Hydrobiologia **285**: 303–309, 1994.
A. Sasekumar, N. Marshall & D. J. Macintosh (eds), Ecology and Conservation of Southeast Asian Marine and Freshwater Environments including Wetlands.

Mangrove conservation in relation to overall environmental considerations

Nelson Marshall
Professor Emiritus of Oceanography and Marine Affairs, University of Rhode Island; Adjunct Professor Horn Point Environmental Laboratory, University of Maryland, Cambridge, MD 21613, USA; Postal address: P.O. Box 1056, St. Michaels, MD 21663, USA

Key words: alternate uses and environmental subsidies

Abstract

The role of mangroves, as nursery and feeding areas, in the enrichment of coastal waters, in the stabilization of the shoreline, and in trapping silt and wastes from upland runoff, is repeatedly being threatened by suggestions for reclamation, whether for aquaculture, agriculture, or development projects. Proposals for such alternatives should only be judged after taking into account the environmental subsidies involved, and possible losses in energy transformation steps. Assurance is needed that renewable resources and other environmental capital will not be sacrificed.

My approach in this presentation is to consider alternative uses of mangrove areas as I judge these from my travels about Malaysia and to a lesser extent in Indonesia, Thailand and the Philippines. These alternatives are:

1. leaving the habitats in their natural state so as not to detract from their potential in the enrichment of coastal waters, from their role in the stabilization of the shoreline and river banks, from their effect in counteracting the stress of inland runoff, and from their role as nursery and feeding areas,
2. managing mangrove forests to optimize the potential yields of forest products while effectively sustaining the values realized when mangroves are retained in their natural state,
3. altering or reclaiming substantial areas of the mangrove swamps for aquaculture,
4. similarly reclaiming mangrove areas for agriculture or grazing,
5. reclaiming mangrove areas for non-living resource use, for example for ports, urban settings and even tourist accommodations.

From the conservation advocate's point of view the first alternative is generally considered ideal. The second may be even better. There are various pros and cons, *and unknowns*, relative to converting mangroves to aquaculture ponds and cropland. Reclamation for non-living resources has been relatively localized yet sometimes constitutes a serious loss.

As to the role of mangroves in contributing to coastal productivity, the most convincing information involves the correlations between mangrove area and fisheries harvests. Jothy (1984) reports on the harvest of molluscs, crustacea and fish indicating that, with the area of mangroves along the west coast of the Malaysian peninsula being about five times that of the east coast, the overall fisheries of the former are about twice those of the latter. This differential is a bit less for species not associated with mangroves. Limiting the comparisons to shrimp (prawns) Sasekumar & Chong (1987), in state by state summaries for Peninsular Malaysia, show that, where the mangroves are most extensive the yields of shrimp are highest (Table 1). The general association of

Table 1. Area of mangrove forests and the yields of shrimps listed by states in Peninsular Malaysia

State	Mangrove area in hectares	Yield of shrimp (mean of 4 years 1980 to 1983) in tonnes (source, Fisheries Statistics 1980–1983)	Yields kg shrimp ha^{-1} yr^{-1}
Kedah, Perlis & Pulau Pinang	9,443	14,845	1572.1*
Perak	40,497	23,596	582.7
Selangor	22,522	15,284	678.6
Negeri Sembilan	1,355	58	42.8
Melaka	77	228	2961.0**
West Johore	17,164	5,283	307.8
East Johore	8,454	1,690	199.9
Kelantan	22	471	21409.1**
Terengganu	976	2,735	2820.7**
Pahang	2,573	746	289.9

Data from Sasekumar and Chong (1987).
Yield per hectare calculations by N. Marshall.
* The harvest included catches from distant locales not included in the area column.
** Mangroves are very limited; contribution to yields probably outweighed by other factors.

mangrove area and shrimp yields is also discussed on a trans-tropical basis by Turner (1977) and by Martosubroto & Naamin (1977) who report on 14 provinces in Indonesia.

