IMPACTS OF BRACKISHWATER POND CULTURE ON THE MANGROVE ECOSYSTEM

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I. Introduction

Thirty-five percent of the total 18 million ha of mangrove forests worldwide are found in Southeast Asia (Spalding *et al.*, 1997). Indonesia alone has 4.5 million ha followed by Malaysia with 640,000 ha (Fig.1). At the same time, the region also leads in brackishwater aquaculture, producing for example 446,000 mt of farmed shrimp or 60% of 1997 global yields (Rosenberry, 1997). This paper aims to describe Southeast Asian mangroves, the impacts of brackishwater pond culture on these ecosystems, and lessons from the region for the development of aquaculture in Malaysia.

II. Mangrove Goods and Services

Mangrove systems have three functions: information, regulatory and resource. The information function may refer to aesthetic, religious, cultural or historical aspects. For example, the premier city of Manila or *Maynila* owes its name to the species *Scyphiphora hydrophyllacea* locally called *nilad*, which grew abundantly along Manila Bay in pre Hispanic times (Merrill, 1918). What are usually referred to as services and amenities fall under the regulatory function, and may be geomorphic/hydrologic (coastal protection, erosion control and sediment trapping) or ecological (nurseries, nutrient supply/recycling and storage) in nature.

Mangrove resources (Table 1) are the most familiar among the three functions. Utilization of these forestry and fisheries products may be traditional, small-scale extraction for domestic needs (e.g. domestic food, fuel and medicines) or commercial in scale (charcoal, timber and harvest of fish, shrimps and bivalves).

A positive relationship between fish/shrimp nearshore catches and mangrove area has been documented for Indonesia (Martosubroto and Naamin, 1977), Malaysia (Sasekumar and Chong, 1987) and the Philippines (Camacho and Bagarinao, 1987). Mangrove-associated fish, crustaceans and molluscs contribute 21% (1.4 million tons) yearly to the inshore capture fisheries in the ASEAN region (Singh *et al.*, 1994). Mangrove-associated fish contribute around 30% (1.09 million tons) of annual finfish resources excluding trash fish, while mangrove-dependent prawns provide almost 100% (0.4 million tons valued at US$1.4 billion) of total prawn resources in ASEAN.

The link between fish/shrimp yields and adjacent intertidal area (Fig. 2) has been associated with the nursery function, larval trapping or retention, and trophic subsidy or 'outwelling' (Hatcher *et al.*, 1989; Chong, 1996). Because there is little evidence that the exported detritus enhances primary productivity offshore (Lee, 1995), the mangrove-fisheries connection may therefore lie in the nursery function through provision of food and shelter from predation (Hatcher *et al.*, 1989) and the lateral trapping or retention of planktonic prawn larvae in mangrove swamps (Chong, 1996).

Mangroves have declined worldwide over the last century, but especially within the last few decades in Southeast Asia. Such loss due to anthropogenic factors include overexploitation by coastal communities and conversion to settlements, rice and other agriculture, salt beds and industrial activities. But brackishwater pond culture—which dates back to at least 1400 in Java, Indonesia (Herre and Mendoza, 1929)—has also taken its toll. Most of the thousands of hectares of brackishwater ponds in the Philippines and Indonesia were carved out of mangrove swamps for milkfish cultivation. However, the recent mangrove-pond conversions in Southeast Asia have been for shrimp farming. For example, 102,000 ha of Vietnamese mangroves had been developed into shrimp ponds in 1983-1987 (Table 2).

III. Ecological Impacts of Brackishwater Pond Culture

The ecological impacts of brackishwater pond culture, whether for shrimp or milkfish crops at extensive, semi-intensive or intensive levels of farming include effluent release into waterways, chemical use, salinization of soil and water, destruction of fry bycatch, introduction of exotic species and pathogens, and loss of mangrove habitats.

