Malaysia, for example, mangrove land comes under the protection of the Department of Forestry at State level, whereas coastal aquaculture is a responsibility of the Department of Fisheries, which operates at Federal and State level. Sabah and Sarawak are two examples of states in Malaysia operating in the Way. But in Sarawak, coastal aquaculture development comes under the state Department of Agriculture, rather that Department of Fisheries.

In Vietnam, the Ministry of Fisheries and the Ministry of Agriculture and Rural Development are responsible for policy setting for aquaculture development and mangrove forests, respectively. In addition, the Ministry of Planning and Investment plays an important role at the planning stage in aquaculture development and the approval of larger projects. The implementation of the policies is largely the responsibility of provincial government agencies via the Department of Fisheries and Department of Agriculture and Rural Development at provincial level. Vietnam (and several other countries) have on the one hand policies to expand coastal aquaculture to increase revenues from shrimp and other aquatic products; and on the other hand legislation and a zoning policy to protect mangrove forests. These policies are not in themselves conflicting, but require careful coordination and integrated planning for their successful implementation.

The situation in most shrimp-producing countries is greatly complicated by the fact that some shrimp farms were established before zoning and other wetland conservation policies were introduced, or implemented; many such farms may now exist in contradiction to current legislation. In northern Vietnam, for example, shrimp ponds occupy large areas of mangrove land in nature reserve, which is also now designated as a Ramsar Site for wetlands conservation (Xuan Thuy in Nam Dinh Province). In describing the Xuan Thuy Nature reserve Pedersen and Thang (1996) noted that "The majority of ponds are situated inside Xuan Thuy Nature Reserve, where they are generally managed using the extensive method".

Legal and regulatory framework

The general approach of many countries to the problems of mangrove destruction has been to adopt ever more stringent and unenforceable regulations designed to prohibit, or severely limit, human activities in mangrove wetlands. In some cases, this has led to still greater difficulties for management. In the southern part of Vietnam, for example (see case study 9) the designation of a Full Protection Zone (FPZ) of mangroves around the coastline of the Lower Mekong Delta (LMD) has required that 10,000 people be subjected to compulsory resettlement. The very poor are now excluded from utilising the mangrove forest of the FPZ, but in fact illegal felling of trees is carried out not only by local people, but also by organised criminals from other provinces (Euroconsult, 1996). The high cost of patrolling the FPZ in terms of manpower and operating costs for patrol boats means that effective control of all destructive human activities in the FPZ (which is 470 kms long!) is almost impossible. The only workable solution seems to be by promoting community awareness and cooperation, assisted by the authorities, to protect the mangrove zone. Such action is part of the Coastal Wetlands Protection and Development Project (CWPDP) funded by World Bank and Danida which is helping Vietnam to reforest and protect about 50,000 Ha of mangrove forest in the LMD.

Government regulations that can be applied to control land use effectively in coastal mangrove areas include planning controls and farm licensing which prevent the establishment of aquaculture projects in unsuitable locations, the application of EIA requirements and the adoption of coastal zoning policies. The registration of farms can be an important tool to control development. In Thailand, for example, technical support and quality control is provided free to encourage shrimp farmers to register. Farms located on mangrove land now zoned as conservation forest are not allowed to register. In practice, the registration process is also being used as an indirect, but effective, technique to control the siting of new shrimp farms. Ecuador provides a good example of a shrimp producing country which has clear institutional responsibilities for the management of mangrove forest, supported by ample legislation for the protection of mangroves. Some of the most important and recent laws are listed in the Table 15 below.

Other laws related to the protection and management of mangroves in Ecuador include:

- The fisheries law and its regulation: this prohibits the destruction or alteration of mangroves.
- Rules for the farming and culture of bio-aquatic species: these act as a mechanism to ensure that everyone involved in aquaculture is forced to protect mangroves and are considered responsible for the damage they might cause to the mangrove forest.
- Law for the creation of the Program for the Management of Fishery Resources.

As Table 15 shows, there is an impressive list of laws, decrees and regulations for the protection of mangroves in Ecuador. Mangroves have been protected in the strongest way possible by including them as part of the protected areas patrimony (National Parks system). Ecuador has also tried to give ancestral communities priority in the sustainable use of mangroves; it has reformed the penal code so as to impose tougher sanctions on felons; and it has created a program for the integrated management of coastal resources.

Despite this strong legislative support, mangrove deforestation still continues in Ecuador. Some of the probable causes of this continuing problem are explained in Table 16.

Table 15: Some of the most important and recent laws in the Ecuadorian legislation directed towards the protection of mangroves

- Inter-Ministerial accord No 0322 of November 20th 1979, through which the Ecological Reserve Churute Mangroves, is declared an area protected by the state.
- Law 74 of August 24th 1981: natural forests are constituted as forestry patrimony of the state
- Executive decree No 824, on June 17th 1985: declares all mangroves existing in the country as protected forests.
- Law 91 of August 7th 1990: declares mangroves state assets, including those that are privately owned. They are not subjects of possession or any other means of exploitation.
- Executive decree 1907, of July 7th 1994: declares regulations for the protection, conservation and control of natural forests and mangroves.
- Executive decree 3327 of December 22nd 1995: sets the regulations for the arranging, management and taking advantage of mangroves.
- Ministerial accord 001 DE, of January 16th 1996: created the Ecological Reserve Cayapas Mataje Mangroves.
- Executive decree 410 of December 30th 1998: creates the Committee for the Inter-Institutional Coordination of actions for the protection and conservation of mangrove ecosystems.
- Executive decree 1102 of July 28th 1999: allows ancestral communities and users, the sustainable use of mangroves for subsistence, taking advantage of and selling of species that develop in mangroves.
- Environmental Action Law 99-37 of July 30th 1999: sanctions with a USD13.000/ha. fine to restore the mangrove area that has been cut down or destroyed.
- Law 99-49 of January 25th 2000: reforms the penal code regarding felonies against the environment, 1 to 4 years of prison will be the sanction to anyone found cutting down, destroying or burning mangroves.

Australia provides a valuable example of a country where mangrove protection is enforced effectively. In Queensland, shrimp farms are licenced by the Department of Primary Industries under the provisions of the Fisheries Act (1994). This act specifically limits development (including aquaculture) within intertidal areas. Mangroves are regarded as a public resource in Queensland and a permit is required to manipulate mangroves in any way – including collecting propagules or other harvesting, cultivation, or relocation (see case study 8). Queensland also has far-sighted legislation protecting the aquatic resources associated with mangroves. The fishery for mud crabs (*Scylla serrata*), for example, is controlled by limiting the allowable catch to mature male crabs exceeding 13 cm in carapace width. The taking of female crabs is completely forbidden in order to protect the breeding stock (Heasman and Fielder, 1971).

Table 16: Causes of continuing mangrove deforestation in Ecuador

1.	The regulations (1995) for the arranging, management and taking advantage of mangroves have not been fully put into practice, mainly due to: a) Once mangrove forests are part of state's forestry patrimony and not even private property rights have a standing, it makes it very difficult for reforestation, as the reforested area will then be Government property. b) It uses the concept of "mangrove ecosystem" for its delimitation; however, this makes it necessary to determine all the biotic and abiotic mangrove interactions in order to pin-point its boundaries. It would have been easier if the "mangrove forest" concept was used, and resource management must be carried out by several institutions that have competence over mangrove ecosystems. c) It introduces the term "transition zone" to describe the mangrove ecosystem, as it states that in order to be considered a mangrove, it must be located within the high tide limits plus a transition zone, however, this last one is not defined and can be considered an unlimited area; the right thing to do would have been to define a buffer zone which would also have allowed the management of the resource to fall within only one Government institution.
2.	Territorial planning or normative laws to regulate the shrimp farming sector, do not exist. Today a significant informal shrimp farming sector exists, which due to a lack of clear regulations for the practice of aquaculture or due to an institutional weakness of enforcing authority, go beyond the established dispositions and affect the mangrove forests.
3.	Inter-Institutional competition for the management of the resource. There are three institutions which are responsible for mangrove forests: the Ministry of the Environment, the General Directorate of the Mercantile Navy and the Sub-Secretary of Fisheries. Instead of reinforcing mangrove conservation, the efforts of these institutions are diluted when the responsibility is shared by more than one institution.
4.	The Ecuadorian legal system: is too inefficient to carry through all the demands initiated against parties that have harmed the mangrove forests.
5.	Negative publicity created by certain organised groups, such as some environmental NGO's, that takes an extreme and does not contribute positively to a solution to environmental management problems.
6.	No measures are taken to incorporate the aquaculture sector in the different issues of mangrove management, regulations, laws and decrees, which haven't even been discussed with the producing sector.

Local policy and planning initiatives

An alternative strategy that is now gaining more support among both governmental agencies and the public sector is the development of action on mangrove management that promotes a diversity of sustainable activities organised and administered at the local level. Many schemes have been introduced and various names are used to describe them, such as partnerships, stewardship schemes, multi-lateral cooperation schemes or concerted actions, and negotiated agreements for local area management (e.g. covering a particular lagoon, estuary or bay area). Three successful examples are summarised below. Local area initiatives depend primarily on strong local community organization and participation, which is the subject of the following section. The distinction here is that, in addition, there must also be official governmental recognition and support for the initiative.

<u>Partnerships – an example in Ecuador</u>

In Ecuador, there has been a project partnership between the National Chamber of Aquaculture and the Natura Foundation-Guayaquil chapter, known as the "Control and Surveillance System for the Mangrove Deforestation in the Continental Coast of Ecuador". The purpose of this initiative is to control the indiscriminate deforestation of mangroves and identify the persons and companies that commit this infraction over a test period of two years.

According to the annual report presented by the Natura Foundation, during the first year of execution (01 November 1998 to 31 October 1999) the project organised 44 aerial monitoring surveys over the mangroves located in the Estuary of the Guayaquil Gulf (the Jambelí Gulf included), the Estuary of the Chone River – Portoviejo River, the Estuary of Esmeraldas – Muisne – Cojimíes and the Estuary of San Lorenzo.

The monitoring flights tried to include deforestation sites detected earlier allowing, the technical personal of the project and delegates of the competent authorities, to realise the proper follow up. By now, 88 % of the cases of infringement have been followed up by on the ground inspections between the UCV (Unit of Conservation and Control) and the Natura Foundation.

In eleven months of follow up on the established cases of violation, and as a product of ten administrative resolutions executed by the Forest Provincial District of Guayas, the sentenced violators have been required to reforest 80.09 hectares of mangrove in the Gulf of Guayaquil.

Likewise, eight cases has been sentenced through the administrative resolution in the Forest Provincial District of Guayas, while six cases detected before the initiation of the project were also sentenced through the administrative resolution to the same organism; four dislodges to informal violators of mangrove deforestation were executed by the Port Captain of Guayaquil.

A “Stewardship” scheme in the Philippines

In an effort to return State-owned mangrove forests back to a more traditional communal ownership and management system, the Philippines has enacted “Mangrove Stewardship Agreements” (FAO, 1998). Under this scheme, which is administered by the Department of Environment and Natural Resources (DENR), local communities (or private individuals) can obtain a usufruct lease on a designated area of mangrove for 25 years. The leasee is permitted to cut trees selectively, harvest fish and shellfish and develop new mangrove plantations, based on an agreed management plan for the area. The department can provide assistance for start-up activities and the management plan. Local NGOs can be contracted by DENR to assist the local community with the initial stages – these include an explanation of the steps involved in applying for a Certificate of Stewardship Contract issued under the Integrated Social Forestry Program (PCARRD, 1991). The community can also receive help to promote an awareness-raising campaign to explain the benefits realisable from the mangrove forest area under its stewardship.

Multi-lateral cooperation/concerted action in Thailand

In the 1980s, small-scale coastal fishing communities in Trang Province, southern Thailand were facing acute poverty and child malnutrition. Their mangrove forest and fisheries resources had become severely depleted after several decades of the government granting concessions for mangrove felling for bark (tannin extraction) and charcoal production, and for the development of commercial trawling. The poorest villagers were labourers, woodcutters and hired crewmen for the trawler fishing. Better off villagers could afford to invest in grouper farming using floating cages, which was very profitable initially, but this too became threatened by a decline in the availability of wild grouper fingerlings, and poor water quality due to pollution.

Concerned people from various backgrounds in Trang Province met to consider the plight of the small-scale fisherfolk. They concluded that neither fish farming, nor investing in modern fishing gear was the answer, rather “..to bring about fishing security, it was necessary to recover and conserve coastal resources." (Charnsnoh, 1998). From 1985 onwards, and with the help of the Yadfon Association (a Thai NGO), the concept of village "utility" forests as common property areas was revived in Sikao District. With the co-operation of the provincial governor, local authorities and the forest concessionaires, mangrove reforestation was started in Thung and Laem Sai villages. The reforested area was later recognised by the Royal Forest Department as a community mangrove forest (the first in Thailand). The concept spread to other villages, leading to a total reforestation area of about 253 ha. From 1991, this local initiative has expanded and developed into a "five-tiered" co-operation system, or concerted action, involving the fishing communities, government agencies and civil servants - including the governor, academics, business groups, journalists and students. Yadfon and WWF Thailand play a supporting, mainly liaison role for these groups (Charnsnoh, 1998). The outcome today is that the Trang provincial government has given close attention to the conservation of coastal resources, the role of public participation has increased, and conservation areas have been designated, included protection zones for sea grass beds.