In assuming that the association between mangrove area and coastal fisheries yields involves some cause and effect relationship, it is useful to consider what is known of the nursery/feeding role of the mangrove environment and the extent to which outwelling of nutrients from the mangrove might be important. Anyone who has explored the mangrove and adjacent mudflats can attest to the abundance of juvenile shrimps and fishes. Chong *et al.* (1990) have quantified this for mangrove and mudflat sites along the coast of Selangor in Malaysia (Table 2). They point out that, while these grounds are the nursery for certain species of shrimp, they serve more as feeding than as nursery areas for many of the wide-ranging species of fishes that frequent them. While their data do not indicate annual production, the large biomass reported clearly suggests a very large contribution to coastal harvests, particularly when growth (minus mortality of course) is taken into account. In reports on estuarine populations in mangroves of northern Australia, Blaber *et al.* (1983) and Morton (1990) do not offer data for shrimp but, for fishes, their biomass data are even larger than those reported for Selangor.

In contrast to the nursery/feeding area role of mangroves, their role in the nutrient enrichment of nearby coastal waters is not consistent. As Twilley (1985) states: 'Problems associated with the measurements of these tidal fluxes have resulted in a controversy surrounding the hypothesis that intertidal wetlands affect the productivity and nutrient cycles of estuarine waters'. An extensive literature indicates the large quantities of litter produced by mangrove forests. As Twilley's (1988) summarization indicates, for fringe and riverine mangroves, *i.e.* those strips next to the coastline or adjacent to waterways, much of this litter is directly exported to the coastal waters by the sweep of the tides. As to basin mangroves, appreciably behind the fringe, some of the litter is

Table 2. Biomass and density of the major species groups as sampled in four habitats on the Selangor coast of Peninsular Malaysia.

Habitat	Biomass/in kg ha^{-1}			
	Fish	Prawn	Others	Total
Creeks/inlets	17.7	3.18	0.52	21.4
Mud flats	5.96	0.77	1.79	8.52
Near inshore	6.06	0.23	1.32	7.61
Far inshore	3.74	1.14	1.79	6.67

Data from Chong *et al.* (1990).

incorporated in the mangrove floor, yet in almost every case studied there is an excess of litter and very fine particles that is flushed out. And there are impressive examples of dissolved organic carbon being exported.

The pattern is not that simple with respect to dissolved inorganic nutrients. For example Boto & Wellington (1988), in reporting on a mangrove system in northern Australia, where they observed substantial export of plant litter, found that over the year there was little net transport of nitrate and nitrite to or from the system while reactive phosphate was imported. Further, in the area they studied, there was not even a net export of dissolved organic carbon. They suggest that nitrogen and phosphorus are conserved within the mangrove system. This is also suggested by the mixing diagram observation of Nixon *et al.* (1984) indicating no increase in dissolved N and P off the mangroves of the Matang Forest in western Malaysia (Fig. 1).

Another insight is gained from the sampling of the various forms of dissolved nitrogen done by Thong *et al.*(ms. in prep.) on the Sementa Besar, a mangrove creek near Klang in western Malaysia. The values were high in the rivulets running off the floor of the mangrove, and either high amplitude tides or heavy rainfall augmenting the drainage from the soils of the mangroves greatly increased inorganic nutrient levels in the creek. Even so, for two 24 h tidal cycle observations, plus sampling of less duration, there was no evidence of net export from the mouth. There had not been any appreciable rainfall to augment flushing from the creek coincident with this sampling, otherwise the results might have been different.

In essence there is no question that, in macrolitter and in fine particles, carbon and the nutrients contained are exported from mangroves, more from the fringe areas than from those behind. This probably enhances coastal productivity though, by the time the detritus reaches the coastal waters, some of it may be highly refractory. This was suggested by Rodelli *et al.* (1984) who, using stable carbon isotope analyses, found that offshore shrimp did not assimilate the mangrove detritus as found in their guts. Such a refractory state was also suggested by Alongi (1990) from chemical analyses of mangrove detritus in coastal sediments.