A. *Nutrients, organic loading and sediments*

The water quality in high-density culture ponds deteriorates as shrimp biomass and food inputs increase during a cropping cycle. Mean levels of nitrogen, phosphorus, turbidity and chlorophyll and other water parameters in Hawaiian shrimp ponds were generally higher in effluent than in influent water (Ziemann *et al.*, 1992). Similarly, N and P levels in waste water discharged from Thai shrimp ponds were significantly higher compared to inflow water (Vorathep, 1991). Effluent water during regular flushing and at harvest accounts for 45% of N and 22% of organic matter output while sediment is the major sink accounting for 31% of N output, 84% of P, 63% of organic matter and 93% of solids (Briggs and Funge-Smith, 1994).

The quality of receiving waters deteriorates if the assimilative capacity of the environment is exceeded. Due to shrimp pond effluent loadings, levels of nitrates, nitrites, phosphorus, sulphide, turbidity and biological oxygen demand increased considerably from 1983 through 1987 to 1992 in the Dutch Canal in Sri Lanka (Jayasinghe, 1995) and water quality in Kung Krabaen Bay, Thailand significantly deteriorated over time (Tookwinas, 1998). An Australian study showed that levels of Vibrio and other bacteria were 10 times higher in shrimp pond sediments compared to mangrove sediments, and were also higher in mangrove sediments near effluent canals compared to those located 2 km away from farms (Smith, 1998).

Because sediment or sludge accumulates at the rate of 20-290 mt DW/ha/cycle in intensive shrimp ponds, their direct disposal in waterways may cause eutrophication and self-contamination in ponds through intake water (Frederiksen *et al.*, 1998). Nevertheless, sludge is largely mineral soil whose chemical composition is probably not toxic to organisms and whose removal is unnecessary, expensive and destructive to ponds (Boyd *et al.*, 1994). Neither does sediment removal reduce levels of *Vibrio* and other bacteria (Smith, 1998). Instead, sludge should be spread and compacted over the pond bottom to reduce erodibility by aerator-induced currents (Boyd *et al.*, 1994), and dried between crops to reduce *Vibrio* and bacterial levels temporarily (Smith, 1998). Alternatively, pond sludge may be collected and used in mangrove planting projects near farms (Macintosh, 1996).

B. *Chemical use*

Chemicals used in shrimp culture may be classified as therapeutants, disinfectants, water and soil treatment compounds, algicides and pesticides, plankton growth inducers (fertilizers and minerals), and feed additives (Primavera, 1993). Excessive and unwanted use of such chemicals result in problems related to toxicity in nontarget species (cultured species, human consumers, and wild biota), development of antibiotic resistance, and accumulation of residues. The antibiotics oxytetracycline and oxolinic acid were detected above permissible levels in 8.4% of 1,461 *P. monodon* sampled from Thai domestic markets in 1990-1991 (Saitanu *et al.*, 1994). From June 1992 to April 1994, Japanese quarantine stations found antimicrobial residues in 30 shipments of cultured shrimp from Thailand (Srisomboon and Poomchatra, 1995).

C. *Groundwater removal; salinization of soil and water*

Pumping large volumes of underground water to achieve brackishwater salinity have led to the lowering of groundwater levels, emptying of aquifers, land subsidence and salinization of adjacent land and waterways in Taiwan and Southeast Asia. Even when fresh water is no longer pumped from aquifers, the discharge of salt water from shrimp farms located behind mangroves still causes salinization in adjoining rice and other agricultural lands (Dierberg and Kiattisimkul, 1996). Salinization reduces water supplies not only for agriculture but also for drinking and other domestic needs.

D. *Destruction of wild fry bycatch*

Extensive farming of the giant tiger prawn, *Penaeus monodon*, also depends on natural seed that comprise only a fraction of wild fry catches. In India and Bangladesh, where ponds are stocked mainly with wild fry, up to 160 fish and other shrimp fry are discarded for every tiger prawn collected from open waters (Banerjee and Singh, 1993). Given a yearly seed collection of one billion *P. monodon* in Southeast Bangladesh, the amount of bycatch destroyed is staggering and could have major consequences for marine food webs (Deb *et al.*, 1994).