Community organisation and participation

The above example of concerted action on behalf of fishfolk in Trang Province started from the organisation and empowerment of the local communities. Without these two vital first steps, it is unlikely that community participation in coastal resources management can be effective. As explained by Yadfon (Charnsnoh, 1998), by focusing on self reliance and the initiatives of the Trang villagers themselves, such as mangrove reforestation and protection of sea grass beds, the communities developed a sense of unity and morale-building which was later recognised and supported by the local authorities, and others. The lessons learned by Yadfon over several years in Sikao District have now been adapted and introduced successfully in several other provinces in Thailand, including Pattani, Surat Thani, Krabi and PhangNa. The concept is to first promote organisation in the local community, then to encourage concerted action or "five-tier" co-operation later. Moreover, by starting on a small scale in three villages in Sikao District, and by developing the approach carefully over several years of experience, expansion by Yadfon into other communities was greatly facilitated via an accelerated community learning process.

Similar success with community organisation has been achieved in northern Vietnam. Starting in 1994 in one district of Thai Binh Province, the Red Cross organisation has helped the coastal communes to rehabilitate mangrove forests for coastal protection and environmental improvement. In addition to their general vulnerability to typhoons, many of the local people own extensive aquaculture ponds or smaller ponds for semi-intensive culture of scrab and shrimps (as alternative crops), or they work for the pond owners; the poor people also catch crab seed and collect feed items in their spare time (Macintosh, 1996). Thus the mangroves are also beneficial economically in their support function to the local fisheries and aquaculture sectors.

Local families contracted by the Red Cross planted a trial area of mangroves (300 ha) in 1994. With the experience gained, and after some initial difficulties, the Thai Binh Red Cross became stronger and was able help each commune in the project to plant and protect mangroves. Public information support, training, mangrove planting ceremonies, and meetings involving the community leaders at each level in the province, were some of the key activities of the project, which helped to achieve the community organisation necessary and to develop a sense of unity and empowerment (Macintosh, 1999). This approach has now been repeated in neighbouring Nam Dinh and six other provinces covering the whole Red River Delta; to date the Red Cross has supported the planting of more than 10,000 Ha of mangrove forest.

In the next five-year phase of this programme (2001-2005), the concept of community participation in local area management will be promoted strongly. The coastal communes will be assisted to negotiate with the district authorities and others regarding zoning of the coastal area for aquaculture and other uses, and the issue of "ownership" of the mangrove forests. They will also be assisted to develop a community forest protection system as part of their disaster preparedness planning. As with the example from Trang in Thailand, community unity and sense of purpose have been promoted to a point where concerted action, with the full support of the local authorities, is now a realistic goal for the mangrove programme in Thai Binh and other coastal/provinces of the other Red River Delta provinces.

Self regulation

Codes of Conduct and Codes of Practice

These are instruments that establish principles, standards and guidelines on a non mandatory basis, to help ensure that industries are managed in a sustainable manner with due regard for the environment. Regarding aquatic resources, the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) is the best known and wide-reaching example to date. Another, more local example created by industry itself, is shown by the Code of Conduct formulated by the marine shrimp culture industry of Thailand. The commitment of this Thai industry (nationally the largest shrimp culture industry in the world), and the manner in which it intends to adhere to regulatory, social, educational and other requirements, is provided in Table 17. However, the industry in Thailand has still to fully implement the Code, although progress has been made in some coastal areas (Rayong, and Songkhla in 2002).

The Global Aquaculture Alliance (GAA) has also prepared a Code of Practice for Responsible Shrimp Aquaculture, which includes a section on protecting mangroves (Boyd, 1999). Table 18 below illustrates the management practices identified in the Code.

Table 17: The Marine Shrimp Culture Industry of Thailand Code of Conduct

Code of conduct – Policy Statements
Our Goal: **Sustainable Marine Shrimp Culture:** **A Thai Commitment** The marine shrimp culture industry in Thailand is committed to producing high quality, hygenic products in a sustainable manner that provides for environmental, social, and economic benefits to present and future generations. The marine shrimp industry in Thailand will subscribe to the following: **Environmental Protection** Integrate technically-proven and cost-effective measures to protect the environment. **Regulatory Compliance** Comply with all regulatory requirements pertaining to the marine shrimp culture industry in Thailand. **Quality and Safety** Ensure shrimp products are of the highest quality and facilities are operated in a safe manner for workers. **Efficiency** Develop, design and operate facilities based upon the efficient use of energy, resources and materials. **Social Responsibility** Develop opportunities for small-scale farmers to operate marine shrimp farms. **Education and Training** Improve the awareness of the industry, producers, buyers, consumers and the public of the importance of sustainable marine shrimp culture industry practices. **Public Consultation** Encourage public consultation in planning and management of the marine shrimp culture industry. **Location** Locate shrimp culture operations within areas that minimise environmental and social impacts. **Continual Improvement** Establish ongoing program to improve environmental performance and take preventative and corrective action where necessary. **Research and Development** Support research and development into sustainable marine shrimp culture industry practices. **Monitoring and Auditing** Monitor and audit performance of industry facilities and potential impacts on the surrounding environment. **International Trade** Communicate and consult with importing countries about Thailand's commitment to sustainable development for the marine shrimp culture industry.

In essence, these are basic management standards that many governments and producers would agree with. However, implementation will remain a key constraint. The GAA considers that market incentives can be used to improve practice and it is currently developing a strategy to implement these practices by linking them to a "shrimp certification scheme".

Table 18: Elements of the Code of Practise for Responsible Shrimp Aquaculture relevant to mangroves.

New shrimp farms should not be developed within mangrove ecosystems
Realizing that some mangroves must be removed for canals when new shrimp farms are sited behind mangroves, a reforestation commitment of no net loss of mangroves shall be initiated
Farms already in operation will continue ongoing environmental assessments to mitigate any possible negative impacts on mangrove ecosystems
All non-organic and solid waste materials should be disposed of in an environmentally responsible manner, and waste water and sediments shall be discharge in manners not detrimental to mangroves
The shrimp aquaculture industry pledges to work in concert with governments to develop sound regulations to enhance the conservation of mangroves including regulations regarding restoration of mangrove areas when old farms located in mangroves are decommissioned
The shrimp aquaculture industry will promote measures to ensure the continued livelihood of local communities that depend on mangrove resources

Source: The Global Aquaculture Alliance (GAA) from Boyd 1999

There are a number of other Codes of Practice that are being prepared or negotiated. A detailed description of these codes is provided in Boyd and Hargreaves (2001).

Coastal land use zoning

Background

It is widely agreed that the zoning of coastal land use activities is a vital planning tool to reduce negative environmental impacts on coastal resources and potential conflicts between the various users of the resources (e.g. FAO, 1998). Many of the general environmental and social problems associated with shrimp aquaculture result ultimately from inadequate planning of coastal land use. The specific problems addressed in this review stem from unregulated expansion of shrimp farming into mangrove ecosystems without any regard to sustainability, or to the resource needs of other coastal users. (note that the term coastal land use zoning is used here for simplicity; it is a key (and achievable) step towards the more challenging goals of coastal area management or coastal zone management.).

Land use zoning, therefore, is one option available to governmental agencies responsible for the management of coastal areas. Zoning schemes work by dividing defined areas of land into physical zones, within which different rules apply, typically prohibiting or restricting the activities or types of development allowed in each zone. In a relatively undeveloped coastal environment, zoning enables the authorities to adopt proactive measures to achieve sustainable resource use and prevent conflicts. It is much more difficult to implement a coastal land use zoning scheme in coastal areas already heavily developed or impacted by particular users of the land and water. However, this is being attempted in some existing shrimp farming areas (with mixed success). Examples are reviewed in case study 1, and commented on in the following sections, together with coverage of the general principles for the application of zoning to coastal aquaculture.

Examples of coastal land use zoning

Zoning schemes have long been a feature in the management of nature reserves, Marine Parks and other protected areas allowing certain habitats to be completely conserved for their ecological and scientific value, while others are set aside for public use, but on a controlled basis to minimise human impacts on the natural environment. Zonation in this way also allows for the separation of potentially conflicting human activities in particular areas. In Northern Australia, the Great Barrier Reef Marine Park is divided into a number of zones, which differ in the amount of protection they provide to the natural environment. Some zones, for example, are completely closed to human contact, while others allow for activities such as tourism and commercial fishing.

Zoning has also been applied recently to the management of mangroves in Thailand and Vietnam (see case study 1). All mangrove forests in Thailand have been assigned to zones, again providing them with different levels of protection from human activity. In addition, Vietnam and Thailand each have a mangrove forest Biosphere Reserve (under the UNESCO Man and Biosphere (MAB) Programme). The Biosphere Reserves have clearly defined core, buffer and transitional zones. Human activities are allowed, even in the core and buffer zones, provided they are traditional and non-destructive of the mangrove forest. In the Ranong Biosphere Reserve, for example, there are some small-scale fishing communities living in the core areas that also operate floating cage culture of grouper and sea bass in the mangrove waterways. With a very few exceptions, the shrimp farms in the Ranong Biosphere area are located in the transition zone. An important feature of the Biosphere Reserve concept is that the criteria and objectives for these special conservation areas, and the designation for core, buffer and transition zones, are clearly defined by the Seville Strategy, a published document of the MAB (1994).

There are a number of current examples of land use zoning being applied to the management of aquaculture; for example in Hong Kong and Tasmania. In each case, specified areas of the coastal waterways are allocated for the purpose of cage culture, while restricting other uses of these zones (see case study in annex). Similarly in the Mekong Delta, Vietnam and Krung Kabaen Bay, Thailand, zoning schemes exist which allocate certain areas of coastal land for shrimp aquaculture development; and adjacent areas for mangrove conservation. Within the specified aquaculture zones, farmers are provided with access to training and infrastructure support, such as water supply or wastewater treatment facilities.

The application of zoning in the management of shrimp farming has numerous potential benefits to both producers and regulators. These include the separation of potentially conflicting activities, ease of monitoring and assessment, and provision of centralised access to infrastructure and information and a streamlined approval process. On the other hand, zoning schemes are constrained by their rigidity i.e. they are difficult to change once established; there are also potential problems associated with disease due to the inevitable proximity of farms constructed in a designated zone. Zoning schemes are also difficult to establish and manage, as they require close co-operation amongst different interest groups and a considerable financial commitment from governments. Furthermore zoning schemes are limited by the fact that they can be affected by influences outside the management area. Table 19 summarises the specific aspects of zoning, which should be considered with respect to coastal shrimp culture.

Table 19: Key points for consideration when applying the concept of land use zoning to shrimp farming

1.	Management plans should be developed which specify allowable uses of zones in the management area e.g. Great Barrier Reef Management Plan (GBRMP).
2.	Success of zoning schemes will be enhanced through comprehensive public participation programs, ensuring compliance with and support for zoning specifications once established, e.g. GMRMP.
3.	Zoning schemes should have a legal basis to guarantee compliance with zoning specifications as well as providing investors with security of land tenure.
4.	Zoning schemes should incorporate permitting procedures to allow fine control over development in the zones e.g. permits for waste management or adherence to industry best management guidelines.
5.	Zoning schemes should be administered by dedicated authorities, with public participation to promote compliance with the zoning regulations; however these should also be responsive to changing needs and conditions.
6.	EIA procedures should be carried out for the zone as a whole, including assessment of all land uses and values in order to integrate shrimp aquaculture into coastal zone planning. EIA should include assessment of the appropriate area of total shrimp farming area for each region.
7.	Support for farmers using shrimp farming zones should be provided in the form of self-help groups such as farmers' societies.
8.	Incentives should be provided to farmers in the form of infrastructure support, training, access to credit and long term leases.
9.	To ensure the sustainability of zonation schemes, financial mechanisms should be examined such as water use fees, pollution fees, permit or licensing fees, contributions and donations.
10.	The effectiveness of the zoning scheme should be monitored in relation to the original objectives of the scheme.

Source: Case Study 1: see thematic review Annexes

Zoning criteria for shrimp aquaculture

In general terms, the experiences from site selection for shrimp farms suggests that:

- Mangroves are not optimal sites for semi-intensive and intensive shrimp aquaculture, because and there is high risk of failure. Intensive and semi-intensive shrimp farming can be more successful in areas away from mangrove forests, including adjacent salinas
- Shrimp farming sustainability can actually benefit from the conservation of mangrove forests; and
- The siting of shrimp farms outside, but adjacent to mangroves, can reduce the negative environmental impacts on mangroves from aquaculture, but a number of interactions remain which must be considered carefully as part of the zoning plan. This includes impacts on other types of non-mongrove wetlands, like salinas and supratidal tidal marshes typically found adjacent to mangrove forests.

Because loss of the ecological attributes of mangroves may be a factor in unsustainable shrimp farming, it follows that (1) locating ponds outside of mangrove areas is highly desirable; and (2) mangrove conservation, and the restoration of destroyed or degraded mangrove habitats, may improve ecological conditions and thereby reduce the risk of aquaculture failure.

There are also good technical and economic reasons why mangrove forestland is not recommended for shrimp farming. An ASEAN manual (Pawaputanon, 1997) which attempts to harmonise good shrimp farming practices in ASEAN countries states (with regard to site selection) that "low land or mangrove swamps are not good sites" for the following reasons:

i. Low land has potential acid sulphate soils;

ii. Deeper ponds cannot be constructed and complete draining is impossible; and

iii. Construction costs in swampland are always higher.

These views are supported by Chan *et al* (1995) who stated that "Mangrove soils are not suitable for farm development due to their high organic content and acidic nature. Pond development, wherever possible, should be behind any mangrove". Further discussion on site selection for shrimp farms can be found in Macintosh and Phillips (1992), Chanratchakool *et al* (1995) and in Sammut and Hanafi (Case Study 10).