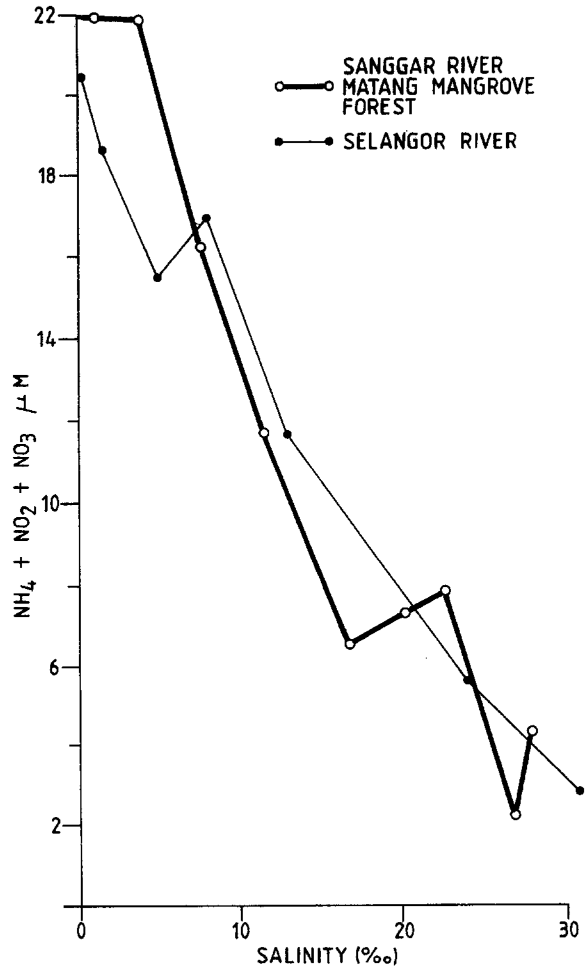

Fig. 1. Mixing diagram of Nixon *et al.* (1984) showing no increase in NH_4, NO_2, NO_3 along a salinity gradient in the Matang Mangrove Forest Reserve.

On the other hand it is not clear that dissolved inorganic nutrients are exported, perhaps under some conditions 'yes'; under others 'no'. Twilley (1988) emphasizes that nutrient enrichment from the mangrove to the coastal waters tends to be site specific, depending on the hydrology and geomorphology of the setting.

As this information is considered collectively, one point seems obvious, namely the outward migration of the fisheries species that use the mangrove environment as nursery and feeding areas is far more important than outwelling in augmenting production realized in coastal waters.

Second on the list of alternative practices are the mangrove areas suitably managed for a sustained yield of forest products. For these there is relatively little to add, especially since the Matang Forest, an excellent example discussed by Ong (1982), contributes to the large fishery off Perak. If anything, the turnover in forest growth probably constitutes an improved utilization of the sun's energy and, what's more, a crop is realized for poles and for charcoal. Obviously, where harvesting is carried out without a systematic means to replenish the tress, as may occur in the wood chip industry in Sabah, this can amount to a substantial loss.

As a first step in considering the alternative of converting mangrove area to aquaculture it is useful to ask what might be lost in terms of harvests along adjacent coasts. Toward this end it is useful to discuss in more detail two papers with information relating to pond culture in Indonesia. Martosubroto & Naamin (1977) compared shrimp harvests with mangrove area for 14 provinces of Indonesia (Table 3). Looking at the variability in the shrimp per hectare ratios and asking which yields represent the full fisheries potential, I am prone to rule out all but five, assuming that harvests far less than 100 kg ha^{-1} y^{-1} represent either undeveloped fisheries or provinces where the loss of mangroves has already adversely affected the yields.

This reasoning is supported by the analysis of

Table 3. Area of mangrove forests and the yields of shrimp in 14 provinces of Indonesia.

Area/Province	Mangrove area in hectares	Annual yield of shrimp in tonnes*	Yields kg shrimp ha^{-1} yr^{-1}
Sumatra			
Aceh	129,375	1,643	34.1
North Sumatra (eastern part)	81,250	7,929	97.6**
Riau	348,750	11,875	34.0
Jambi	67,500	1,138	16.8
South Sumatra	102,500	710	6.9
Lampung	6,875	1,159	168.6**
Java			
North & east	58,700	5,214	88.8**
South coast	26,250	4,308	164.1**
Kalimantan			
West & central	181,250	7,457	41.1
South	68,125	1,805	26.5
East	447,500	2,675	6.0
Sulawesi			
North	37,500	398	10.7
South	58,750	4,845	82.5**
Maluku			
Aru	70,625	4,642	65.7
Irian Jaya			
Irian Jaya	898,125	10,765	12.0

* Martosubroto & Naamin (1977) refer to various national and provincial fisheries statistics sources.

