Integrated mangrove forest and aquaculture systems in Indonesia

WILLIAM J. FITZGERALD JR.

Oceania-Pacific Rim Consultants Services
PO Box 6997
Tamuning, Guam 96931 USA
<wfitzger@ite.net>

Abstract

Silvofisheries is a form of integrated mangrove tree culture with brackishwater aquaculture. It is a form of low input sustainable aquaculture. This integrated approach to conservation and utilization of the mangrove resource allows for maintaining a relatively high level of integrity in the mangrove area while capitalizing on the economic benefits of brackishwater aquaculture. Silvofisheries is being promoted in Indonesia as part of a mangrove rehabilitation, conservation and management program.

Pond-based silvofisheries follow three design models: (1) the basic "empang parit" model that is essentially identical to an extensive aquaculture pond with maintenance of mangrove trees on the central platform; (2) modification of the basic model to include a dike constructed around the treed central platform so that the water level within the mangrove area and the open water perimeter culture area can be controlled separately; and (3) further modification of the second model to completely separate the open water culture area from the mangrove area by a gated dike with the pond culture area consolidated to a square or rectangular shape at the end of the enclosed diked area. The ratio of mangrove tree to open water culture area is 8:2 to 6:4. In addition, various methods of minimizing the costs associated with pond construction are being considered. This includes the cultivation of mangrove crabs (*Scylla* sp.) in pens.

The State Forestry Company in Indonesia has successfully developed and implemented silvofisheries sites (e.g., 6,000 ha in West Java-Cikiong with 1,508 farmers; 5,300 ha in Blanakan with 2,060 farmers). A conditional lease program with non-government organizations providing technical assistance to farmers has been successful. This program exemplifies what can be accomplished in mangrove rehabilitation and management within a controlled and enforced program.

Production and financial return from silvofishery varies with the system, site characteristics, the level of energy input (mainly from mangrove litter - green manure) and utilization by cultured species, among other factors. Annual profit of up to $2,000/ha/yr for a milkfish and shrimp polyculture silvofisheries system has been reported. There is a need to refine data and analysis, since all costs are often not included, and revenue projections are often based on expected production rather than actual production. Farm interviews in West Java showed a range in gross income from $313 to $946/ha/yr while net profit per individual farm (1.5-10 ha farm size) ranged from $943 to $1,558/farm/yr. There was greater production effort per unit area by farmers with smaller farms. Individual silvofishery farmers often combine incomes from multiple sources.

The application of silvofisheries practices requires reasonable measures of caution as with any activity in an environmentally sensitive area as the mangroves. Additional important considerations in the development of silvofisheries as part of an activity within the mangrove ecosystem include the issues of land ownership, integrated coastal zone planning and development, comparative economic assessment, systems models, optimizing use of inputs, selection of mangrove tree and aquaculture species, better understanding of trophic production and food web utilization, and improvement of economic return.

Introduction

Mangrove forests have great ecological and economic potential. The mangroves play an important role in the ecology of the coastal zone area and in support of the marine species that utilize the mangrove ecosystem during part or all of their life cycles. The mangroves' physical location in the coastal zone transitioning between land and sea makes it a unique habitat.

Conservation of the mangrove resource has drawn the attention of national agencies and international environmental non-government organizations (NGOs). There is growing pressure from these NGOs to stop the destruction of mangroves. The major target is the aquaculture industry, specifically shrimp culture. Some NGOs are moving towards promoting an international boycott on the importation of cultured shrimp. This pressure, along with high profile environmental conferences (e.g., United Nations Conference on Environment and Development in Rio De Janeiro in 1992), are impacting national policies on many environmental issues including preservation of the mangrove forests.

There is a need to balance development pressure and conservation of the mangrove resource. Social issues are closely linked to sustainable development. The economic needs of the coastal populations for jobs and income must be addressed. The mangroves are a coastal resource that have been impacted substantially (e.g., clearing for villages, for wood, construction material, and agriculture) by this growing coastal population pressure. Aquaculture is one of the economic activities that has utilized the mangrove area as a resource.

There are a number of ways the further conversion of mangroves to pond aquaculture can be minimized. These include the intensification of aquaculture on existing sites, the promotion of aquaculture which can be developed with minimum impact on the mangrove ecosystem, better pond siting procedures in mangroves, the integrated management of sustainable uses of the mangrove ecosystem, a shift of pond development to outside the mangroves, and non-land based culture systems (i.e., mariculture).