Topography and soil type

During the 1980s shrimp farms were constructed habitually in mangroves, especially in Asia, and this practice has not stopped entirely in more recent years, for example in Ecuador (Snedaker, 1999). Mangroves have been popular sites for shrimp farming for several reasons:

- The land was virtually unutilised from a development perspective and usually inexpensive, or even free (e.g. through governmental land allocation schemes);
- Land elevation is just above mean sea level so that pond water can be tidally exchanged;
- Sources of wild shrimp larvae were generally abundant, either for trapping in the ponds, or for collecting;
- Various governmental programmes, often aided by international donor funding, encouraged mangrove conversion to aquaculture; and
- Fisheries departments and other agencies produced technical manuals advocating shrimp farming in intertidal areas.

It is now obvious that the occupation of mangrove areas by shrimp farms can cause severe damage to coastal ecosystems. It is difficult, therefore, to provide a logical reason for the continued conversion of mangrove areas for shrimp farming today, other than they often comprise the only space available to those occupying marginal land, especially poor farmers who otherwise have to depend on agriculture for their livelihood. Through poverty and low educational status, such people continue to be attracted to the potentially high returns from shrimp farming, irrespective of the longer term consequences. The purpose of this section is to reaffirm the reasons why mangrove land and soil conditions are in general unsuitable for shrimp production.

Topography

The land occupied by mangrove lies within the tidal zone, and those areas that have elevations above low tide will flood on several days per month. Because of their low elevation, mangrove land usually is covered or saturated continuously with water. Low embankments can be constructed around selected areas of mangrove to exclude tidal waters, and surface soils will dry sufficiently to allow the operation of earth-morning equipment. Nevertheless, deeper layers of soil will not dry properly, and usually construction will be difficult, resulting in substandard earthworks. Also, concrete water control structures built in ponds will tend to settle and crack because of the soft underlying sediments, causing operational difficulties.

The low topography, nearby coastal waterways, and vegetation make mangrove areas very productive for fish, shrimp, other invertebrates, and birds. Thus, intake water for shrimp farms in mangroves often has a rich fauna, crabs are abundant around ponds, and birds are plentiful. It is difficult to minimise the contamination of shrimp farm waters with wild fish and invertebrates, and birds may cause severe shrimp predation. Wild crustaceans are known to be carriers of serious shrimp diseases, such as yellowhead baculovirus (Chanratchakool et al, 1995), and even birds can promote infection by carrying diseased shrimp from one pond to the next.

The water in mangrove forests generally flows through many sinuous and interconnected channels, which exchange slowly with the open sea. Thus, effluents released from shrimp farms into mangroves may remain within the system. The nutrients, organic matter, and biological contaminants in shrimp farm effluent often become mixed with the intake water from the same and other shrimp farms. This results in degradation of intake water quality and facilitates the spread of shrimp diseases.

Sites with weak tidal flushing obviously have greater risk of effluent build-up. In Ranong, Thailand, for example, where there is a large tidal range (up to 4.5m), no change in water quality has been detected compared to 1988-89 levels (Macintosh et al, 1991), even after several years of intensive shrimp farming. Conversely, where the tidal range is moderate, flushing between the mangrove water mass and the open coastal waters may be very limited. In the Rufiji Delta mangroves in Tanzania, Francis (1992) described a "trapping effect" whereby suspended sediment concentrations were higher in the nearshore waters (1000mg/l) compared to the estuarine and offshore zones (<49mg/l and zero respectively). The nearshore waters are driven into the mangroves during high tides. Francis concluded that neither tidal currents nor monsoon winds could cause intense mixing between the estuarine and nearshore, and the nearshore and offshore waters. The Mekong Delta is another example where extensive areas of mangrove forest have been converted to shrimp ponds. Poor water quality and water exchange capacity, compounded by high levels of pond sedimentation are now serious limiting factors on shrimp production (ACIAR, 1999; and Case Study 8 in annex).

Soil quality
Mangrove areas often have heavy clay soils formed from the deposition of fine alluvial sediments (Macnae, 1968). These soils are usually rich in woody material and other organic matter resulting from mangrove decomposition. Because of their waterlogged condition and fine particle texture (from alluvium), organic matter and iron, plus sulphate from seawater, accumulate in the soil. Under the anaerobic conditions typical within mangrove sediments, ferrous iron and sulfide combine to precipitate as insoluble iron sulfide (iron pyrite). Thus, mangrove soils often have high concentrations of organic matter and sulfide-sulfur. For example, soils in mangrove areas may have organic carbon concentrations of 10 % or more and sulfide-sulfur concentrations of 1 to 5 % (ACIAR, 1999). Depending on the situation, mangrove soils may be high in organic matter, high in sulfur, or high in both these constituents.

Soils with an high organic matter content are undesirable for shrimp pond development because embankments constructed from such soils will not be stable. When the soil is exposed to the air, the organic matter will begin to decompose through chemical and microbial oxidation. Thus, embankments constructed from mangrove soils tend to decrease in size over time, and have a tendency to breach eventually. Even in the absence of high sulfide-sulfur concentrations, organic soils are often highly acidic and large amounts of liming materials are necessary to make ponds suitable for shrimp production. Organic matter in the pond bottom is continually decomposed by aerobic and anaerobic micro-organisms. Although the rate of decomposition may be slow, ponds with high concentrations of organic matter often develop highly anaerobic conditions in bottom soils. Shrimp live on pond bottoms, and anaerobic zones in surface layers of the bottom soil represent a highly undesirable environment for them. The low oxygen concentrations and high concentrations of hydrogen sulfide, ferrous iron, and other microbial metabolites have adverse effects on shrimp health by causing stress. Also, encrustations of iron and manganese may cause blotches on shrimp which detract from their market value.

When soil containing sulfide-sulfur is exposed to dissolved oxygen at the pond soil-water interface, or to atmosphere oxygen in the case of embankment soils, the sulfide is oxidised. The oxidation of sulfide produces sulfuric acid which greatly increases soil acidity (i.e. lowers soil pH) and dissolves metals such as iron, manganese, and aluminium from the soil. Rainfall washes acidity and dissolved metals from embankments into pond waters. Ponds constructed on acidic, high sulfur content soils (often called acid-sulfate soils) tend to have highly acidic waters and soils. Liming can be used to mitigate acidity problems, but the amounts of liming material needed to solve the problem often are cost prohibitive. Special construction techniques involving installation of plastic liners or blankets of non-acidic soil over acid-sulfate soils are not only technically complex but also expensive (Sammut and Hanafi, Case Study 10).

While all shrimp ponds produce ammonia as a potentially toxic waste product, hydrogen sulphide is most commonly associated with mangrove soils (Lim et al, 1995). On many farms, shrimp suffer the combined stress from ammonia, hydrogen sulphide and low, or fluctuating pH. Such stress will typically interfere with moulting and shell hardening, cause damage to their gills and appendages, and make the shrimp more susceptible to disease. Farming under such conditions, as reported in the Mekong Delta example (seee case study 8) can easily results in crop losses representing 90% or more of the stocked shrimp.
In conclusion, it is usually not feasible to mitigate problems in shrimp ponds constructed from mangrove acid-sulfate soils and such sites should be avoided for shrimp farming.

The problem of extensive shrimp farming

In Asia, conversion of mangrove forests to extensive shrimp farming clearly has caused the most significant impact from aquaculture on mangrove ecosystems. The previous section suggests that extensive farming systems - and particularly those that involve 100% clearance of mangroves – do not make ecological or economic sense, either in the long or short-term. Menasveta (1997) has already pointed out the dangers to mangroves from further expansion of extensive farming and emphasises that development efforts should be directed towards the intensification and diversification of existing systems rather than further expansion of extensive shrimp farming areas. In some cases, partial or complete restoration of mangrove forests may be the most appropriate action in extensive farming areas. This is now happening in several shrimp-producing countries e.g. Ecuador, Indonesia and Thailand (see Case Study 14).

It should also be borne in mind that, particularly in Asia, many poor coastal inhabitants are involved in extensive shrimp farming - one of the reasons why extensive farms are built is because they require comparatively low capital investment. Some countries, and particularly Vietnam, also encourage extensive farming as part of the traditional practice of 'reclaiming' coastal land in accretion areas. Given the importance of extensive farming to coastal shrimp production in many countries, and to the communities involved, efforts should also be made to improve the economic returns from such systems. Integrated aquaculture-mangrove forestry systems (silvo-fisheries) offers one approach. These systems are based on a more conservative utilisation of the mangrove resource in order to maintain a relatively high level of integrity in the ecosystem, while capitalising on the economic benefits and poverty alleviation potential of brackishwater aquaculture (Fitzgerald, 1997). Indeed, silvo-fisheries are being used in mangrove rehabilitation projects being undertaken in Vietnam, Indonesia and Philippines. An integrated approach can help meet rehabilitation objectives, as well as providing food and income for the people involved (see annex case studies). A following section is devoted to an analysis of silvofisheries as a potential "better management" option for aquaculture in mangrove ecosystems.

Table 20: Potential impacts of shrimp aquaculture on mangrove forests and possible mitigation strategies.

Activity	Potential impacts	Mitigation strategies
Construction of ponds, embankments, canals and access roads.	Conversion of mangrove wetland, loss of habitat and biodiversity	Siting of ponds outside of mangrove areas.
	Alteration of estuarine flow and local hydrology leading to habitat changes, loss of productivity, including decline in larval recruitment	Construction that minimises habitat impacts, e.g. does not interrupt flows.
Dredging and deposition of sediment from pond bottoms/construction activities.	Alteration of estuarine flow (as above), changes in sedimentation, hydro- dynamics, water exchange, etc.	Reduce sediment loads, careful dumping of materials away from sensitive habitat.
	Excessive sedimentation in and around mangroves.	(as above)

Conclusions regarding site selection for shrimp culture

As a general conclusion, mangrove forest ecosystems are not optimum sites for shrimp farms because of their low elevation, low or fluctuating water salinity and pH conditions, poor drainage characteristics, and usually high soil organic matter and sulfide-sulfur concentrations, representing potential acid-sulphate conditions. The expense of constructing proper ponds in mangrove areas and mitigating soil problems usually is cost prohibitive and likely to prove unsustainable. Moreover, shrimp farms constructed in mangrove areas are often less productive in the longer term than shrimp farms located on other sites, and in addition, they tend to cause more ecological damage to coastal ecosystems than shrimp farms located in non-mangrove areas.

Coastal land behind the mangrove forest zone offers much better opportunities for shrimp farming, but access through the mangroves for the farms' water supply and impacts to salinas and high marsh habitats remain an issue. The implementation of regulations to exclude shrimp farming in mangrove areas should allow shrimp farmers to pass water supply and discharge canals through mangrove areas and to locate pump stations in mangroves (if necessary) if environmental assessment confirms that land behind the mangrove zone is suitable for shrimp farming.

In mangrove forest areas where large-scale conversion to extensive farms has already occurred (e.g. Bangladesh, Ecuador, Indonesia, Vietnam), a zoning policy may be the best solution – as is being developed in the Lower Mekong Delta (see Case Studies 1 and 9 in Annexes).

As a general principle, coastal zoning schemes for existing shrimp farming would be expected to:

1. Reclassify the seaward zone and critical hydrological/habitat zones (e.g. along the banks of estuaries and creeks) for mangrove conservation, and have provision to carry out mangrove restoration in such areas, as necessary.
2. Redevelop and improve the remaining shrimp culture zone to promote (i) intensification in smaller ponds, and (ii) more sustainable production systems.

3. In addition to the zoning scheme itself, there should be enabling mechanisms to ensure that the scheme can be implemented, monitored for effectiveness, and improved where necessary. These steps require enabling mechanisms as follows:
    a) supporting legislation to uphold the conditions stipulated for the management of each zone;
    b) a monitoring system, including environmental indicators for each zone;
    c) mechanisms for consultation with and feedback from the main stakeholders involved.

Shrimp Farm Operation and Management

There is a large literature dealing with aquaculture management and the use of better practices to promote sustainability (e.g. Macintosh and Phillips, 1992; Pullin et al, 1993; Lim et al, 1995). Much can be done at the project design stage and at operational level to reduce harmful impacts from aquaculture on the environment. It is not the objective of this review to cover the general principles of shrimp farm design and operation (for detailed coverage see Poernomo, 1990; Barg, 1992; Phillips et al, 1993; Chanratchakool et al, 1995), but two aspects of aquaculture management which are directly related to mangroves are described here: (a) the potential use of mangrove wetlands for shrimp pond waste treatment; and (b) the integration of mangroves and aquaculture in mixed farming or “silvo-fisheries” systems. A silvo-fishery may include crab, mollusc or finfish culture in addition to, or in place of shrimpmonoculture. Wood products from the mangrove forest component provide an additional source of income.

The principles underlying these two applications of mangroves in aquaculture are well illustrated by Smith and Masters (1996) who identified the useful properties of mangrove-wetland habitats from an aquaculture perspective, as follows:

- Mangroves act as sediment sinks. The roots and pneumatophores not only slow the water flow, but they act as sediment binders.
- Roots of mangrove-wetland plants can stabilise the walls of effluent canals, so erosion is greatly reduced.
- Mangrove plants and algal epiphytes take up nutrients in the effluent.
- Bacteria contribute to the breakdown of organic matter, ammonia and nitrite.
- Certain bacteria and microalgae are removed by filter-feeding organisms (e.g. certain copepods, polychaetes, and molluscs).
- Mangroves have the added advantage of attracting juvenile fish, shellfish and birds. The pneumatophores, prop roots and overhanging branches increase structural heterogeneity, and complexity of the habitat, providing shelter, food and refuge, thus potentially contributing to environmental improvement.