E. *Loss of mangrove habitats*

Mangrove goods and services may be produced on-site or off-site, and marketed or not. Past valuation efforts have covered only traded products because of the subsistence level of utilization of such items as traditional medicines and domestic fuel, and the difficulties in assigning monetary values to such regulatory functions as coastal protection and waste processing, thereby underestimating the true value of mangroves. Reviews of available valuation data give a range of US$6-400/ha for individual and combined forestry goods (Radstrom, 1998) and $40-5,300/ha for different fisheries products (Ronnback, 1999). But if complete systems are considered, maximum figures of $11,000/ha can be attained (Table 3). Aside from conventional market analysis, valuation tools currently available include non-market methods (hedonic pricing, contingency valuation, indirect opportunity cost), damage costs and preventive expenditure (Turner *et al.*, 1998).

Cost-benefit analysis (CBA) is also useful in comparing alternative uses of mangroves. A CBA of Fiji mangroves including interactions of ecological, economic and institutional factors at the ecosystem level gave a negative net present value (NPV) for alternative uses (Lal, 1990). That is, mangrove reclamation for shrimp ponds or rice culture did not give positive returns. In Trang Province, Thailand, maximum NPV could be generated from 35,665 ha of mangrove economic zones by retaining 61% of the entire area as mangrove forest, reforesting 10%, and allowing only 17% for wood concessions and 12% for shrimp farms (Pongthanapanich, 1996). Considering forest products and fisheries as well as services of coastal protection, shoreline stabilization and carbon sequestration, Sathirathai (1997) concluded that mangrove conversion to commercial shrimp farms in Surat Thani, Thailand was economically available only for private persons but not society as a whole.

F. *Introduction of exotic species*

The most numerous introductions of non-indigenous fish and crustacean species outside their natural range have been for aquaculture purposes (Welcomme, 1988). The potential negative effects of such introductions include degradation of host environment, disruption of host community, genetic degradation of host stock, and introduction of diseases and parasites (Welcomme, 1988). In recent years viruses, notably the Whitespot Virus (WSV) and Yellowhead Virus (YHV), have caused catastrophic multimillion dollar crop losses in shrimp farms across Asia. All save 2-3 of the 20 identified viruses in marine shrimp have been described in cultured animals (Lightner and Redman, 1998). Since 1995, WSV and YSV have appeared in cultured and wild shrimp populations in the U.S. (Nadala and Loh, 1998; Nunan *et al.*, 1998), Central and South America (T. Flegel, Mahidol University, pers. comm.). The release of untreated wastes directly into coastal waters by plants that import Asian shrimp, and international transfers of live shrimp broodstock and larvae are the probable introduction routes of these Asian viruses (Lightner *et al.*, 1997).

The introduction of parasites and diseases, competition from introduced species, loss of mangrove habitats and mortality of wild fry bycatch may all impact negatively on biodiversity.

IV. Lessons from Southeast Asia

The development of shrimp farming in the Philippines, Thailand and Vietnam has many lessons for new players in the industry like Malaysia. They include proper siting and management of culture ponds, aquaculture development and mangrove conservation within the framework of integrated coastal zone management (ICZM), and appropriate policy instruments (Primavera, 1998).

A. *Proper siting and management of farms*

In addition to such standard criteria as soil quality and tidal regime, selecting pond sites must consider the waste-absorbing or assimilating capacity of the environment. Extensive shrimp culture requires an intertidal location (for water supply) which is often associated with clearcutting of wide mangrove stands.

On the other hand, intensive systems located inland spare mangroves but jeopardize water supplies and agricultural land because of saltwater contamination. Various manuals have described proper pond operations including management of cultured stock, water and food. The processing and disposal of effluents and sediments attain greater importance as intensive culture farms increase. Aside from proper pond siting and design, methods to mitigate the impacts on receiving waters include zero or reduced water exchange in combination with sedimentation and treatment ponds, pond liners, probiotics, and sludge collection and storage (Primavera, 1998). Alternatively, mangroves can be used to treat shrimp pond effluents with high levels of solids, organic matter and nutrients (Dierberg and Kiattisimkul, 1996).