** Interpreted by N. Marshall as approximating the yields expected from a fully developed fishery – see text.

Turner (1977) who only used data from stabilized and developed fisheries to derive, on a trans-tropical basis, the formula;

$$j = 158.7e^{-0.070(x)},$$

where y is kg schrimps/hectare/year and x is degrees of latitude between 0° and 35° and I suggest that, for simplification, the exponent be ignored inasmuch as the Indonesian sites are near the equator. Turner's specific entries for Indonesia, contributing to this derivation, were 83.2 and 86.8 kg ha^{-1} for South Java and Sumatra respectively. Since these are less than the formula would indicate, it seems possible that they represent harvests already adversely affected by the depletion of mangroves. These comments and Turner's equation seem to suggest that the two high figures of Martosubroto and Naamin, approximating 160 kg ha^{-1}, come closer to representing the potential coastal shrimp harvests in Indonesia. While this is high, one may wonder why the kg ha^{-1} ratios for Selangor and Perak in Malaysia (Table 1) are almost four times as great. This might be accounted for by realizing that, in placing all the emphasis on the mangrove relationship, other contributing factors are being overlooked. Such an oversight is suggested in Table 1 wherein several states, having modest mangrove areas and small yields of shrimp, nevertheless have a high kg ha^{-1} ratio.

For a comparison with aquaculture Turner (1977) points out that the yield from fish ponds in Indonesia, about 287 kg ha^{-1}, is about 480 kg less than the calculations he presents for the combined harvests of fish and shrimp in coastal waters that are enriched by the mangroves. Though in this paper Turner doesn't establish that the coastal yields are actually less where pond culture is practiced extensively, Turner & Boesch (1987) cite several cases where it is demonstrated that reclaimed wetlands have resulted in declining shrimp yields.

This brings us to the growing interest in pond culture for shrimp, as contrasted with fish, and the extensive use of subsidies in such culture. An evaluation of how this works out in Ecuador, where practiced very widely and seemingly very profitably, is provided by H. T. Odum & Arding (1991). These authors point out that, when adequately analyzed, such culture is not in the best interests of the country's economic and ecological well-being. They put considerable emphasis on the subsidies necessary for success in such advanced aquaculture including the obvious, *i.e.*, fertilizers, food, labor, etc., and the not-so-obvious, particularly a wide range of environmental inputs such as tapping natural sources for shrimp stock and nutrients and depleting the environmental capital of the mangrove ecosystem. They compare the energy required to realize production in ponds with the more efficient energy transformations of the coastal fisheries that must suffer from the depletion of mangroves and accompanying loss of natural habitat. As to the export trade, which is the major stimulus for shrimp mariculture, they calculate that the products are going overseas with much less real wealth returning. Odum & Arding refer to their comprehensive approach as an *em*ergy evaluation and, while for this purpose they are compelled to forge ahead with inadequate data in some respects, they direct attention to many factors commonly overlooked in simplified cost/benefit analyses.

Finally it must be noted that aquaculture in mangroves, though often successful in terms of immediate returns, can fail completely as the high organic and iron content in some mangrove soils, and the ever present sulfate from tidal seawater, results in acid sulfate conditions when oxidized through exposure in pond construction and operation (see for example, Ong, 1982). In some areas it has been possible to counteract this with the addition of lime and careful manipulation of flushing and water levels. Where this proves to be uneconomical, reclamation for pond culture has either been abandoned or, more wisely, never attempted.