Principles of biofiltration using mangroves

Natural wetland habitats, or constructed wetlands, located on or adjacent to shrimp farms can be used to treat shrimp pond effluent (Rajanendran and Kathiresan, 1996). Constructed wetlands have been defined as “man-made systems that are designed, built and operated to emulate natural wetlands or functions of natural wetlands to meet human desires and needs” (Olsen, 1993). Studies of sewage treatment using wetland habitats have shown that levels of ammonia, phosphorus and BOD can be reduced greatly by this form of biofiltration. For example, Soukup et al. (1992) found in Australia that wetlands almost completely removed nutrients. They calculated that on average, each hectare of wetlands treated the effluent from 110 people and could assimilate over 99 % of the nitrogen and phosphorus present. Nutrient enrichment is not harmful to mangroves and may actually promote their growth and productivity (Clough et al, 1983; Clarke and Macintosh, 1996).

The implication from studies of mangroves and other wetland habitats is that they could prove invaluable for treating the effluent from shrimp farms, both physically by trapping clay and silt particles and chemically by absorbing nutrients. Because these habitats require almost no maintenance by the farmers, they are not prone to mechanical failure or fatigue. In fact, they should improve with age. However, further research is necessary to design appropriate systems. For example, what relative areas of shrimp pond-mangrove habitat are required for most effective treatment? How should the waste be pre-treated, and in what form(s) can it be released safely into the surrounding environment?

Mangroves and effluent treatment

Shrimp pond effluents can be characterised by an increase in dissolved and suspended solids as a result of waste production in ponds (Beveridge et al. 1991; Pruder 1992; Boyd and Tucker 1998). Among the effluent treatment alternatives it is possible to consider use of natural or constructed mangrove wetlands as biofilters to remove suspended solids, lower BOD and absorb nutrients (Robertson and Phillips 1995; Wong et al. 1995; Massaut 1999; Rivera-Monroy et al. 1999). Two case studies, one from Colombia the other from Australia, are provided which report on the practical experiences of using natural and constructed mangrove wetlands respectively, for shrimp farm effluent treatment (see Case Studies 2 and 3).

Natural mangrove forest systems

The Colombian example, plus reports from several other countries, suggests that mangrove wetlands can be used to treat pond effluent, apparently without detrimental affect on the mangrove community. In Agrosoledad, a shrimp farm on the Colombian Caribbean coast (Case Study 2), shrimp pond discharge is treated through a mangrove wetland and partially recirculated inside the farm. This management practice was adopted initially to limit the introduction of blue-green algae into the ponds, as this resulted in off-flavors in the shrimp during the rainy season. That is, there was a strong economic incentive to introduce this treatment system. Subsequently this farm has gained significantly in tax savings. The farm's effluent water is now 'cleaner' (lower BOD and TSS levels) than its supply water so the local environmental authority does not levy any contamination tax (giving Agrosoledad an estimated saving of USD 95,000 in year 2000).

Agrosoledad, has been functioning in Colombia as an integrated mangrove wetland-shrimp farm since January 1996. Shrimp farm effluent is partially recirculated through a 120-ha mangrove area. There is a considerable reduction in the amount of suspended solids in the effluent and inorganic nutrient concentrations in the adjacent lagoon have decreased. Mangrove growth and regeneration in the biofilter area are very high. Nevertheless, nutrient cycling in the biofilter is poorly understood and the long-term impact of effluents on the mangrove ecosystem has to be assessed before it can be promoted for wider use. Some of the advantages and disadvantages based on the experiences in Colombia are listed in table 3.2. it should be noted that the mangrove area used by Agrosoledad was a natural mangrove forest, but some improvement planting of mangrove propagules was carried out, mainly in the area used for the biofilter.

Costs and benefits

Within the context of an effluent treatment system, mangroves may offer alternatives to other forms of treatment. In Colombia, Agrosoledad's biofilter was inexpensive because the mangrove largely existed and it has been possible to take advantage of the natural topography of the site to limit the cost of levee construction. The construction cost of the biofilter at Agrosoledad was about USD 800 per ha of biofilter area. Construction work included concrete structures and bridges, levees made of clay, and canal digging.

General assessment and replicability

Agrosoledad's integrated system is a new approach that appears to have great potential for reducing effluent impacts of shrimp aquaculture, while encouraging mangrove growth. Many operational parameters, however, are still poorly understood. Before divulging any recommendation about the application of such a system in shrimp farming, more ecological studies are required. A major difficulty to deal with natural ecosystems for water treatment is the lack of control, which can lead to unpredictable results. As a consequence, any theoretical calculations, as proposed by Robertson and Phillips (1995) and Rivera-Monroy et al. (1999), or practical results such as those from Agrosoledad, cannot be recommended for general reference or adoption. In particular, it is not possible to give any recommendation about an appropriate ratio of mangrove:shrimp pond area as nutrient assimilation capacity of different kinds of sediments and plants remains unknown. Moreover, while highly promising for shrimp pond effluent treatment, wider adoption of such practices elsewhere may require modification to current environmental legislation.

Constructed wetlands

Case study 3 describes research being conducted in Queensland, Australia to evaluate the effectiveness of mangroves built artificially as a treatment area for shrimp pond waste.

There is still only limited experience on the basic design principles for constructed wetland biofiltration systems, but results such as those described in Queensland are encouraging. Given the effects of wetland plants, soils and associated micro-fauna on nutrient uptake, a general principle for the waste water entering a mangrove wetland is that it should be well dispersed through the vegetation rather than channelled into drains through the forest (Clough et al., 1983; Boto, 1992; Robertson and Phillips, 1995). Various biotic and a-biotic factors dictate the efficacy of a wetland’s nutrient removal capacity e.g. plant species present, invertebrate communities, sediment type, sediment porosity, flow dynamics and duration of tidal inundation (Clarke et al., 1996). Of these attributes probably the most important for a constructed wetland is the site's sediment characteristics. Tam and Wong (1994, 1995) demonstrated that mangrove soils (particularly the upper 4cm) were effective as traps to immobilise phosphorus and heavy metals, but were less efficient in retaining nitrogen from waste water. The capacity of mangrove systems to remove and immobilise nutrients is also strongly influenced by tidal and drainage characteristics and by the redox state of the soil (Clough et al., 1983).

Table 21: Ecological, technical and economical advantages or benefits and costs or limitations of using natural mangrove wetlands as a biofilter to treat shrimp pond effluents, based on experimental observations at Agrosoledad, Columbia (from case study 2)

Advantages and actual or potential benefits	**Costs and Limitations**
Low cost of construction	Land requirement
Possibility of reusing effluents	Cost of planting mangrove seedlings
Reduction of the use of fertilisers in ponds	Lack of control of the biological processes
Blue-green algae removal - avoidance of off-flavors	Heavy fertilisation of the water with guano from the bird community
BOD and TSS removal - Contamination tax avoidance	Water quality for reuse in the farm (low in D.O., rich in guano)
Preservation and protection of the adjacent mangrove ecosystem	More studies on nutrient cycling and water circulation are needed
Increased mangrove productivity - Possibility of extracting poles and wood	Long-term effects of effluents on mangrove ecosystems need to be assessed
Reduction of coastal water contamination - Stabilisation of ecological conditions	Legislation limitations for using mangroves owned by States
Opportunity for ecological education and scientific research	Legislation limitations for managing and exploiting mangroves managed as biofilters
Promulgation of a responsible attitude by the shrimp industry regarding the preservation of natural resources	Absence of incentives or assistance to improve management of ponds and effluents, and to perform ecological studies
Ecotourism development potential	

Integrated mangrove-aquaculture systems

Silvo-fisheries and some forms of mariculture offer more sustainable alternatives to shrimp farming in mangrove ecosystems. The term silvo-fisheries is derived from the combination of silviculture, using mangrove trees, and fisheries/aquaculture management. It is not a traditional system, but follows closely the principle of the Indonesian tambaks that are based on trapping and holding wild fish and shellfish fry (Schuster, 1952). Silvo-fisheries follow the principle that the more a cultivation system recognises and mimics natural ecosystem functions, the less additional resources are required and the lower any negative environmental impacts will be. Integrated systems strive for increased efficiency, reduced resource use, avoidance of chemicals and medicinal products, less waste generation and the recycling of nutrients. Mud crab farming using the silvo-fishery concept is an attractive alternative to shrimp culture as mud crabs are particularly adapted to living in association with mangrove forest and, like shrimp, are a high value commodity.

The best options for mariculture within mangrove ecosystems are culture systems that do not destroy the mangrove trees, or alter the hydrological features of the area. Mangrove waterways can be used as sites for floating rafts to rear fish, crabs or molluscs, and the mudflats in front of the mangrove forest can be developed for cockle or clam culture, as in Malaysia and Vietnam, or for fixed structures such as cement pillars or wooden poles to rear oysters or mussels, as in India, Thailand and the Philippines (e.g. McCoy and Chongpeepien, 1988).

The silvo-fisheries concept and the use of mangrove waterways and mud flats for mariculture are non-destructive ways of conducting aquaculture in mangrove ecosystems. But because they depend much more on the natural ecology of the system than intensive shrimp farming does, "ownership" of the habitat and water resources they depend on is a major issue.

Silvo-fisheries models
Population growth creates one of the strongest pressures for development in the mangrove coastal zone and adjacent area. Development must take into account environmental, conservation, social, and economic issues. The overall development strategy should be one that integrates all four issues. Silvo-fisheries development can be incorporated where appropriate into a comprehensive coastal planning process that identifies the environmental characteristics of specific areas and the carrying capacity of each area. An integrated approach will allow for both sustained economic activities while implementing a conservation and rehabilitation program for the mangroves. Nonetheless, the application of silvo-fisheries should be approached with a reasonable measure of caution. Although it is ecological more compatible with mangrove ecosystems than many other forms of aquaculture, there are still issues of sustainability to address. For example, the impact on the natural population of species cultured must be assessed, including the availability and impact on seed stock recruitment and survival. Marketing of the silvo-fishery products is also an important aspect of planning, as farmers need to be convinced of the economic benefits, which will tend to be lower than the potential profits from shrimp culture.

The actual production models that are adopted will, to a large degree, develop to suit local environmental and socio-economic conditions. Demonstration projects have been important in this regard and examples are described in several case studies. While the ecological features of each model are important from a conceptual and research viewpoint, the benefits of one model over another usually come down to the farmers' ability to manage a given system. Investment and operating costs are equally important constraints and farmers may require financial incentives to adopt silvo-fisheries practices. For these reasons, the socio-economic aspects of silvo-fisheries, rather than the technical aspects of the different models available, are described below.

Ownership and incentives
Silvo-fisheries have been successful as part of a community-based project on community property, or as individual/family operations on controlled government land conditionally leased for this specific purpose (e.g. Blanakan and Cikiong in Indonesia). However in areas that are under private ownership, the owner normally would have little incentive to put cleared property back into forest that would be perceived as being of lower value. This point emphasises the importance of maintaining government ownership of mangrove areas. Governments should maintain ownership and control of the mangrove area where it has not already been privatised. This will allow for a more controlled utilisation through conditional leases in an integrated and environmentally sensitive manner, based on an overall land use plan.

In the case of silvofisheries and private land ownership of the mangroves, an important component of implementation that seems to be considered inadequately is the capital costs required to construct the pond unit. The construction cost associated with the dike and gate construction of a silvofishery pond is similar to that of an aquaculture brackishwater pond. The revenue generation from a silvofishery model would have to justify this type of investment on private property with private capital as opposed to an activity with a greater rate of return on investment (e.g., semi-intensive or intensive shrimp culture). Underwriting silvofishery demonstration projects that are not designed carefully by government agencies within basic economic realities can create a misleading model that is not viable on privately owned land without a substantial government subsidy. Therefore, demonstration projects have to be designed realistically to fulfil the implementation objectives of the program. If the mangrove forest is under private ownership and it is considered that environmental friendly development is in the public good, government incentives appropriately designed to provide sufficient incentive to private landowners to develop silvo-fisheries (as opposed to less environmentally benign options) should be carefully considered. These should be designed to provide a reasonable economic return to the owner within an enforceable regulatory framework.

To make the rehabilitation /reforestation model more attractive to private landowners, the options within an incentive program could include the following:

- Tax rebate or abatement on property tax. This could be based on a formula that essentially defrays some of the economic loss the private landowner would incur through reduced production and land value.
- Higher property tax on brackishwater ponds in former mangrove areas that are abandoned or low in production. This would be a negative incentive approach that places an increased economic cost on owners who leave their property unproductive. This would create an incentive to either reforest the property or develop silvo-fisheries or increase production (improved brackishwater pond operations) to relieve the increased tax levy on the property.
- Land exchange with government property in a non-critical habitat area of equivalent economic value.

The use of both incentives and disincentives can be utilised in the implementation of a policy that has been determined to be desirable (at national and local level). The use of "green taxes" has been advocated as a means of addressing environmental externalities.

System model

Silvofisheries are labour-intensive farming systems appropriate for an individual, family or community operation that can be a viable alternative to brackishwater pond culture. Thay diversify products from the land and aquatic production within an environmentally benign framework which is integrated into the mangrove forest ecosystem. The silvofishery model is not suited to commercial large-scale aquaculture production on privately owned land. The cost of pond construction with reduced management options makes the "empang parit" silvofishery model not economically attractive without fuller integrated resource utilisation into economically valued products. However, "empang parit" and other silvofishery models can be a useful alternative activity within the mangrove intertidal zone as a subsistence and conservation type of activity. Silvofishery models can also be a viable form of aquaculture when converting abandoned brackishwater ponds into an integrated reforestation and utilisation program especially where the cost of pond construction is avoided by utilising pre-existing ponds. Government subsidies in the form of a low cost lease and a package of technical and capital assistance could make this an attractive option to meet the needs of the rural poor as part of a mangrove rehabilitation program.