Calculations show that 2.4-7 ha and 3-22 ha of mangroves, respectively, can filter the nitrogen and phosphorus wastes from a one-ha intensive shrimp pond (Robertson and Phillips, 1995), whereas 0.04 to 0.12 ha of mangroves can absorb the dissolved inorganic nitrogen load produced by a one-ha semi-intensive shrimp pond in Mexico (Rivera-Monroy *et al.*, 1999). Waste processing is only one of the many ecological services required by shrimp farms, including food inputs, postlarval nurseries and water supply. The "ecological footprint" or ecosystem area that provides these goods and services to a one-ha semi-intensive shrimp farm in Colombia has been calculated as 35-190 times the surface area of the farm (Kautsky *et al.*, 1994).

B. *ICZM and mangrove management*

Integrated coastal zone management coordinates the interests of various stakeholders, e.g., fisheries, aquaculture, forestry, settlements and navigation to ensure the optimal use of resources, maintenance of biodiversity, and conservation of critical habitats. The expansion of brackishwater pond culture in Southeast Asia for milkfish and shrimp has been a sectoral rather than holistic exploitation of the coastal zone. This shortsighted approach to aquaculture development has caused serious socioeconomic impacts such as loss of mangrove goods and services, food insecurity, and marginalization of coastal communities (Primavera, 1997), aside from the ecological consequences earlier discussed.

Based on their ecological and economic functions, mangroves can be designated into four zones: a) preservation-conservation (for coastal protection, biodiversity, ecotourism), b) sustained yield (of forestry and fisheries products), c) conversion to aquaculture, agriculture, salt beds and other uses, and d) reforestation. Ecologists have recommended that no more than 20% of a given mangrove area be converted (Saenger *et al.*, 1983) to ponds and other uses. Consistent with the ecological footprint concept where ponds can exist side by side with mangrove areas, such recommendation can be applied to Malaysia and other countries whose swamps remain luxuriant. In the Philippines where all but a few (notably in Palawan) mangrove forests have been converted mostly to aquaculture, the solution lies in replanting of degraded areas and reverting abandoned or underutilized ponds to mangroves. This whole-scale destruction of mangroves??, especially in north and central Philippines, could be one reason local shrimp farms have not recovered from devastating luminous vibriosis; only newly-opened culture areas in the south remain productive.

Practically all countries in Southeast Asia require a coastal greenbelt whose width ranges from 20 m for Philippine riverbanks to 540 m in Indonesia (Table 3), although enforcement is inadequate (Primavera, 1995). Forming part of the preservation-conservation zone, such mangrove greenbelts and buffer zones should be retained or planted not only along shorelines and riverbanks but also between adjacent uses, e.g., shrimp pond and rice field.

Not all aquaculture requires clearcutting of mangroves. Examples of mangrove-friendly aquaculture exist either in waterways (seaweeds like *Gracilaria*; bivalves like mussel, oyster and cockles; and cages for crab and fish) or land-based (ponds and pens for crabs, shrimps and fish). These technologies, particularly integrated mangrove ponds and pens (also called aquasilviculture or silvofisheries) optimize the utilization of mangroves for both forestry and aquaculture production (Primavera *et al.*, 1999) and can be promoted in areas where mangroves are being conserved or replanted.

C. *Policy options*

The conversion of mangroves to milkfish and shrimp ponds was premised on the early belief that mangroves and other wetlands are wastelands. This is reflected in the low fishpond lease fees charged in the region; for example the $2/ha/yr charged for Philippine ponds hardly captures the economic rent of $20-127/ha/yr when these ponds culture shrimp and/or milkfish (Evangelista, 1992). The 1950s fishpond boom followed by the 1980s shrimp fever and the attendant mangrove loss in Southeast Asia have been fueled by loans from the International Bank for Reconstruction and Development, the Asian Development Bank, the FAO-United Nations Development Programme and other multilateral development agencies.

The World Bank (1989) has recommended the imposition of fees for the use of mangroves and other natural resources to levels commensurate to economic rent. Governments can impose green taxes based on the Polluter Pays principle to mitigate the environmental and socioeconomic damages from brackishwater aquaculture (e.g., correcting water quality problems and rehabilitating mangroves and other damaged landscapes), revoke early policies and withdraw subsidies used to stimulate aquaculture expansion (e.g., declaration of coastal land as public resources, loans and tax breaks for aquaculture), and require environmental planning and performance as preconditions to the approval of pond culture loans. credits and access to resources.