Two main sustainable alternatives to aquaculture pond development are silvofisheries and mariculture. Silvofisheries is a form of low input sustainable aquaculture integrating mangrove tree culture with brackishwater aquaculture. This integrated approach to conservation and utilization of the mangrove resource allows for maintaining a relatively high level of integrity in the mangrove area while capitalizing on the economic benefits of brackishwater aquaculture.

The more a cultivation system recognizes and mimics natural ecosystem functions, the less resource inputs are required and the less negative environmental effects occur (Folke & Kautsky 1992). Integrated systems strive for increased efficiency, reduced use, avoidance of chemical and medicinal products, less waste generation and the recycling of nutrients. Further extension of aquaculture to meet the needs of the rural poor may be tolerable, provided it is carried out in a controlled manner outside those areas already heavily exploited and environmentally sensitive. The effort must be within an integrated program of conservation and utilization, such as silvofisheries.

Silvofisheries

There are two basic silvofishery models (Figure 1). One model (Type I A, B) consists of mangroves within the pond with a ratio 60-80% mangrove and 20-40% pond canal culture water area. The second model (Type II C, D) consists of the mangroves outside the pond with similar mangrove to water ratio. The pond/mangrove forest (Type II) should be constructed with mangrove strips perpendicular to the coast so that the flow of surface runoff or rainfall is allowed to be transported through the mangroves coastward (not obstructed by pond dikes). The advantages of the Type II model, with the mangroves outside the pond, include greater manageability of the brackishwater pond, greater control, greater flexibility of culture practices, higher potential production, and lower construction cost. It also avoids the potential toxic levels of tannin from the mangrove trees. In addition, it allows for a natural species diversity and flushing of the mangroves. The disadvantage would be that the system is more susceptible to development abuse with encroaching on the mangrove area; however, that can be controlled with lease conditions and regulation enforcement.

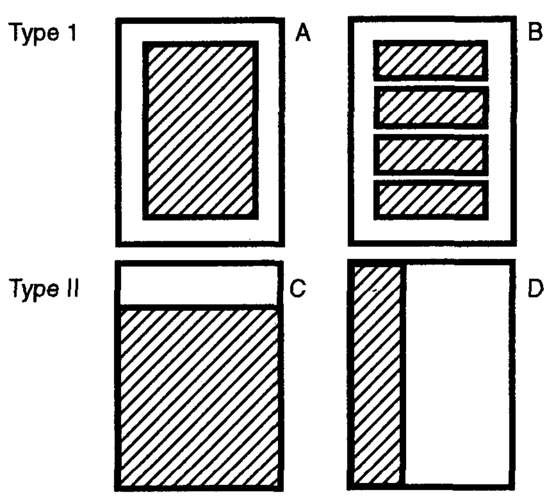

Figure 1. **Silvofisheries models** (cross-hatched areas represent mangrove forest)

There are a variety of designs within these basic models that attempt to balance the conservation issue while maximizing economic opportunity. A number of countries are pursuing a form of silvofisheries, including Hong Kong, Thailand, Malaysia, Vietnam, Philippines, Kenya, Tanzania, and Jamaica. Some of the systems are traditional long-term practices and others are new approaches.

The productivity of the pond is based essentially on the use of "green manure." The organic enrichment of the pond is from plant material, in this case mangrove tree debris. The amount of debris varies by the size and density of trees and rate of litter fall. This debris has to undergo a decay process before it becomes usable within the food chain of the cultured species.

"Empang parit" model, Indonesia

Indonesia's mangrove forests (4.25 million ha) represents approximately 25% of the world's mangroves and is a biogeographical center for a number of mangrove genera. Various entities from university research programs to national programs within the Ministry of Forestry and the Directorate General of Fisheries of the Indonesian government have been studying, demonstrating and promoting silvofisheries. These silvofisheries development range in size from one hectare to thousands of hectares at each site. "Empang parit" (sometimes referred to as "tambak tumpangsari") is the traditional application of this integrated aquaculture in the mangrove area. It is a silvofisheries model that is being promoted in Indonesia.

The Southern Sulawesi Province Fisheries Office has three demonstration "empang parit" sites that have been recently initiated. A fourth is to be built (1998) in the Luwu District This is part of a national program to promote silvofisheries through the Directorate General of Fisheries Office. The *Mangrove Rehabilitation and Management Project* in Sulawesi (Ministry of Forestry) has "empang parit" demonstration sites in Luwu and Kwandang. As part of the *Island Sustainable Livelihood and Equity Program* (University of Hasanuddin), there is a community development project that includes a demonstration "empang parit" project in Sinjai, Sulawesi. In addition, there are large-scale silvofisheries programs in Cikiong and Blanakan in West Java. Unfortunately, controlled production trials, with the collection of production data and inputs and an economic analysis of these systems have been very limited.