The selection of the most appropriate silvofishery model will be site dependent and influenced by the status of the mangrove ecosystem in the particular area concerned. Therefore, no single model is the best for all situations. The preferred silvo-fishery combination for most applications in Asia is an integrated mangrove-crab culture system. The advantages of this system are the absence of any permanent alteration to the mangrove forest area, low capital investment, low labour requirement, low technology, small unit size, incremental ability for expansion, and production of a high valued product. The advantages of mud crab as an alternative to shrimp for the small-scale farmer are discussed further in Overton, Macintosh and Thorpe (1997) and specific examples of mudcrab framing integrated with mangroves are described in case studies.

Based on these studies of the silvo-fisheries in Indonesia described in Case Studies 6 and 7 it is recommended that units of two and four-hectare pond areas be standardised as the model units with individual pond size of one hectare. This would mean that for every two hectares of pond area there would be an eight-hectare area of mangroves maintained around the pond unit. For areas under private ownership, the Brackishwater Pond/Mangrove Alternation model would be the most appropriate. An advantage of this model is that the mangroves outside the pond would be structurally unaltered and the tidal and ground water movement would not be constrained. The major disadvantage of this model is that it is particularly susceptible to violation of the mangrove area by encroachment or non-compliance where regulations are not rigorously enforced.

Research needs for silvo-fishery systems

Optimisation of production within an integrated mangrove/aquaculture silvofishery system is a priority area for research. Studies should be conducted to increase the production from the various silvofishery models. This is particularly important for reforesting private land area. The different silvofishery models, specifically the two main types (mangroves integrated within the pond area and mangroves integrated around the outside of the pond area), should be evaluated. This would include optimising use of inputs and stocking strategies for different species within a polyculture production system. Density of trees and silviculture management (e.g. trimming, selective cutting, etc.) to maximise the production of litter needs to be evaluated as part of an overall optimisation of the silvo-fisheries system. The preferred species of mangrove trees that can be used for specific pond conditions should be determined, as well as an analysis of the type and amount of vegetation cover in relation to litter production rates of the different trees and the litter decomposition rates. These would be important factors in the food web contributing to the productivity of the pond. The food web resulting from mangrove vegetation litter transferred to the ponds and optimisation of this input should be researched to obtain a better understanding of this process so that appropriate management practices can be developed.

Evaluating the system to better understand the trophic production and food web dynamics will be an area of major importance in moving towards the optimisation of the system. It is necessary to include all forms of macrophytes and algae to evaluate the importance of different autotrophic compartments in the total primary production and then to study the energy flow and its utilisation in the mangrove ecosystem. It will be equally important to determine and document the difference in the food items ingested by aquatic species from those that are actually assimilated. This will assist in selecting where possible the most appropriate potential aquaculture species for the system.

A thorough study of the macroalgae and microalgae in mangroves to understand their growth dynamics within the mangrove forest and the physical growth parameters along with how to maximise their production to benefit production of aquaculture species is essential to maximising the production efficiency. Changes in the balance of autotrophs on nutrient cycles in the aquatic ecosystem will be a component in maximising the energy available to the food web supporting the aquaculture species. It will also be important to determine how to best balance the mangrove growth (density, height, canopy cover, species, etc.) with production of algae, since excessive shading from maximum growth density of macrophytic vegetation would impair production of the algae within the platform area. These are all criteria which must be studies in order to learn how to enhance the quality and quantity of the food web.

Silvo-fisheries has the potential of capturing some of the economic benefits of the mangrove areas within an environmentally sensitive framework and a sustainable activity. Improvement in the economic return from this system will be a key factor in the wider acceptance of silvofishery methods as an economically viable activity in the mangroves. Silvo-fisheries can also provide an alternative economic activity to the rural poor and reduce development pressure on the mangrove forests. Therefore, it should be considered in an overall development and management strategy for the coastal zone and could serve a key role in the transition that shifts more intensive aquaculture to areas outside the mangroves.

Rehabilitation of coastal wetlands

Background

The FAO "Code of Conduct For Responsible Fisheries" (1995) states that "All critical fisheries habitats in marine and fresh water ecosystems, such as wetlands, mangroves, reefs, lagoons, nursery and spawning areas, should be protected and rehabilitated as far as possible and where necessary. Particular effort should be made to protect such habitats from destruction, degradation, pollution and other significant impacts resulting from human activities that threaten the health and viability of the fishery resources." These statements reflect recent developments in awareness that fishery resources can be affected seriously by coastal habitat loss. They also point out the twin issues of habitat protection and rehabilitation that are central to this section of the Thematic Review. Because the terms rehabilitation, restoration and reforestation are frequently used ambiguously, they are defined below, together with terms in common use to denote shrimp farms which are no longer in operation and may, therefore, be suitable for mangrove rehabilitation.

Rehabilitation Streever (1999) defines "rehabilitation" as: "… an umbrella term that includes both 'restoration' and 'creation,' where 'restoration' is the return of a system to some previous condition, and 'creation' is the establishment of a wetland where no wetland had existed in the past." Within the context of this review, the concept of rehabilitation is applied not only to mangroves but also to rehabilitation of other ecologically significant habitats (uplands, freshwater wetlands and saltwater wetlands) that have been impacted by the construction and operation of shrimp aquaculture ponds (farms).

"Decommissioned old farms" is another important term that deserves explanation. These are areas where aquaculture has ceased permanently. These areas have been referred to in other publications as "abandoned ponds" or "disused ponds" (Stevenson et al. 1999). Decommissioning denotes a planned for, and organised effort to remove equipment and generally to clean-up a site. The question of future ownership and land use would be legally determined. While this may take place in some cases, when a shrimp aquaculture pond ceases to be a profitable operation, even temporarily, in many countries the operator simply walks away. They may return, and resume operations, even if use of the land for this purpose is technically illegal, and thus technically the land is not "abandoned." It is virtually impossible to examine ponds that are not operational and know for sure whether they have been decommissioned or abandoned, either permanently or temporarily. Therefore the term "disused ponds", as interpreted by Stevenson *et al* (1999) will be the term applied here in referring to all non-operational shrimp aquaculture ponds.

The rehabilitation of a disused shrimp farm back to mangrove forest is one of the most challenging issues in coastal zone management today. The problems are not technical, but legal and political, since ownership of the land, or at least its status, will almost certainly change in the transition from aquaculture to mangrove forest. There also issues surrounding the responsibility for mangrove rehabilitation, mangrove protection, and use of the forest once it is re established (see discussion in Case Study 13)

Magnitude of the Problem

The area of disused or abandoned shrimp farms existing in former mangrove areas is significant but unknown. Stevenson *et al*. (1999) cite various sources listing up to 45,000 ha of disused ponds in Thailand, and similar numbers for the Philippines. Lewis et al. (Case Study 13) cite one such location within the publicly-owned Don Sak National Forest Reserve in Surat Thani, Thailand where 2,000 ha of former mangroves have been converted to shrimp ponds. Attempts at restoration back to mangroves have been made on about 300 ha, with plans for an additional 500 ha of restoration over the next five years.

Sammut and Hanafi (Case Study 10) list an estimate of 128,420 ha of abandoned ponds in Indonesia (their Table 1). It is, therefore, probably safe to say that there are several hundred thousand hectares of disused ponds potentially available for rehabilitation in Southeast Asia alone.

The objectives of rehabilitation

As noted by Stevenson *et al.* (1999), rehabilitating a disused pond can take several directions depending on the final goal. Restoration back to the original plant and animal community is the primary concern here, but under some conditions, the goal may be to restore the site to a sustainable shrimp pond operation, or another productive use besides natural habitat. These may include fruit production on the elevated levees, salt production, fish aquaculture ponds, paddy fields or other agricultural land.

As noted by Lewis et al. (Case Study 9), any rehabilitation project should seek to restore the maximum benefits at the minimum cost. These are logical choices that can be made after review of rehabilitation options since the methodologies for rehabilitation are now better known and are predictably successful (Lewis and Marshall 1997, Turner and Lewis 1997, Lewis and Marshall 1998, Lewis 1999), their costs, in the range of USD200-700/ha also make the process inexpensive relative to the benefit. The problem of technology transfer and application of best practices are still important management issues, however. The remainder of this section examines specifically the requirements for restoring mangrove forest on sites previously converted to shrimp farming.

Site conditions

Hydrology
Rehabilitation of disused shrimp ponds back to a productive mangrove forest depends initially on restoring the normal tidal flooding regime that is typically blocked by existing the farm infrastructure of ponds and water gates (Stevenson et al. 1999, Lewis 1999). Some rehabilitation attempts have just planted mangrove seedlings, without restoring hydrology first. Predictably, many of these efforts have failed. Restoration of normal tidal flooding, by itself, can also achieve full restoration if conditions are appropriate. Stevenson *et al*. (1999) document the conditions within an abandoned shrimp aquaculture pond ten years after natural restoration by breaching of the outer dike. Natural mangrove regeneration had covered 64.2% of the basal area of an adjacent undisturbed control mangrove forest within that time period.

Soils
Sammut and Hanafi (Case Study 10) describe the problems and possible solutions, including rehabilitation of potentially acid sulfate soils that are exposed to contact with oxygen as a result of their excavation to create shrimp aquaculture ponds. They state that:

"Seawater is often used to neutralise, dilute and remove acid and iron flocs. However, the amount of acid generated by ASS can overwhelm the acid neutralising capacity of seawater. For example, 150 exchanges of seawater would be required to neutralise each 10 cm of acidic soil in a 1 ha by 1m deep shrimp pond… Such a high number of exchanges may be impractical and could increase the risk of importing pathogens and lead to the loss of nutrients and alkalinity. The environmental impacts of seawater flushing must be evaluated for it to be an acceptable method of management."

Although 150 exchanges may seem considerable, with diurnal tides (2 highs and 2 lows per day) one could theoretically flush a pond with its bottom elevation at the historical level for mangroves (typically + 0.45 cm MSL in an area with a 1 m tide range) in 75 days. Even if twice that time were required, allowing a pond to flush naturally for 5-6 months before planting (if needed), or natural mangrove recruitment, is not an inordinate amount of time in the habitat restoration process. The dichotomy of view here regarding the practicality of seawater flushing to neutralise AAS stems from the shift in objectives from a shrimp production ("time is money") perspective to a habitat restoration perspective where the time horizon to re-establish a mangrove forest is several years.

Planting of mangroves may be essential if large numbers of floating propagules are not readily available. For example, if surrounding mangrove forests have been eliminated or reduced in such numbers as to reduce or eliminate large scale propagule production. But as noted by Lewis (1999), failure to properly assess the existing and proposed hydrologic conditions is the primary cause of failure in mangrove restoration projects. Large scale plantings of propagules of *Rhizophora* spp. on existing unvegetated natural mudflats, for example, where natural tidal conditions are typically too wet for mangroves to establish naturally or thrive, have resulted in large scale failures and a waste of limited funds for mangrove restoration (Lewis 1999). Mudflats are also valuable habitats with high productivity, for both nature (e.g. midratory birds) and for man (as sites for cockle and clam beds). Thus, conversion of mudflats to mangroves may not make ecological sense (Erftemeijer and Lewis 2000). There is a clear intertidal zone suitable for mangroves, starting from the upper level of most mud flats (MHWN). The lower mud flat zone should be left unplanted.

For the above reasons, Lewis and Marshall (1998), Lewis (1999) and Stevenson et al. (1999) have supported the use of five sequential steps in the design and implementation of any successful mangrove restoration project, including restoration of disused ponds. These are:

1. Understand the autecology (individual species ecology) of the mangrove species at the site, in particular the patterns of reproduction, propagule distribution and successful seedling establishment.
2. Understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species.
3. Assess the modifications of the previous mangrove environment that occurred that currently prevents natural secondary succession.
4. Design a restoration program to initially restore the appropriate hydrology and utilise natural volunteer mangrove propagule recruitment for plant establishment.
5. Only utilise actual planting of propagules, collected seedlings or cultivated seedlings after determining that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilisation, or rate of growth of saplings established as goals for the restoration project.

Wetland rehabilitation and biodiversity

Biodiversity conservation is a highly topical issue, which applies to mangrove ecosystems just as it does to other important species-community-habitat associations. The general issues of importance in biodiversity conservation are described in (Heywood 1995, Thorpe et al, 1995, IUCN, 2000). Some special features of biodiversity in mangrove ecosystems are high-lighted in this section.

The relationship between living organisms and their environment determines the structure and function of an ecosystem. In the case of the mangrove ecosystem this point is especially relevant as the vegetation provides such an important physical structure to the intertidal habitat mangroves colonise. The trees control many of the key physical and chemical processes there (e.g. trapping sediments, soil formation, sulphate reduction, regulation of salinity and evaporation). Indeed it is the loss of these attributes and their corresponding reversal (via soil erosion, oxidation, salinisation and desiccation) which has led to some of the most widespread problems associated with conversion of mangroves to shrimp ponds.