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Table 1. Products of mangrove ecosystem (Saenger *et. al.*, 1983)

A. Mangrove forest products

Fuel	Firewood (cooking, heating)	Charcoal, Alcohol
Construction	Timber, scaffolds Heavy construction (e.g., bridges) Railroad ties Mining pit props Boat building Dock pilings	Beams and poles for buildings Flooring, paneling Thatch or matting Fence posts, water pipes. chipboards, glues
Fishing	Poles for fish traps Fishing floats Wood for smoking fish	Fish poison Tannins for net and line preservation Fish attracting shelters
Textiles, leather	Synthetic fibers (e.g., rayon) Dye for cloth	Tannins for leather preservation
Food, drugs and beverages	Sugar Alcohol Cooking oil Vinegar Tea substitute Fermented drinks	Dessert topping Condiments from bark Sweetmeats from propagules Vegetables from propagules, fruit or leaves Cigar substitute
Household items	Furniture Glue Hairdressing oil Tool handles	Rice mortar Toys Matchsticks Incense
Agriculture	Fodder, green manure	
Paper products	Paper of various kinds	
Other products	Packing boxes Wood for smoking sheet rubber	Wood for burning bricks Medicines from bark, leaves and fruits

B. Other natural products

Fish	Birds	Crustaceans
Shellfish	Honey	Reptiles and reptile skin
Wax	Mammals	Other fauna (amphibians, insects)

Table 2. Mangrove areas converted to shrimp farms in Asia and Latin America (Primavera, 1998)

Location	**Period covered**	**Area converted (ha)**	**Reference**
Thailand	1961-1993	65,200	Menasveta, 1997
Ho Ko Nok, Chanthaburi, Thailand	1975-1991	1,428	Raine, 1994
Vietnam	1983-1987	102,000	Tuan, 1997
Mekong Delta, Vietnam	1985-1988	60,000	Trong, 1995
Chokoria Sunderbans, Bangladesh	1967-1988	6,527	Choudhury *et al.*, 1994
Puttlam District Sri Lanka	1983-1994	1,650	Liyanage, 1995
Ecuador 1992	1979-1985	33,000-75,000	Skladany & Harris,
Honduras	1973-1992	4,307	DeWalt *et al.*, 1996

Table 3. Economic values placed on products and services of mangrove systems (after Primavera, 1997).

Country	Year	Product or service	Value (US$/ha/yr)	Reference
Puerto Rico	1973	Complete mangrove ecosystem	1,550	Hamilton & Snedaker, 1984
Trinidad	1974	Complete mangrove system	600	Hamilton & Snedaker, 1984
		Fishery products	125	
		Forestry products	70	
Fiji	1976	Complete mangrove system	950-1,250	Hamilton & Snedaker, 1984
		Fishery products	640	
Indonesia	1978	Fishery products	50	Hamilton & Snedaker, 1984
	1978	Forestry (charcoal, woodchips)	10-20	Hamilton & Snedaker, 1984
Thailand	n.d.	Charcoal production	4,000	McNeely & Dobias, 1991
	1982	Fish and shrimp	30-2,000	Hamilton & Snedaker, 1984
		Forestry products	30-400	
Brazil	1981-82	Fish (based on extent of open water)	769	Kapetsky, 1987
Malaysia	1979	Shrimp and fish (inc. estuaries & lagoons)	2,772	Gedney *et al.*, 1982
	n.d.	Fishery products	750	Ong, 1982
		Forestry products	225	
	n.d.	Managed forest (sustained harvest)	11,561	Salleh & Chan, 1986
India	1985	Complete system (inc. fishery products, maintenance of fauna, air/water purification)	11,314	Untawale, 1986
Thailand	1996	Local uses, offshore fisheries, coastline protection	3,207-4,116	Sathirathai, 1997

[a] NPV

Table 4. Width of greenbelt/buffer zone required in Southeast Asia.