The "empang parit" model represents the greatest level of reforestation or maintenance of existing forest to pond area. The model is illustrated in Figure 1 A. It essentially consists of an unexcavated central platform (80% of total pond area) that alternates between being flooded and exposed depending on the tide. A canal that runs parallel to pond dikes surrounds this platform. The canal is normally 3-5 m wide and 40-80 cm deeper than the platform. Fish, shrimp, and crabs are cultured extensively in the canal and they can enter the central platform area during periods of flooding.

The density of the planted mangrove trees on the platform area ranges from 0.17 to 2.5 trees/m^2. Tree density influences the quantity of litter production and organic load in the pond along with non-mangrove flora and fauna (e.g., algae), among others. Non-mangrove flora/fauna may form an important part of the diet of cultured species. Tree density also influences aquaculture production, with farmers preferring a more open density (approximately 0.2 trees/m^2) for milkfish. The higher openness of the forested areas allows accessibility to the platform area in milkfish culture while a greater tree density can be used in shrimp and mangrove crab culture as these species prefer additional structural habitat and shelter afforded by the mangroves.

The "empang parit" model has a number of disadvantages compared to a brackishwater pond or open pond, as follows:

- greater construction cost per unit of culture area
- greater difficulty to manage
- reduced water circulation and greater potential for stagnant areas with low oxygen levels
- limitation on species cultured (e.g., seaweed would be shaded by trees, reducing growth)
- mangrove trees reduce the penetration of sunlight to the ponds, lowering the productivity of phytoplankton and benthic algae
- potential toxicity of tannin from mangroves

Sinjai (South Sulawesi) site

The "empang parit" operation located in Tongke-Tongke, Samataring, Kecamatan Sinjai Timur (South Sulawesi) was constructed in 1994. It is a cooperative project of the Ministry of Forestry (Province Office), District Government, and the University of Hasanuddin. This evolved out of a community-initiated mangrove replanting program that started in 1984. The replanting consisted mainly of *Rhizophora* (85%) and minor planting of *Avicennia, Bruguiera,* and *Sonneratia* covering an area of 559 hectares. The replanting was an effort to stop the increasing coastal erosion of the fishing village.