There has also been a new realisation world-wide that biodiversity has a great potential value beyond that of protected areas alone. It is also appreciated that commercial exploitation of mangroves should now be accompanied by efforts to preserve the natural system as far as possible to ensure its resilience and sustainability of production (Field, 1996). However, mangrove biodiversity may be particularly difficult to value because many of the associated species have great dispersal abilities and spend only part of their life history within the mangrove ecosystem. The best known of such groups are mangrove-associated fish and shellfish which have been well studied because of their fisheries value (e.g. groupers, snappers and Asian seabass, penaeid shrimps, mud crabs and oysters (Macintosh, 1982). Use of the mangroves as nursery grounds by these organisms demonstrates indirectly the importance of the mangroves for aquatic biodiversity protection linked to fisheries sustainability (Thayer et al, 1987; Chong et al, 1990; Sasekumar et al, 1992).

Mangrove forest biodiversity is comparatively easy to assess as the type and the numbers of plant species are well known. However their genetic composition and relationships need much greater research attention in order to maintain genetic diversity for reforestation programmes and to be able to select for desirable characteristics such as salinity tolerance and growth rate. Protection of the few remaining areas of pristine mangrove forest worldwide is therefore a priority for conservation of their genetic material. However, almost nothing is known about the minimum areas, which should be protected to achieve this aim, or the extent of genetic exchange between different mangrove forest areas via seed and propagule dispersal.

The effects of mangrove habitat restoration on coastal biodiversity are now being studied as restoration projects begin to have a significant impact on the coastal environment in various locations. An abandoned shrimp farm and a similar degraded mangrove forest site (resulting from wood extraction for charcoal) were replanted with four different mangrove species in Ranong, Thailand (Case Study 12). To assess the development and ecological function of these plantations, they were compared to semi-natural mature mangrove forest in a nearby reserve area. The most common intertidal macrofauna groups (crustaceans and molluscs) were used as ecological indicators. Thirty crustacean species and thirty-four mollusc species were recorded in total. The macrofauna abundance, species number, diversity and composition were different between the sites, reflecting the effects of forest age and structure on the habitat. Sesarmid crabs, and pulmonate and Neritidae gastropods dominated the mature forest, whereas ocypodid crabs, Littoraria, Assiminea and Cerithidea gastropods dominated the plantations. It was concluded from theis study that sesarmid crabs may be good ecological indicators of mature mangrove forest.

These findings (presented as a Case Study 12), also confirm that abandoned shrimp ponds can be restored succesfully provided the tidal regime at the site can be reinstated. In this particular example, total diversity, as measured by the number of true mangrove species and species of associated intertidal crabs and molluscs, reached that of a natural mangrove area within about five years. However two important environmental conditions have contributed to the recovery of biodiversity in the Ranong site: (a) hydrological conditions at the site had been little altered by pond construction - it remained tidally inundated as the project had depended on natural water exchange when the ponds were operating; (b) the site was still surrounded by extensive mangrove forest with large mature trees of various species. Under such conditions it would be easy for both mangrove seedlings and the macrofauna to recolonise by migration from the surrounding mangrove, and/or to settle into the area as juveniles since nearly all mangrove crustaceans and molluscs have a larval dispersal stage. In fact observations conducted in other cleared mangrove sites in Ranong showed that crabs re-colonised by both routes.

Because of the good dispersal abilities of most mangrove plant and animal species (including the main tree species, mangrove birds, insects, crustaceans, molluscs, polychaete worms, etc.), recolonisation of an abandoned area is usually quite rapid (Table 22). The speed of biodiversity recovery can be expected to be controlled by the factors noted in the Ranong example, namely (i) the area of habitat destroyed; (ii) the proximity and area of the nearest remaining mature mangrove forest; (iii) the degree of disruption to the natural hydrological regime of the site.

Where shrimp farming created an ecological imbalance it is not only biodiversity which suffers overall, certain species may proliferate to the level of becoming pests, or even reach toxic levels to shrimp. Blooms of blue-green algae, dinoflagellates or fluorescent bacteria are unfortunately a common problem for shrimp farmers (Chanratchakool et al 1995), especially where coastal areas have experienced eutrophication from excessive amounts of pond effluent discharge. Massive populations of the mangrove snail *Cerithium* are another feature of poorly drained, nutrient-rich ponds well known to Asian shrimp farmers. Such organisms are not usually encountered in elevated numbers in mangrove forest ecosystems.

Table 22: Total density, species number and diversity of crustaceans and molluscs at three sites in the Ranong mangrove ecosystem, southern Thailand

Crustaceans: Site	1	3Ra	3Rm	3Bc	3Ct	4RR	4BC
Density	46	142	157	178	143	65	99
Species number	12	14	12	10	16	6	10
Diversity (H')	2.11	1.19	1.66	1.73	1.87	1.11	1.51
Molluscs: Site	1	3Ra	3Rm	3Bc	3Ct	4RR	4BC
Density	23	45	59	67	77	72	39
Species number	10	8	13	9	8	16	13
Diversity (H')	2.04	1.63	2.15	1.70	1.36	2.39	1.14

Source: Case study 12

Site 1 = semi-natural mature mixed mangrove forest;

Site 3 = replanted degraded forest site (area 2 ha);

Site 4 = replanted abandoned trapping and holding shrimp pond (area 2 ha).

Ra planted with Rhizophora apiculata, Rm = R. mucronata, Ct = Ceriops tagal,

Bc = Bruguiera cylindrica, RR = mixed Ra and Rm, BC = mixed Bc and Ct..

An important indirect affect of shrimp aquaculture on coastal biodiversity is the collection of wild shrimp seed to supply shrimp farmers (see Table 23). Shrimp seed collection occurs on a large scale in Bangladesh, India, Indonesia and other countries. The main reason for concern is the huge loss of other species resulting from the fishing from shrimp seed. Hoq (2000) reported that about 10 kg of other shrimp larvae and fish are destroyed for every kg of *P. monodon* seed collected in the west Bengal Sundarbans.

In Bangladesh up to 50 shrimp seed are destroyed for every marketable seed obtained by shrimp collectors, while other losses include finfish fry and zooplankton. Hoq (2000) calculated that the Bangladesh Sundarbans support about 225,000 shrimp fry collectors, plus a further 20,000 traders who supply the shrimp seed to shrimp farmers. In total, around 2 billion *P. monodon* seed are supplied to the aquaculture sector annually in Bangladesh.

Table 23: A conservative assessment of seed supply of black tiger shrimp needed per year in Asian Countries.

Country	No. of hatcheries #	PL needed (*10^9)	Supply status
Bangladesh	8	2.8	Natural
China	160	0.9	Hatchery
India	60	6.5	Natural, Hatchery
Indonesia	200	10	Natural, Hatchery
Philippines	400	3	Hatchery
Thailand	2,000	28	Hatchery
Vietnam	800	2,6	Natural, Hatchery
Total	3,628	54,8	

Source: Asian Shrimp Council. # The number of hatcheries is the existing one

Factors Limiting the Success of Rehabilitation Efforts

As noted by Lewis (2000) the main technical factor limiting successful coastal habitat restoration are the failure to adequately train coastal managers in even the basics of hydrologic and ecosystem restoration, and to point out the pitfalls that have been proven over and over again to prevent successful rehabilitation. There are also a number of significant social, economic and institutional factors that severely limit the potential for rehabilitation of mangrove areas. Land ownership is particularly important; this and other issues are discussed below.

The technology to cost effectively restore mangroves in general, and disused shrimp aquaculture ponds in particular, is well known. But as quoted by Lewis (2000) even 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) states that “the principal obstacles to wider use of coastal engineering capabilities in habitat protection, enhancement, restoration and creation are cost and the institutional, regulatory and management barriers to using the best available technologies and practices.”

Thus it is not surprising that Lewis (1999) states that most mangrove restoration projects typically fail to achieve their goals, many failing even to establish any significant mangrove cover. Lewis and Streever (2000) provide some basic guiding tenets that follow the same as those cited above. Know the hydrology of the area, and don't think that planting can overcome those basic ecophysiological requirements of mangroves. De Leon and White (1999), for example, describe the portions of a USD 35 million World Bank loan program (the Central Visayas Nearshore Fisheries Project) that targeted mangrove restoration by planting mangrove seeds, and noted that successful establishment of mangroves at studied sites ranged from 0 to 66%, averaging 18%. Lessons learned included "technical expertise and guidance is vital...survival was low because of poor site selection."

Costs and Benefits

In case study 10, Lewis states that:

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

Actual reported costs per hectare have ranged from USD 225 to USD 260,000, with the lower figures representing successful hydrologic restoration of mangroves (no planting) previously impounded for mosquito control on the east coast of the United States (specifically the Indian River Lagoon in Florida). It would be expected that similar costs would be encountered with disused shrimp pond restoration. In fact a figure of USD 709/ha is what the Royal Forest Department of Thailand is spending to restore disused ponds in Surat Thani (see Case Study 13). This includes substantial costs for collecting and planting mangrove seeds. Lewis (This volume /Costs and Benefits) lists benefits of mangroves as ranging from USD 126/ha/yr to USD 7,833/ha/yr. Thus, it would appear that restoring ponds back to productive mangrove ecosystems, would be a very cost-effective effort.

Economic Incentives

Great progress has been made recently in relating the cost of restoration to the economic value of mangroves (see case study 10 in annex). Mangroves provide many indirect, and therefor less recognised benefits with high value (e.g. coastal fisheries support function and coastal protection value). When these are added to the more familiar direct values from forestry, etc., the overall valuation is greatly increased, and better reflects the "true value" of mangroves to society. Estimation and interpretation of the indirect values of coastal resources are still somewhat subjective and vary between studies, but they provide a strong justification and incentive in relation to restoration costs. Table 23 provides several estimates of mangrove planting and protection costs. These vary considerably because of technical factors (site conditions, species of mangrove selected for planting, planting density, survival rate, etc.). Moreover, the success of restoration projects often depends on awareness raising among the stakeholders, provision of training and technical advice. The costs shown reflect inclusion of most of these items, unless stated otherwise.

Table 23: Estimates of mangrove restoration costs from various projects

Location and project	Planting details	Basis of cost estimate	Average cost per hectare	Source
Indian River Lagoon, Florida, USA	No planting, just hydrologic restoration	All costs including design, permitting, construction and monitoring	USD225	Brockmeyer et al. (1997)
Don Sak National Forest Reserve, Surat Thani, Thailand	Primarily *Rhizophora apiculata* propagules on 1 m centers	Actual costs from records of expenditure. No monitoring	USD709	Lewis et al. (this volume)
Florida and Texas, USA	Various	Synthesis of all projects. Excavation and planting of seedlings at all sites in most cases.	USD45,000	King and Bohlen (1994)
Pattani, southern Thailand.	Mixed species planting from seedlings	Direct planting costs only. All project costs included.	USD 288 USD 958	Wetlands International
Red River Delta, Vietnam	Mainly *Kandelia*	Direct planting and protection costs only using propagules. All project costs included.	USD 84 USD 164	Macintosh (2000)
Mekong Delta, Vietnam	Mainly *Rhizophora*	Direct planting using propagules, including land survey, site preparation and protection	USD 320	RMFP (1998)

Incentives for wetland rehabilitation and protection

Background

This is a key issue in coastal zone management, which is fundamental to the success of mangrove restoration efforts. Since different stakeholders are involved, there are many factors concerning their level of motivation and objectives for restoration, their logistical, technical and financial support base, and the forms of incentive which will be most effective in each case.

In addressing this topic, especially the economic incentives based on cost-benefit analyses, the following distinctions should first be made between: (a) prerestoration evaluation and design for success, including hydrologic considerations, (b) costs and incentives for just planting mangroves as a restoration measure versus on site hydrologic modifications and (c) costs and incentives for monitoring and reporting on success or failure, caring and protecting the mangroves after planting and remedial actions. The incentives for (b) are usual clear and immediate, whereas those under (a and c) are long-term and are often neglected, or under-resourced.

Taking Thailand as an example, there are several ways that mangroves are planted namely by the national level programme, by forest concessionaires, the private sector, 50th anniversary celebration of H.M. King's accession to the throne and by Cabinet decree (Havanond, 1997). Plathong (1998) states that the Royal Forest Department reported 11,009 ha of mangroves planted as part of a restoration plan in Southern Thailand between 1991-1995 but noted that RFD is "unable to justify the success of the plan because the replanted mangrove areas are just at the seedling stage. There is no report that replanting mangroves are survived (sic) or destroyed by natural factors and human. The data recorded are only the planted areas and the amount of areas planed (sic) to be replanted." Ceremonial planting, donor projects, NGOs, and local communities and associations also account for smaller areas of mangrove restoration in Thailand. Thus careful planning for success (as above), and careful monitoring, reporting and learning from both successes and failures (c above) are **not** typical of mangrove restoration efforts in Thailand. Incentives to date have been to just plant and hope for the best. Unfortunately, Plathong estimates that a budget of USD30 million has been budgeted for such, largely unsuccessful, efforts.

The motivation and incentives for mangrove restoration are described below, particularly seen from the viewpoint of the governmental and private sectors (including shrimp farmers).

Economic incentives

The economic incentives include requirements by consumer groups in the primary consuming countries, like the United States and Japan, for sustainably produced shrimp marketed with a "green label." Green labelling schemes exist for other products like lumber, which is labelled as part of a certification program by the Forest Stewardship Council. Similar economic incentives to keep future shrimp aquaculture ponds out of sensitive wetland habitats, and restore significant areas of existing disused ponds that formerly supported shrimp aquaculture are under discussion. An alternative might be a minimum "green tax" on all shrimp products that would be exclusively dedicated to disused pond restoration. In the Mekong delta in Vietnam, a pilot project is being carried out to produce "organic shrimp" from shrimp culture. The shrimp comes from farms that have replanted mangroves in former denuded forest areas. Whilst "organic shrimp" are likely to remain a niche product, this is the first attempt in Asia to promote a shrimp that has been produced in ways that promote mangrove reforestation. It will be interesting to see how this project develops.