Indonesia (Soemodihardjo *et al.*, 1993)

- 200-540 (1,100) m
  width = 130 x mean spring tide

Malaysia (Chan *et al.*, 1993)

- Natmancom: 100 m pond to MHWL
- CRMP: 100 m aquaculture/tourism
  500 m housing
  1,000 m industries
- WWF-AWB (for pond sites):
  50 m riverbank
  100 m MHWL in non-mangroves, ex-mangroves
  200 m coastline with accreting shorelines, state mangroves
  400 m coastline with stable, eroding shorelines, state mangroves

Philippines (Primavera, 1995)

- 20 m strip along creeks, rivers (fishponds)
- 50 m strip fronting seas, oceans (fishponds)
- 20-50 m along riverbanks (typhoon areas)
- 50-100 m along shorelines (typhoon areas)

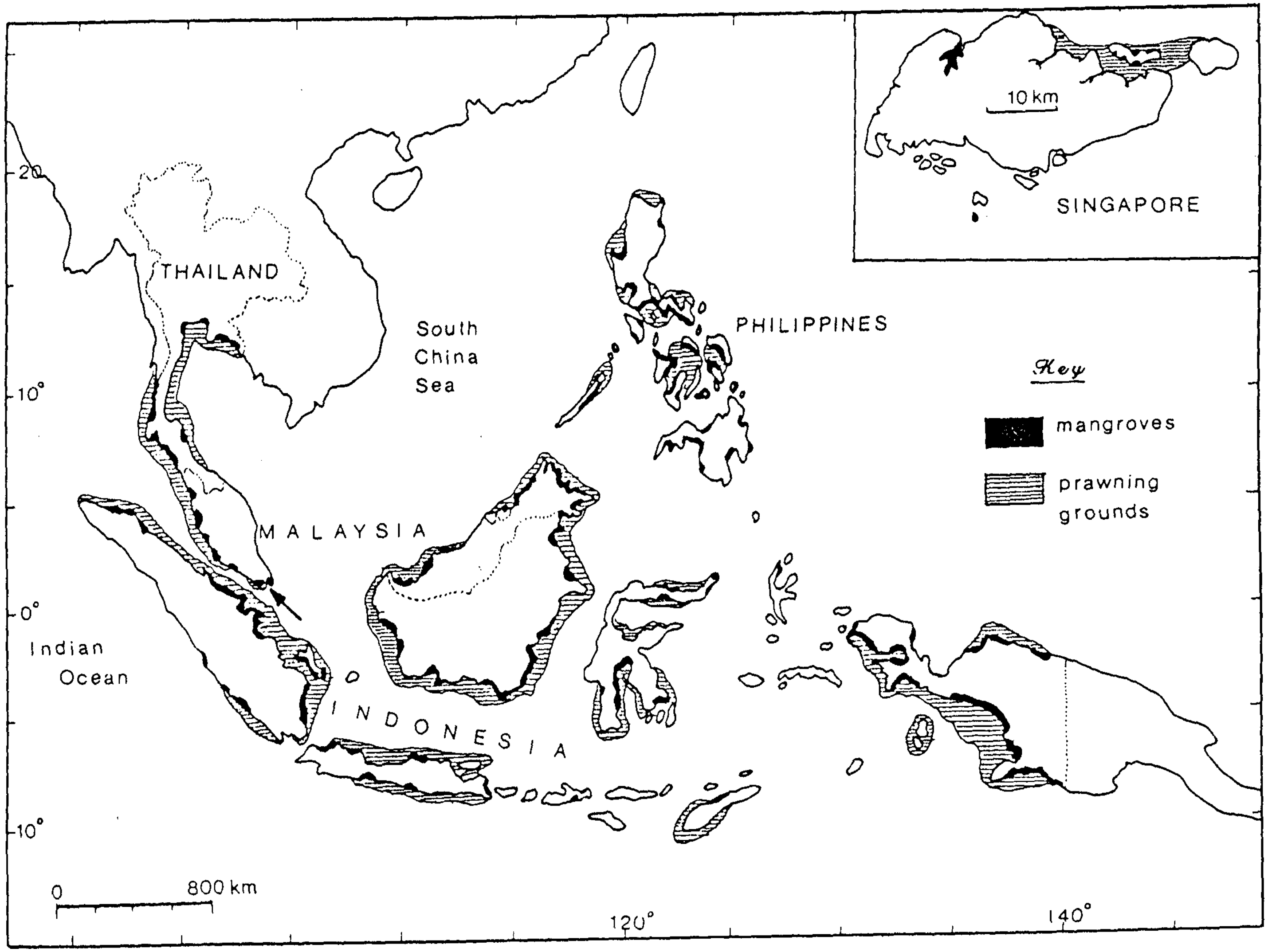

Fig. 1. Major mangrove areas and prawn fishing grounds in Southeast Asia (Chong et al., 1994).