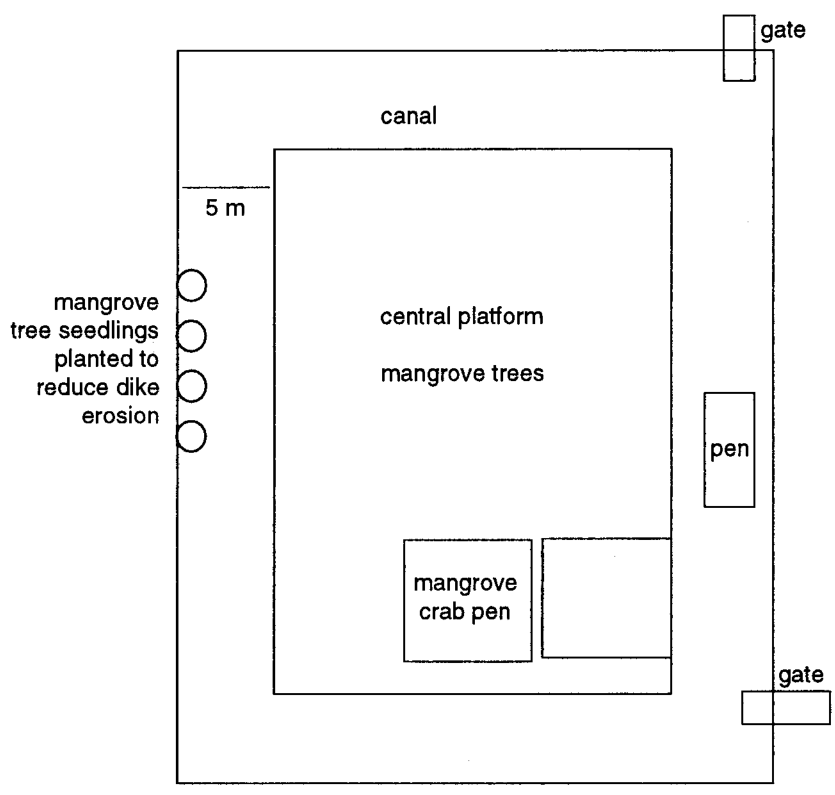

Figure 2. **"Empang parit" pond layout in Sinjai**

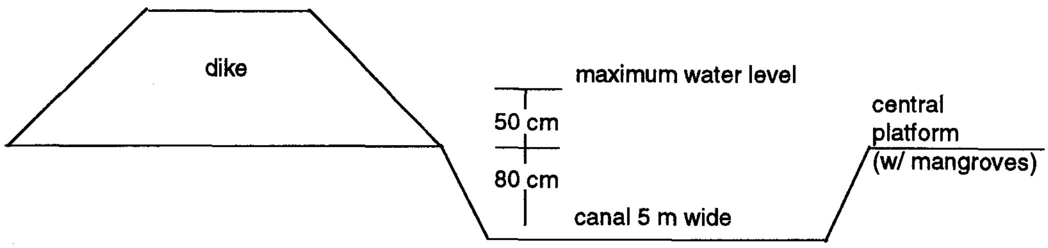

Figure 3. **Cross section of "empang parit" pond at Sinjai, South Sulawesi**

The planted mangrove area consisted of 11 -year old *Rhizophora mucronata* trees that were planted 0.5 m apart. They provided a very dense growth (2.5 trees/m^2) that had to be thinned to 0.6 trees/m^2 to accommodate pen culture in the central platform.

The "empang parit" pond was constructed within the planted mangrove (Figures 2 and 3). Its design and operation is advanced compared to other demonstration or private efforts implemented within the *Mangrove Rehabilitation and Management Project in Sulawesi.* However, it exemplifies the standard or traditional "empang parit" model.

The pond is one hectare in size with two wooden gates. The screened gates are left open all the time to allow the water level inside the pond to fluctuate with the tides. The canal that runs around the inner perimeter of the pond is 5 m wide and has a maximum depth (below the central platform area) of 1.0 m and a minimum of 0.7 m (average 0.8 m). The tide range in the pond is 50 cm (relatively small tidal range which reduces pond flushing capacity). The central platform has a water depth range of 50 cm to complete exposure at the lowest tide, but the average depth is 20-30 cm.

Potential problems with the system include the following:

- The two gates are located on the same side of the pond. This reduces water flushing especially along the opposite canal and would tend to have a greater build up in organic matter on the bottom and potential stagnation of water with lowered oxygen levels.

- The mangrove trees are extremely dense in the central platform area. These will contribute a large amount of organic matter to the pond. With the reduced flushing of water in the pond, this has the potential of high BODs and reduced oxygen levels.

- The construction of pens for mangrove crab culture in the central platform area will further add to the organic matter and associated decomposition of by-products. The additional input of trash fish — 5% of the mangrove crab weight daily -- may increase the BOD to a detrimental point and build-up hydrogen sulfide in the pond bottom.

- With the tidal height of only 50 cm in the pond, water exchange potential is reduced.

- The pond canals cannot be completely drained since the bottom of the canal system is below the lowest tide level. This results in greater stagnation potential and eliminates the periodic drying and oxidizing of built-up organics in the pond bottom.

- Large amounts of organic debris in the pond dike make the dike susceptible to shrinkage, leakage, erosion.

The pond is stocked naturally with juveniles of species entering with incoming tides. These species include siganids (*Siganus* sp), mullet (*Mugil* sp), milkfish (*Chanos chanos*), tilapia (*Oreochromis* sp), shrimp (*Penaeus monodon*, *P. merguiensis*, and *Metapenaeus* sp), mangrove crab (*Scylla serrata*), jacks (*Caranx* sp), and seabass (*Lates calcarifer*). These are harvested by gill net during low tide when they are concentrated in the perimeter canal.

Hasanuddin University is conducting a research project with the Ministry of Forestry and the District Government to improve the aquaculture production of the "empang parit" system. The project is part of a multi-faceted community empowerment and development program called *Island Sustainability, Livelihood and Equity Program.* It has international counterpart.

One of the project's innovative approaches is the addition of mangrove crab (*Scylla serrata* and *S. oceanica*) pen culture (stocking density is 3 crabs/m^2; average size is 70 g). Initially, 12 pens (10 x 10 m; 100 m^2) were constructed within the central platform area (8 pens by Hasanuddin University and 4 pens by the District Government). They intend to construct additional pens to fill the platform area. When completed, there will be 36 pens with a total area of 3,600 m^2. The pens are spaced 1 m apart. There are two smaller pens that are constructed in the canal as part of a Fishery Office experiment. The pens have been stocked with 16.6 crabs/m^2.