Social Incentives

Rehabilitation, whether of mangroves or other forest types, creates strong community identity and bonding. The activities might include joint site selection, seed collection, nursery establishment and planting as necessary. Activities can themselves have a high ceremonial value, as in Thailand, while logistically a large number of local people have to be involved to provide the labour for the work. Planting days bring people together, as a high level of logistical planning and co-ordination is required. Moreover, because forest restoration is so visible, it provides lasting reinforcement of the communities decision to co-operate in the restoration process.

Various social incentives are used in Asia, ranging from ceremonial planting days, to activities for schoolchildren and youth groups. In northern Vietnam schoolchildren have been organised to write poems and make paintings about mangrove restoration, and some excellent posters and other extension literature has been produced for the local schools and communities. Japanese students have even flown to Thailand to plant mangroves together with the local people, elevating the social status of the event to one of international co-operation and participation.

Achieving compliance

While governments may pass legislation controlling the use of coastal resources, it is vital that the coastal communities themselves decides on the incentives, and also the penalties for non compliance. Social incentives for the long term maintenance and protection of mangroves are usually based on awareness-raising within the local community through workshops, public debates, training courses and so on. This is done well by NGO supported projects e.g. Wetlands International in Pattani, Thailand (Anon, 1999) and the Red Cross in Thai Binh, Vietnam (Macintosh, 1996). Experiences from both these projects are described below.

In Thailand, there has been a ban imposed by the Department of Fisheries s since 1972 on trawling and push-net fishing within 3kms of the coastline However it is widely ignored by fishermen and mangroves are destroyed when boats fish close to the shore. This has been a problem for the mangrove restoration efforts of the local community in Pattani Bay, so recently the villagers and provincial authorities jointly surveyed and demarcated the 3km zone. An official village committee has now been formed to facilitate co-ordination with the governmental officials, including policing of the protected zone.

In Thai Binh Province, Vietnam, the coastal communes have been involved with mangrove planting since 1994 to create a coastal protection zone of mangrove forest (Case Study 12). Each commune has erected notice boards stating the benefits of the mangroves, but also setting out community regulations regarding their unlawful exploitation, based on an agreed punishment and reward system.

The principles of social responsibility, and the importance of having incentives for compliance, apply just as strongly to mangrove restoration in relation to shrimp farming. In cases where shrimp farmers and other private sector groups have planted mangroves, success has also depended on co-operation from the other resource users. The Shrimp Farmers Association in Surat Thani found that fishing boats repeatedly destroyed the mangroves the association planted in Ban Don Bay. Co-operation with the appropriate governmental agencies is also important for success. Companies like Charoen Phokapand (CP Group) in Thailand have collaborated with the Royal Forest Department when supporting mangrove restoration. RFD will identify and prepare the sites for planting, while the private sector provides the funds for seedlings, planting and maintenance (Plathong, 1997). Unfortunately, monitoring and reporting for success and learning from mistakes has not been a funded item under these schemes to date, as noted above.

Table 24: Community regulations for mangrove protection in Thai Binh, Vietnam

Regulations	Penalties and Rewards
1. All people have responsibility for protecting mangrove forests	
2. Planters have to fulfil their contract duties	
3. Cutting, catching aquatic species and grazing by domestic animals is not allowed	For cutting trees or grazing animals – VND 50,000 For cutting mangrove branches - VND 20,000 For catching aquatic products in newly planted areas – VND 5,000
4. People using boats must use the designated corridors	
	A reward of 50% of the fine paid is given to the persons informing the guard team

Note: VND 14,000 = USD1.00

Successes and failures in mangrove rehabilitation

Risk factors

A number of human ecological factors place severe restrictions on forest restoration projects, including mangroves (Walters, 1997). A checklist of relevant questions that should be considered, based on experiences in the Philippines, is given in Table 3.9. In seeking answers to these questions, one can readily visualise that opinions would differ between different social groups.

Table 25: Examples of the questionnaire approach for the assessment of mangrove rehabilitation from a socio-economic perspective

1. Questions about economic impacts: How are local people likely to be economically affected by the proposed restoration? Are there particularly vulnerable groups that may be impacted by the restoration? If so, how? Can the restoration be used directly to economically benefit local people?
2. Questions about land use, resource management and tenure: How was the proposed restoration area previously used? Who owns the land in the proposed restoration area, and who has rights to use it? What are the current uses of the area and how can they best be managed for restoration? How can the expected future uses of the area best be managed to ensure long-term sustainability?
3. Questions about local knowledge, skills and customs: Have the local people done, or are they doing, ecological restoration activities of any kind? Do local people have knowledge that might be relevant, or skills that may be applicable to the proposed restoration? Are there any local customs that could benefit or conflict with the proposed restoration?
4. Questions about local social organisation and institutions: How might local social groups and networks contribute to or impede restoration efforts? What opportunities might there be for collaboration with local, non-government organisations?
5. Questions about government administration, policies and capacities. Are relevant government laws and policies friendly to restoration? How committed are relevant government administrations to environmental protection and restoration? What opportunities might there be for collaboration with interested government agencies?

Just as important as the incentives for mangrove restoration are dis-incentives stemming from the failure of mangrove planting efforts. Unfortunately these are all too common as they have many causes. Those experienced in southern Thailand are listed in Table 26, but they are also typical for many other locations.

Table 26: Problems and causes of the failure of mangrove planting schemes in southern Thailand

Problem	Probable causes	Possible solutions
Seedlings washed away by tidal currents and/or wave action	Planting site too exposed, or wrong mangrove species chosen	Better site and/or species selection:
Hard or dry soils	Loss of normal hydrological regime	None
Mangrove trees damaged or destroyed	Fishermen or boats enter the site to catch fish and shellfish	Mark plantation sites clearly with notice boards; Support community awareness-building
Mangrove seedlings die or grow poorly due to barnacle infestation	Barnacle larvae settle on the young seedlings; in severe cases the seedlings become bent over with the weight of attached barnacles	Better site selection, higher elevation sites have fewer barnacles
Seedlings fail to mature	Environmental conditions at not optimal for the species planted	Use species naturally flowering and fruiting in the locality
Seedlings are destroyed by crabs, insects, etc.	Herbivorous crabs and insects are natural pests of young mangrove seedlings	Plant larger seedlings more resistant to attack; avoid using insecticides!

Modified from Plathon, 1997

"Ownership" issues

A focal issue surrounding the debate on coastal wetlands and development (in relation to aquaculture and other sectors) is that of "ownership" of the land and resources. Mangroves and tidal wetlands are often traditionally common property resources with rather low perceived value in developing countries. Use or optimum yield from any common property resource must be carefully executed and must consider a mix of benefits, including those of environmental, social and economic significance. There is usually competition between the traditional users of previously open-access resources and those who are encroaching on and expropriating these resources, including shrimp farm owners. This issue has already been highlighted in the case of Nellore in India. Shrimp farming and other development activities impact on the social, economic, cultural, and environmental status of the area. Therefore, it is critical that the interactions among these factors are fully integrated into the assessment and planning process to increase the level of success in meeting the goals and objectives of land use and development planning to reduce potential user conflicts.

Land ownership is an important criterion for decision-making regarding the use of mangroves. The "no associated land cost" or relatively low cost is a significant incentive for development. Therefore, the use of the mangroves allows the rural, low-income, land-less to enter land ownership through a lower entry barrier regardless of the long-term development costs (mainly in labour) and environmental costs. This is important from a social aspect in that land ownership brings a higher status in the community, which potentially raises the individual's influence in the community. This land ownership not only benefits the individual, but also bestows long-term benefit to his family and heirs.

The success of mangrove rehabilitation in the Red River Delta, for example, has been closely identified with the perception of ownership by the local community (Case Study 12). In the project described, the families who planted mangrove seedlings were allowed to lease the land for (usually) 20 years from the district authorities. In some communes, the people living there strongly perceive the mangrove forest as belonging to their community. This view enhances their willingness to protect the mangrove plantations, including reporting any violation of the rules established by the communities regarding allowable and prohibited activitiews.

Tobey et al (2001) relate experiences from Sumatra (Pematang Pasir) which also highlight the importance of land ownership to the success of wetland restoration efforts. It was found that some shrimp farmers in the village indicated interest in restoring mangroves and a Committee to address mangrove and conservation issues was formed. The Committee not only wanted to replant mangroves but also to establish village regulations concerning the use of coastal accretion areas. Accretion is the result of both natural processes and sediment build-up from pond discharge. Where there is coastal accretion, these areas are typically converted very quickly to new shrimp ponds. Instead, the Committee felt that regulations should be established that direct the use of accretion areas for mangrove replanting and coastal protection.

The Committee developed guidelines concerning use of accretion areas and obtained the technical assistance of the Faculty of Law of Lampung University to convert the guidelines into legislative language. For the work on mangrove replanting in the "green belt" of the coastal no development area, priority areas were identified and then the Committee talked to the shrimp pond owners in those areas to reach an agreement on mangrove restoration. The Forestry Service planted the trees where requested, but because there was little interaction between the Forestry Service and the shrimp farmers, the rate of survival of the planted trees was low. Some 60,000 seeds were planted on about 30 hectares of land. A high percentage did not survive. The most important and immediate reason for failure is thought to be inappropriate planting—they were not planted in the rainy season. The underlying reason for failure is related to land ownership. All the land falls under the authority and ownership of the Forestry Service and the seeds he Forestry Service without discussion or collaboration with the shrimp pond operators. If the Forestry Service had been willing to promote a sense of partnership (co-management) and shared responsibility for land stewardship with the local residents and shrimp pond farmers, the results of the replanting would probably have been different. Most people close to the land in coastal villages know how to grow trees and crops successfully in their local environment. As in many coastal villages, participatory coastal management in Pematang Pasir is retarded by institutional constraints. Some institutions still maintain tight control of their program boundaries, and institutional structures and program policies do no readily allow for joint programs.

It was concluded by Tobey et al (2000) that the current land stewardship situation in Pematang Pasir is dysfunctional. Shrimp pond operators and village residents have little self-interest in mangrove restoration since the trees fall under public jurisdiction and ownership. Lack of tenure security produces an overvaluation of the present and under valuation of future generations. Without secure private property rights the potential energy and creativity of individuals in caring for the land in the long run and in their commitment to conservation ethics are restricted. Ensuring a socially desirable level of coastal conservation falls on public agencies that do not have the necessary resources and expertise. The result is the current situation in which most of the land that is under government authority (and that was once forested). Thus these type of local institutional and ownership issues have to be given a higher priority in mangrove rehabilitation efforts, where such rehabilitation is justified from a social, economic and environmental perspective.

Coexistence of Mangroves and Shrimp Aquaculture: Implementation Guidelines

General Principles

The guiding principle adopted by this review is:

"To promote coastal aquaculture in an environmentally responsible manner, adopting the principles of co-existence of mangroves and aquaculture, of supporting the livelihood needs of local communities, and of promoting a net increase in mangrove area where this is a policy of the country concerned."

To achieve this objective, the emphasis of coastal management strategies for coastal aquaculture has to shift from the "either mangroves or shrimp" to an integrated approach which allows for "mangroves and shrimp" i.e. to the concept of coexistence, expounded above.

Many of the general environmental and social problems associated with shrimp aquaculture result ultimately from a lack of planning of coastal land use. The specific problems addressed in this review essentially stem from unregulated expansion of shrimp farming in mangrove ecosystems without regard to sustainability, or the to resource needs of other coastal users. Shrimp farming must also be promoted in a more sustainable manner. Regarding "sustainable aquaculture", New (1998) defined this as "responsible guided change for the cultivation of animals and plants in water".

An important condition for the sustainable use of mangroves, whether for aquaculture, timber production or other uses, should require no net loss of the area of mangroves in existence prior to the "sustainable" activity commencing (through restoration or creation of equivalent habitat), and the restoration back to former conditions of mangrove areas temporarily used for a defined sustainable activity.

An important reason why coastal ecosystems continue to be used in unsustainable ways is that their economic value is not adequately represented in decision-making. Many of the economic values associated with mangroves are non-market and "off-site" and therefore are not easily quantified. Only the direct production of mangroves is included in most economic valuations, yet this represents only part of the total value of mangroves to society.

The most widely used and accepted general definition of "sustainable development" is that by the Brundtland report. "…development that meets the needs of the present without compromising the ability of future generation to meet their own needs". It has also been pointed out that this definition might be characterised as an "inter-generational equity" definition for the term.

The prominence given to shrimp culture has, however, also raised controversy in both the shrimp producing and shrimp importing countries. Public opinion is being influenced by high profile concerns over environmental and social impacts of shrimp culture development, the food safety of shrimp products, and, more generally, over the long-term sustainability of shrimp farming. Major issues raised include the ecological consequences of mangrove conversion to shrimp ponds; salination of groundwater and agricultural land; pollution of coastal waters from pond effluents; biodiversity issues arising from collection of wild shrimp seed and social conflicts between shrimp farmers and other coastal resource users. Conversely, the employment generated benefits an estimated 2 million people world-wide in generally poorer shrimp-producing countries.

The issues involved above have been summarised succinctly by Patil and Krishnen (1998): "Sustainable shrimp farming practices require minimal disruptions to the surrounding ecosystem and coexistence with rural communities that have historical ties to the land and waters. A delicate balance is needed between promoting the development of an industry that generates large capital flows to the national economy and industrial growth in rural areas, and punishing this sector for its associated negative externalities."