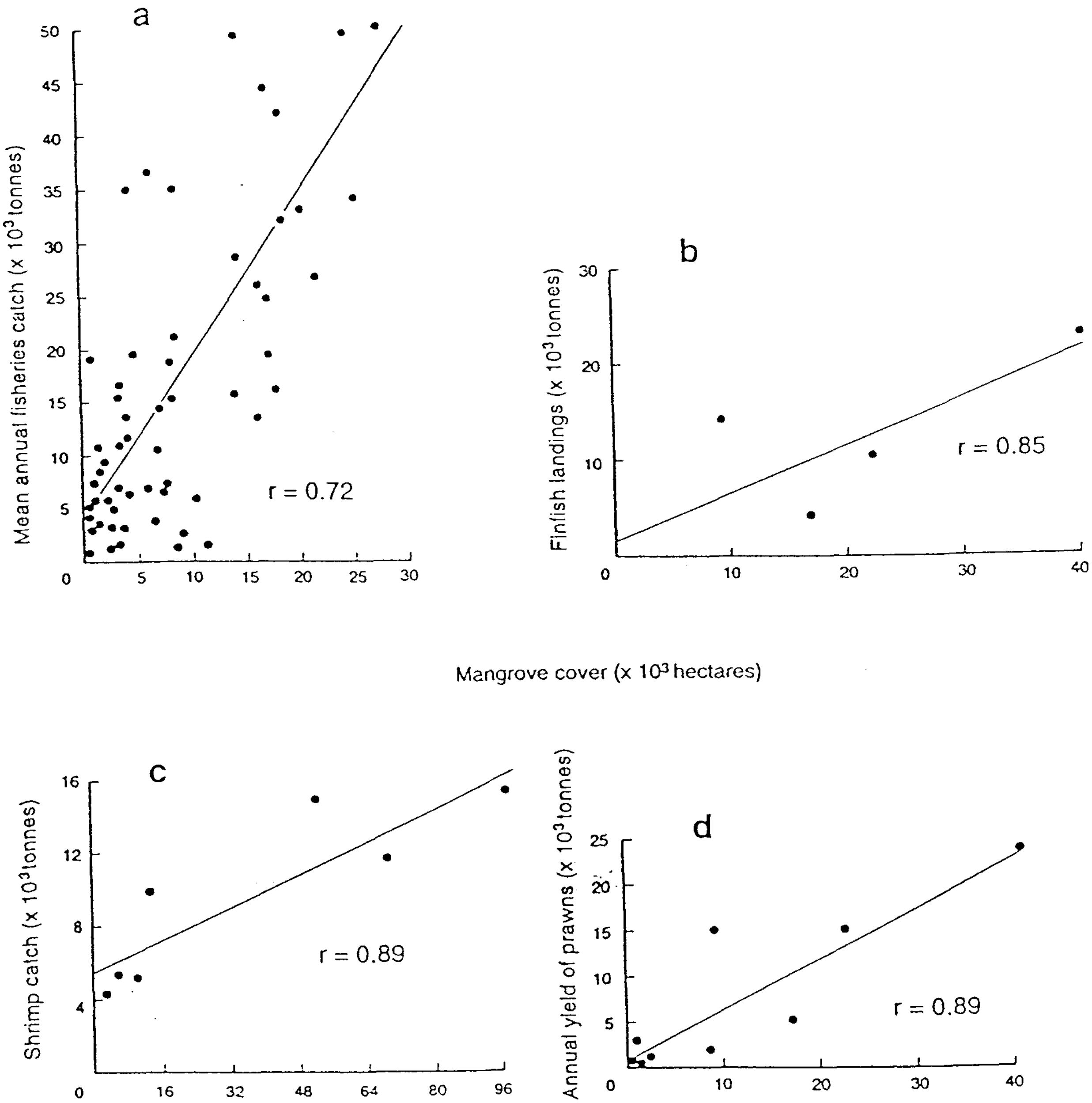

Fig. 2 . The relationship between fisheries landings and mangrove areal cover in the ASEAN region.

a) Philippines. Annual fisheries catch by province (Camacho & Bagarinao 1987)
b) Malaysia. Mangrove-dependent finfish landings on the west coast of Peninsular Malaysia (State Fisheries Statistics 1990)