Initial results show that the crab culture in the central platform has better water flushing conditions compared to the pens located in the canal. It may be recalled that the canal has about 80 cm of water and is below the lowest *tide* level. Options should therefore be explored to maximize production and to make the system more attractive as a viable option for less productive brackishwater ponds.

Two alternative and innovative designs of the "empang parit" model are being planned. One consists of reducing the pond dike to a low wall 50 cm in height but placing a net on top, effectively increasing dike height while allowing greater water exchange. The central mangrove planted area would be the same. The advantage of this model is lower construction cost with the lower dike wall and elimination of gates. The greater water exchange would minimize water stagnation and the possibility of low oxygen levels that can result in fish mortality. However, there is still a need for a mechanism to drain the pond (e.g., gate or stand pipe). There will also be problems with the extended submergence of mangrove trees.

A second design is to eliminate the pond dikes completely and to construct the bamboo pens within the standing mangrove forest. The pens would be for the culture of mangrove crab as described above. The advantage of this design is the elimination of capital investment associated with the construction of pond dikes, canals, and gates. Furthermore, it reduces aquaculture impact on mangrove forest. The disadvantage is the elimination of profits associated with raising fishes/crustaceans in canal areas.

Cikiong and Blanakan, West Java

Cikiong and Blanakan are part of a government mangrove management and rehabilitation program that includes silvofisheries. The program is administered by Perum Perhutani (State Forestry Company). The sites exemplify what can be accomplished by a controlled and enforced program. All silvofishery farmers must sign a conditioned lease.

Cikiong has 6,600 ha of silvofishery brackishwater ponds with 1,508 farmers involved. All farms use the traditional "empang parit" model with an 8:2 ratio of mangrove: water. The State Forestry Company has experimental projects that modify the design. The modification consists of an additional dike around the central mangrove platform of the pond with separate gates for the canal and mangrove portion of the pond. This would allow the water level to be controlled separately for the trees (which cannot tolerate being submerged for extended periods) and the canal (to maintain a maximum water level during fish culture). Shrimp are harvested daily using a bamboo trap with a kerosene lantern during the evening hours. Average harvest is about 1 kg of shrimp per ha per night (mainly *Metapenaeus ensis).*

Blanakan has an area of 5,300 ha of silvofishery brackishwater ponds with 2,060 farmers. The majority use the traditional "empang parit," however, there are silvofishery models similar to Type IB (Figure 1). There are also ponds with different mangrove to water area ratios up to fully cleared brackishwater ponds. The annual rental fee is US$90/ha (220,000 Rp/ha) for brackishwater ponds (no mangroves), US$37/ha (90,000 Rp/ha) for 1:1, and US$12/ha (30,000 Rp/ha) for 8:2. The main cultured species is tilapia.

A study in 1991 compared production data for the different West Java silvofishery operations (Table 1).

Table 1. **Production from "empang parit" in West Java (kg/ha/yr)** (Anon. 1991)

Location	Total "empang parit" area (ha)	Tilapia	Milkfish	Trash fish	Shrimp	Crab
Bogor						
Tanggerang	1,113		700	200	200	
Ujung Karawang	7,934		600	200	200	
Purwakarta						
Cikiong	6,268		600	250	250	1
Pamanukan	4,263	1,500	500	50	300	
Indramayu						
Indramayu	6,421	1,500	500	50	300	

Full economic analysis of silvofisheries is limited. Annual profit from milkfish and shrimp polyculture was reported to be US$2,091/ha/yr (5,122,000 Rp/ha/yr) (Anon. 1991). However, these figures do not account for all costs of production (e.g., hired labor, annual leases, construction, depreciation, supplies, and equipment). Therefore, they can be overly optimistic and misleading.

Widiarti & Effendi (1989) conducted a more complete economic evaluation of operations under the Perum Perhutani at Blanakan and Cangkring in West Java. Results showed an annual net income of US$248/ha (608,500 Rp /ha) for farms at Blanakan and US$408/ha (1,000,700 Rp/ha) for farms at Cangkring. These farms utilize the traditional "empang parit" model with an 8:2 ratio of mangrove to water channels. Therefore, a reasonable expectation of annual net income from this model type would be the average of the above two sites which is US$328/ha/yr (804,600 Rp/ha/yr). Approximately 50% of the farmers' income was attributed to "empang parit" with the balance from agricultural or other sources of income. The difference in net income between the two sites was mainly attributed to the species cultured. Blanakan farms mainly produced tilapia while the Cangkring produced mainly milkfish. Milkfish had a market value approximately 33% higher than tilapia.