Fortunately, there is increasing recognition of the problem and positive efforts are being taken to mitigate negative impacts caused by shrimp culture. The shrimp farming industry is actually showing responsibility and initiative in advocating for a more enlightened approach to all issues concerning shrimp farming, mangroves and the environment. As a single sector with good organisational capacity in many countries, the potential for concerted action by shrimp farmers in support of the environment should be recognised and encouraged.

Causes of Mangrove Loss

Table 27 summarises some of the major causes of mangrove loss as indicated from the different case studies and other literature reviewed. Only a few of these relate specifically to aquaculture, most relate more generally to difficulties in management and the overall (unsustainable) patterns of resource use in tropical coastal zones.

Table 27: Summary of key reasons for the decline in mangrove wetlands worldwide

- Major coastal land use changes, encouraged by the view that mangrove ecosystems have low value compared to other development options.
- Uncertain land ownership and rules governing access to mangrove areas.
- Governance and institutional failure to effectively manage coastal mangrove resources.
- Extensive shrimp farming in some countries.
- Environmental changes and shrimp diseases, leading to shifting aquaculture practices.
- Poor planning of coastal land use and implementation of development plans.
- Unrealistic design of implementation of laws e.g. zonation, weak enforcement.
- Lack of involvement of communities in decision-making (e.g. regarding management, development of legislation, enforcement). Lack of understanding on why zonation and other regulatory measures are being applied.
- Poor co-ordination between different levels and different sectors of government.
- Lack of a clear understanding of shrimp farming "sustainability" in terms of the time-frame, ecological versus economic cost-benefits, social issues (who actually benefits?).

Implementation guidelines

Despite a history of conflicts, the findings of this thematic review demonstrate that there are opportunities for the co-existence of shrimp aquaculture and mangroves, provided planning, management and consultation procedures are improved. Recommendations for better management practices for coastal wetlands and aquaculture – given in the form of some tentative "implementation guidelines" are summarised below.

Institutional issues

Institutional factors – policy, legal framework, and institutional framework – play an important part in land use changes in coastal areas, including those related to the development of shrimp and other forms of aquaculture. In general, such issues are largely ignored in many analyses. Institutional responsibilities and policies may suffer from conflicting mandates - this is often caused by a narrow and rigid sectoral approach to natural resources management and development. Many of the wider problems in coastal resource management and sustainable aquaculture at the community level must be addressed through complementary legal and institutional strengthening at the regional and national level. Unless there are effective mechanisms to connect local resource management with governance arrangements at higher levels, a coherent nested program of environmental and natural resource management can not be achieved.

Policy, planning and development

Consultations conducted during the preparatory phase of the Thematic Review confirmed the need for transparency in the planning and policy process for coastal aquaculture development. A framework approach is recommended, whereby there is (a) a Planning Framework; (b) a Policy Framework, (c) a Legal and Regulatory Framework, and (d) a supporting Institutional Framework. These will normally be in place at national level, but there should also be parallel structures at local level. The example of Ecuador is presented as a country with a clear institutional and regulatory framework for coastal resources management.

In practical terms, this means that coastal aquaculture must be integrated into rural development planning, rather then being regarded by planners more narrowly (as previously) as a sectoral development.

It is now obvious that the occupation of mangrove areas by shrimp farms can cause severe damage to coastal ecosystems. It is difficult to provide a logical reason for the continued conversion of mangrove areas for shrimp farming today, other than they often comprise the only space available to those occupying marginal land, especially poor farmers who otherwise have to depend on agriculture for their livelihood. Through poverty and low educational status, such people continue to be attracted to the potentially high returns from shrimp farming, irrespective of the longer term consequences. This review reaffirms that, in general, mangrove ecosystems are not optimal sites for shrimp production.

Implementation requirements

Many countries already have policies and legislation to protect mangroves and other wetlands, but these often come under different legislative and institutional responsibilities to the national policy towards shrimp farming. Policy coherence regarding coastal resources management is a much needed prerequisite to effective implementation of legislative and regulatory measures for wetland conservation.

Government regulations that can be applied to control land use in coastal mangrove areas effectively include planning controls and farm licensing which prevent the establishment of aquaculture projects in unsuitable locations, the application of EIA requirements and the adoption of coastal zoning policies.

The registration of farms can be an important tool to control development. In Thailand, for example, technical support and quality control is provided free to encourage shrimp farmers to register. Farms located on mangrove land zoned for mangrove conservation are not allowed to register, therefore registration is also being used as an indirect, but effective, technique to control the siting of new shrimp farms.

In Queensland, Australia, the Fisheries Act (1994) specifically limits development (including aquaculture) within intertidal areas. Mangroves are regarded as a public resource in Queensland and a permit is required to manipulate mangroves in any way – including collection of propagules or other harvesting, cultivation, or relocation (Case Study 8). There is also a complete ban of the catching of immature and female mud crabs as a regulatory measure to protect the stock of this important mangrove-associated fishery species.

Regulations prohibiting destructive activities in wetland ecosystems are clearly the most effective control measures – **provided they are enforced.** Queensland is not typical of the main shrimp –production regions of the tropics, but even in developing countries with high population pressure on natural resources, the case studies and other experiences demonstrate that regulations can be enforced effectively, provided (a) the local community understand the regulations and the advantages to them of complying with them; (b) violations are actually reported and penalties for violation are acted upon. The examples from north Vietnam and Ecuador illustrate this fact.

It is widely agreed that the zoning of coastal land use activities is a vital planning tool to reduce negative environmental impacts on coastal resources and potential conflicts between the various users of the resources. The potential effectiveness of zoning to demarcate wetland conservation areas, buffer areas, and aquaculture (and other) development areas, is strongly endorsed by the findings of this review.

Land-use rights and related issues

There are a number of important social issues associated with land-use for shrimp farming (based on Tobey et al, 2001):

1. Natural resource stewardship is only likely to occur if the land-holders are aware of the problem, and are motivated to do something about it.
2. A community with experience working together or with a tendency for participatory processes and decision-making is more predisposed to developing broad-based consensus and proactively solving resource use issues.
3. The legal system relating to land tenure, use and management matters greatly to land-holders' freedom of action.

Land use and issues of best practice

Following on from the three issues listed above, other related socio-economic conditions have an important bearing on the prospects for introducing better management practices (from Tobey et al , 2001):

1. The more important shrimp culture is to the community, the more interested and committed it is likely to be in adopting better practices.
2. Farmers are motivated to adopt sustainable management practices where there are economic benefits associated with the practices.

It is obvious from these conclusions that contact with shrimp farmer associations and other sectors of the shrimp industry is a very appropriate way to explain and introduce best management practices, since they represent collective, high interest groups in the community. But, even more importantly, the recommended practices must be based on thorough testing and with sound economic analyses supporting the stated benefits.

Comparative economics of land use

Shrimp farming benefits from conservation of mangrove forests, mainly in terms of protection from storms, erosion and water quality control. There are clearly a number of "win-win" situations that can be identified and promoted.

There are models demonstrating that coastal aquaculture, including shrimp farming, can exist within and without supplanting the mangrove forest area. The findings from Colombia show that mangrove replanting can provide water quality benefits to the shrimp farm – particularly in terms of clean up of effluent. The mangrove forest at the farm studied in Colombia also provided opportunities for improving the livelihoods of local people, who were involved in trimming of the dense forest growth. However, it should be noted that the legislation – because it placed strict controls on effluent quality - provided a favourable tax incentive to plant and maintain mangroves for effluent quality control. While such examples are promising, the use of wetlands for aquaculture waste treatment have not yet been tested on a large scale.

Poverty issues and aquaculture as a livelihood option to improve coastal management and conservation of mangrove resources

The debate on shrimp aquaculture and mangroves has so far been too polarised, either pro-mangrove or pro-shrimp. But, the over-riding issue in many coastal areas of Asia, Latin America and Africa is poverty. One cannot expect improvements in coastal resource utilisation unless this issue is addressed. Shrimp aquaculture has demonstrated its capacity to create wealth in coastal communities, and the case studies illustrate that some forms of shrimp aquaculture can play a valuable role as part of the process of poverty alleviation and coastal rehabilitation.

The emphasis therefore has to shift more towards a co-existence and an approach that places more emphasis on people at the centre of planning. There is a need for planning of aquaculture and mangrove management within a coastal development framework, focussed on poverty alleviation and reflecting the local resource base and people's priorities. The experiences in the Red river and Mekong deltas in Vietnam show that people involved in mangrove planting projects need aquaculture as a vital means of income and food. Indeed, the experience in the Mekong delta shows that further unsustainable mangrove resource extraction will occur unless poverty issues are addressed. Therefore an integrated approach that focusses on alleviation of poverty is required to promote effective rehabilitation and co-existence of aquaculture and mangroves.

The experiences from the case studies in Vietnam and to a certain extent in Bangladesh emphasise that a more community-focussed approach to shrimp aquaculture can contribute to poverty alleviation objectives but that special attention is needed to risk and development in ways that limit access by the poorest people to credit and land, and exclusions from extension services (e.g. due to language difficulties among Khmer people in Tra Vinh, Vietnam).

The example of concerted action by the NGO Yadfon on behalf of fishfolk in Trang Province (Thailand) demonstrates the importance of organising and empowering local communities. Without these two vital first steps, it is unlikely that community participation in coastal resources management can be effective. By focusing on self reliance and the initiatives of the Trang villagers themselves, such as mangrove reforestation and protection of sea grass beds, the communities developed a sense of unity and morale-building which was later recognised and supported by the local authorities, and others. The lessons learned by Yadfon over several years in one District have now been adapted and introduced successfully in several other provinces. The concept is to first promote organisation in the local community, then to encourage concerted action or "five-tier" co-operation later. Expansion by Yadfon into other communities was then greatly facilitated via an accelerated community learning process.

Wetland valuation as a management tool

An important reason why coastal ecosystems continue to be used in unsustainable ways is that their economic value is not represented adequately in decision-making, with many of the economic values associated with mangroves being non-market and "off-site" and therefore not easily quantified. Only the direct supply of mangrove products is included in most economic valuations, yet this represents only part of the total value of mangroves to society.

By undervaluing mangrove ecosystems, "development" has too often favoured their rapid conversion and loss. Mangrove conversion usually leads to short-term economic gain at the expense of larger, long-term ecological benefits and off-site values. The issue is how to decide between the true social and economic costs of mangroves and the potential gains from other uses? For example, the true net benefits of transforming mangroves to shrimp ponds should be adjusted downward to reflect the environmental costs of shrimp culture, as well as the revenues foregone from mangrove goods and services, including the non-marketed as well as marketed ones.

Implementation issues

Much of the original area lost to shrimp ponds was because of the development of large extensive culture ponds during the 1980's (Tookwinas, 1996; Menasveta, 1997).

The figures reveal that the average pond yields in both Asia and Latin America are still less than 1,000 kg/ha/yr, indicating that a substantial proportion of shrimp is still coming from extensive and semi-intensive culture systems. The data for Bangladesh, Indonesia and Vietnam indicate a collective total of almost 900,000 ha under culture, but an average production per country of only 200-300 kg/Ha.

Opportunities to improve information dissemination

There are considerable opportunities to raise awareness, education and training to help build community understanding concerning environmentally sustainable aquaculture practice, mangrove stewardship and mangrove rehabilitation. Several case studies use study tours and cross-visits to other sites provide concrete evidence of the benefits of good practices and habitat restoration and to motivate people to take action.

It would also be useful to continue bring together case studies – sucesses and failures – to demonstrate how aquaculture and mangroves can co-exist.

Role of the private sector

The global private sector involvement in shrimp aquaculture is substantial. In this regard, Governments have a crucial role in creating an enabling environment. The institutional and regulatory capacity to manage the private sector has to be enhanced.

Whilst there has been some movement, such as the GAA Code of Practice, a greater commitment and participation by the private sector is necessary to implement Codes of Conduct.

Follow up recommendations

The following recommendations are made as follow up actions from this Thematic Review:

- Explore the opportunities for preparation and agreement of an agreed "code of conduct" for mangrove management, which provides basic principles for management of mangrove forests. Such a code should consider also non-aquaculture uses, recognising the multi-sectoral development pressures on coastal mangrove forests. It should be developed through a strong concensus building, open process, involving the range of stakeholders concerned with mangroves.

- Communication of experiences on implementation of better mangrove management practices for aquaculture should be enhanced. Particular emphasis should be given to rehabilitation, the role of co-existence of mangroves and aquaculture in supporting poor people's livelihoods and understanding on non-technical issues – ownership, institutional arrangements for example – and their role in mangrove rehabilitation.

- There is a need for a more comprehensive analysis of legal aspects of mangrove management, covering such issues as what is the minimum requirement for effective legislation. Such issues may also be included in the proposed code above, focused on legislation to key implementation issues.

- Implying co-existence is possible, and documenting its actual occurence, are two different things. It would be to the advantage of all parties if the shrimp aquaculture industry adopted an active, and funded, research program, in conjunction with the World Bank, to see that all the above recommendations are tested in the field, and successful examples of co-existence are documented. Research on the concept of no-net-loss of mangroves or other important wetlands via shrimp aquaculture is essential. Successful restoration, on a large scale, of disused shrimp ponds, would be a good start. The experience of the authors, however, is that there is a strong tendency for industry to ignore the existing disused pond problem. Opportunities of disused pond rstoration represent a win-win issue for the shrimp aquaculture industry. We recommend they take advantage of this opportunity and fund the necessary research, in conjuction with the World Bank, to implement large scale (thousands of hectares) of pond restoration testing various methods, including hydrologic restoration without planting which likely could be implemented on a large scale for USD 100 per ha

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