c) Indonesia. Shrimp landings (Martosubroto & Naamin 1977)
d) Malaysia. Annual yield of prawns (Sasekumar & Chong 1987)

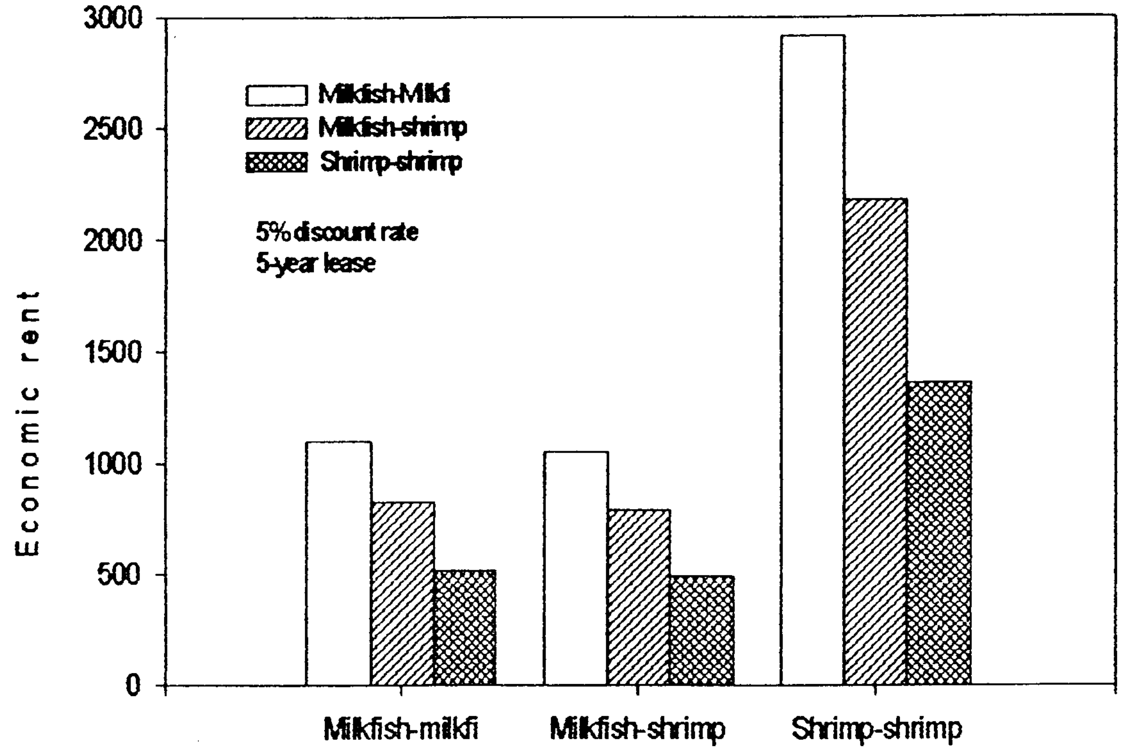

Fig. 3. Economic rent (Php. peso/ha/year) of mangrove areas in Quezon, Philippines (Evangelista, 1992)