A similar financial analysis was made by the Forest Management Division (Bagian Kesatuan Pemangkuan Hutan) of Perum Pertuhani (Table 2). The mangrove crab, seabass (*Lates calcarifer*), tilapia-chicken and milkfish-shrimp production data are from Cikiong silvofisheries operation. The milkfish monoculture (for food and bait) is from silvofisheries in Cibuaya (Karawang District, West Java). On a per unit production basis, the mangrove crab culture out-performed all other species by a substantial margin. This would justify increased research on the various aspects of mangrove crab culture (e.g., larval culture, grow-out, optimized cost-effective feed conversion, species differentiation and hybridization, among others). As in the financial analysis reported above, all costs were not included; however, the results are useful to point out the magnitude of difference in the potential economic return among the species considered. This assists in designing a production strategy for an "empang parit" system that improves the economic returns of farmers.

Table 2. **Value of production from "empang parit" systems in Cikiong and Cibuaya, West Java** (US$1=2,450 Rp) (Anon. 1994, 1995)

	[1]Mangrove crab	[2]Seabass	[2]Tilapia and chicken coop	[2]Milkfish and shrimp	[2, 3]Milkfish
Annual net profit (ha/yr)	US$1,367 Rp 3,350,000	$1,347 3,300,000	$2,601 6,372,000	$2,508 6,144,000	$1,322 3,240,000
Net profit per unit area (m^2/yr)	US$22.79 Rp 55,833	$0.13 330	$0.26 637	$0.25 614	$0.13 324

[1]Cultured in 60 m^2 cage
[2]Cultured in "empang parit" system with an 8:2 (mangrove:water) ratio
[3]Monoculture for food and bait

An abbreviated interview of farmers involved in the *Mangrove Rehabilitation and Management Project* in Sulawesi (FitzGerald & Sutika 1997) at both Blanakan and Cikiong showed an average gross income of US$580/ha/yr (1,419,859 Rp/ha/yr) (range: US$313-946/ha/yr or 766,200-2,318,200 Rp/ha/yr).

The net profit was an average US$476/ha/yr (921,632 Rp/ha/yr). The variation in net income per farm was less, an average US$1,283/farm/yr (3,143,4154 Rp/farm/yr) (range: US$943-1,558/farm/yr or 2,310,400-3,816,400 Rp/farm/yr). The individual farmer operated between 1.5 to 10 ha of silvofisheries ponds. This may indicate a greater production effort per unit area by farmers with smaller farms. In addition, the individual with 1.5 ha supplemented his income (approximately 40%) from rice fields. The individual with 10 ha obtained 100% of his income from silvofishery. This assessment of production and costs at least provides a more reasonable evaluation of silvofisheries' potential. However, more research is needed to gather a fuller assessment of the silvofishery models.

Recommendations

Considerations in silvofisheries models

Silvofisheries should be approached with reasonable caution as with any development in environmentally sensitive areas such as the mangrove ecosystem. The basic principles of sustainability must be considered prior to development. For example, the availability and impact on the natural population of species cultured must be assessed including the availability and impact on seedstock recruitment and survival.

The overall development strategy should integrate environmental, conservation, social, and economic issues. Development is a dynamic, evolving process that changes over time with expanding activities, research, and emerging technology. These changes should be reflected in the comprehensive coastal plan which can be periodically revised. Baseline information on the environmental characteristics of specific areas, in particular, carrying capacity and potential uses, must be considered.

Development should be diverse in nature and serve the fundamental needs of the community while providing an economic base for expansion within an environmentally sensitivity framework. The integrated approach will allow for both sustained economic activities while implementing a conservation and rehabilitation program for the mangroves.

Comparative economic assessment

From a strictly economic perspective, it is useful to evaluate the capital costs and the potential value of products in silvofisheries, and compare them to brackishwater extensive culture. This is of value in decision making for the community or individual entrepreneur, and to planning/policy organizations. It can also provide a measure of the level of incentives that may be necessary to make silvofisheries a comparable economic activity for private land owners or entrepreneurs.

Both silvofisheries and brackishwater extensive culture ponds are essentially the same in construction. The exception is the central platform area; in extensive aquaculture, the area is cleared of all vegetation. The cost associated with perimeter dike construction would usually be less in silvofisheries because of the cost efficiency in reduced perimeter length associated with the adoption of a square design. The construction costs associated with the clearing of the central platform would be zero for a silvofishery pond except when cross channels are constructed through the platform. Therefore, from a construction cost perspective in comparing a silvofishery and an extensive brackishwater aquaculture pond, these costs can be represented as follows:

Silvofisheries pond = X (D_s) + Y (CA_s)

Brackishwater extensive aquaculture pond = X (D_a) + Y (CA_a)

where: X = cost per linear meter of perimeter dike
D = linear length of perimeter dike
Y = clearing/construction cost per square meter of central platform
CA = area of central platform cleared
subscripts a, s = indicate brackishwater extensive aquaculture or silvofisheries ponds, respectively

If the difference in annual net operating value of products between the silvofisheries and extensive pond ($\Delta V_{s\text{-}a}$) minus the difference in the annual depreciated cost of construction between the silvofishery and extensive aquaculture pond ($\Delta C_{s\text{-}a}$) is equal to or greater than zero ($\Delta V_{s\text{-}a} - \Delta C_{s\text{-}a} \geq 0$), then, from an economic perspective, the silvofisheries pond would at least be equal to or have an advantage to an extensive aquaculture pond system. This economic assessment can be further refined in a benefit/cost analysis that takes into account the tangible and intangible values associated with environmental benefits of maintaining the mangrove vegetation in silvofisheries.

Ownership

Mangroves and tidal wetlands are traditionally common property resources with rather low perceived value in developing countries. The use or optimum yield from any common property resources must be carefully executed and must consider a mix of benefits, including those of environmental, social and economic significance. In coastal aquaculture, the competition is usually between the traditional users of previously open-access resources and those who are encroaching on and expropriating these resources. This competition impacts 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 plans, and to reduce potential user conflicts.

Land ownership is an important decision criterion in the use of the mangrove area. 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, and landless to enter land ownership through a lower entry barrier regardless of the long-term development costs (mainly in labor) and environmental costs. This is important from a social perspective in that land ownership brings a higher status in the community, which potentially raises the individual's influence in the community. Land ownership not only benefits the individual, but also bestows long-term benefit to his family and heirs.

Silvofisheries has been successful in situations where community property or government land is conditionally leased to community projects or individual/family operations (e.g., Blanakan and Cikiong). However, in areas that are under private ownership, the owner normally would have little incentive to reforest cleared property because forests are perceived as being of lower value. This emphasizes the importance of maintaining government ownership and control of mangrove areas. This will allow more controlled utilization through conditional leases in an integrated and environmentally sensitive manner under a land use plan.

In the case of private ownership of mangroves, capital cost related to pond construction seems to be inadequately considered. The cost of dike and gate construction is about the same for silvofishery pond and for aquaculture brackishwater pond. The revenue generation from silvofishery 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 aquaculture operation). Underwriting silvofishery demonstration projects that are not carefully designed within basic economic realities can create a misleading model that is not viable on privately owned land without substantial government subsidy. Therefore, demonstration projects have to be realistically designed to fulfill its long-term objectives. If the mangrove forest is privately owned, and the environment-friendly development is in the public good, the government can consider providing incentives to private landowners to use silvofisheries, and rehabilitate or reforest former mangrove areas. This incentive system should be designed to provide a reasonable economic return within an enforceable regulatory framework. Some incentive options 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 negative incentive approach would place an increased economic cost to the owner to leave the property unproductive. Therefore, he would have the incentive to reforest the property or utilize silvofisheries to increase production (or improved brackishwater pond condition) and relieve the increased tax expenses of the property.

- *Land exchange with government property in a non-critical habitat area of equivalent economic value.*

Incentives and disincentives can be used in implementing policies that have been determined to be desirable (national and local level). The "green tax" has been advocated as a means of addressing environmental externalities. "Green tax" is cheaper to administer, does not distort economic activity, and is fair (Anon. 1996).

Systems model

Silvofishery is a labor-intensive technology appropriate for an individual, family or community operation and can be a viable alternative to brackishwater pond culture. It diversifies products from the land and aquatic production within an environmentally benign framework and is integrated into the mangrove forest ecosystem. But it is not suited to commercial large-scale aquaculture activity on privately owned land.

The cost of pond construction makes "empang parit" not economically attractive without fuller integrated utilization of resources. 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 viable forms of aquaculture in converting abandoned brackishwater ponds into an integrated reforestation and utilization program especially where the cost of pond construction is not included. Government subsidy in the form of low-cost lease and a package of technical and capital assistance should make it an attractive option to meeting the needs of the rural poor within a program of mangrove rehabilitation.

The selection of the most appropriate silvofishery model will be site-dependent and influenced by the status of the mangrove ecosystem. Therefore, no single model is the best. Silvofisheries should be integrated into an area-wide integrated approach to coastal zone management. This allows for maintaining a relatively high level of integrity in the mangroves while capitalizing on the economic benefits of brackishwater aquaculture.

The silvofishery model preferred in most applications is the integrated mangrove-crab culture systems. Its advantages include: (1) no permanent alteration of mangrove forest, (2) low capital investment, low labor requirement, low technology, and small unit size; (3) incremental ability for expansion; and (4) production of a high value product.

For areas under private ownership, the alternating brackishwater pond/mangrove model would be the most appropriate (Figure 4). It has a number of advantages and disadvantages that are site dependent. It maintains the same maximum ratio of mangrove to pond culture area as high as any of the other models while providing superior management and production. Variations in the ratios can be made based on environmental, conservation, development, and policy considerations. It is recommended that units of 2- or 4-ha ponds be standardized as the model units. This would mean that for every 2-ha pond, there would be an 8-ha mangroves maintained around it. Advantages of this model are: (1) the mangroves outside the pond are structurally unaltered; and (2) the tidal and ground water movement are not constrained. But the model is susceptible to violation - by encroachment or non-compliance — where regulations are not rigorously enforced.

Mangrove research

Studies on how to increase production from various silvofishery models should be conducted. This is particularly important for reforesting private lands. The different silvofishery models, specifically the two main types (mangroves integrated within the pond area and mangroves integrated around or outside pond area), should be evaluated. This should include optimizing the use of inputs and stocking strategies for different species within a polyculture system.

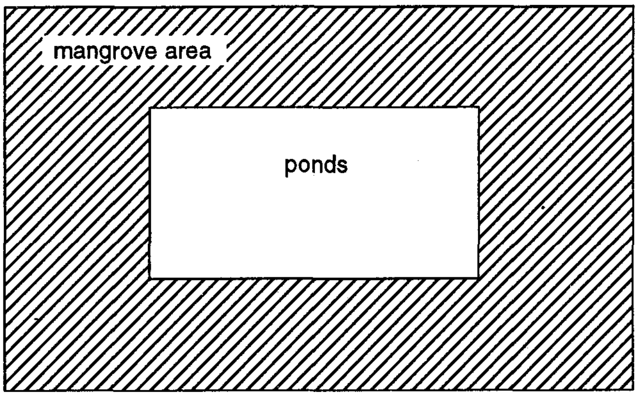

Figure 4. **A 10-ha silvofisheries site (with 8:2 mangrove to brackishwater pond ratio) alternating brackishwater pond and mangrove (not to scale)**

Density of trees and silviculture management (e.g., trimming, selective cutting, etc.) to maximize the production of litter has to be evaluated. The species of mangrove trees that can be used for specific pond conditions should be determined as well. Analyses should be made on the type and amount of vegetation cover, rate of litter production of different trees, and decomposition rates of different tree litters. These are important factors in the food web supporting pond productivity. The food web itself -- from mangrove vegetation litter to ponds -- should be studied so that appropriate management practices can be developed.

Evaluating trophic production and food web dynamics is of major importance. It is necessary to include all forms of macrophytes and algae to evaluate the different autotrophic compartments in total primary production, and then to study the energy flow and its utilization in the mangrove ecosystem. It will be equally important to determine and document the differences in food items ingested from those that are actually assimilated. This will assist in selecting the most appropriate aquaculture species for silvofisheries.

A thorough study of macro- and microalgae in mangroves to understand their growth dynamics and growth parameters within the mangrove forest is essential to the aquaculture component. Changes in the balance of autotrophs in nutrient cycles can maximize the energy available to the food web supporting the aquaculture species. It will also be important to determine how to best balance mangrove growth (density, height, canopy cover, species, etc.) with production of algae, since excessive shading from dense macrophytic vegetation would impair production of algae within the platform area. These are all part of a requirement to best enhance the quality and quantity of the food web.

Silvofisheries 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 its widespread acceptance. Silvofisheries can also provide alternative income 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 role in the transition that shifts more intensive aquaculture to areas outside the mangroves.

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