As to the agriculture alternative, such use often seems especially wasteful. The mangrove soils, with their high iron, sulfide and salinity, are unfavorable to many crops (Law, 1984) and, unlike aquaculture, the coastal physiographic features are usually of little advantage. Since crops are primary producers, the yields per hectare are likely to be greater than in pond culture for shrimp or fish; however, as Turner & May (1977) show for rice, the lesser protein content offsets this advantage. An even further alternative, reclaiming mangrove areas to use for grazing, seems even more wasteful in view of the production inefficiency of the cattle, goats or sheep as the case may be.

Reclamation for either aquaculture or agriculture raises a very practical question; namely how much mangrove is needed to provide for the full carrying capacity and yield potential of the adjacent offshore waters. Just as the data available suggest that 'the more mangrove area the greater the yields', they might be interpreted as suggesting 'the less mangrove area the lower the yields'. One might suggest, for example, that were it not for reclamation activities which have sacrificed about 30% of the mangroves along the Selangor coast, both the forested area and the total yields would be closer to those of Perak; however, the information needed, in terms of reliable catch records of the past, a knowledge of the comparative fishable areas, the carrying capacities, and the effects of fisheries management practices, are insufficient to extend this beyond mere speculation. But it seems doubtful that the mangrove/yield relationship is limitless. There may be some level at which the extent of the coastal mangroves is in excess, that is additional mangrove area will not increase the yield of the adjacent fishery.

The foregoing considerations lead us to dealing with situations wherein we reclaim mangrove tracts in favor of port development, housing and even tourist facilities. The development of Klang and Port Klang on the west coast of Malaysia amounts to a substantial sacrifice of mangrove area; yet it may be that, with the vast expanse of mangroves seaward of Klang, the loss has not greatly diminished the nearby coastal productivity. I hasten to add that this example may lead to undue complacency. I would not as casually dismiss, for example, the mangrove loss in Singapore, where almost the entire coastline has been converted to urban and associated development, and along the east coast of Malaysia, where there is so little mangrove yet some has been sacrificed for harbors.

It is noteworthy that the pressure to convert mangrove to pond culture or to cropland is greatest where the population is most dense, for example along the north coast of Java or in the strip between Klang and Selangor in Malaysia. If the sacrifice of mangroves is a net loss when all considerations are weighed, this may be looked upon as a serious example of the adverse impact of population pressure. This takes a toll not only on the fisheries potential but also on the overall viability of the environment, with more industrial and domestic pollution, more CO_2 and acidity in the atmosphere, less wooded area, etc. As E. P. Odum (1983) points out, '... the urbanized or fabricated environment is 'parasitic' on the life-support environment (natural and domesticated) for basic biological necessities. ... Much more can be done to ... reduce the stress of high energy and densely populated 'hot spots'. In applying this concept to coastal management, my view is that mangroves are obviously natural life-support environments. Aquaculture ponds and agriculture generally are not equally supportive.

Since there is considerable variation in the settings and circumstances in which alternate uses are or may be practiced and since a number of unknowns and assumptions are involved when comparisons are made, it is impossible to offer simple answers to the management questions that arise. Inasmuch as the mudflats, inlets, creeks and fringe habitats associated with mangroves are obviously so valuable as nursery areas for shrimp and feeding areas for fish, the extent to which any alternative detracts from this role amounts to a serious loss in coastal fisheries. Less clear is the possible loss in coastal productivity from a possible decrease in nutrient exports where mangroves are sacrificed. Where alternatives seriously undermine auxiliary functions of the mangroves, such as stabilization of the shoreline and river banks, moderating inland runoff and even absorbing pollutants, destroying wildlife habitat, and decreasing biodiversity, they constitute a serious loss. The composite of such effects, not elaborated upon directly in this discussion, contributes to what E. P. Odum (1983) refers to as the natural life-support environment, too readily sacrificed due to development and population pressures.

Finally, in management planning and decision making, it is important to weigh all factors. Environmental subsidies and the relative efficiencies in energy utilization must be thoroughly considered. And there must be assurances that renewable resources and other environmental capital, as needed for the future, will not be sacrificed. Policy makers should be encouraged to recognize costs and subsidies that they may tend to overlook.

I gather that the objective of this symposium is to sharpen our approach to marine environmental problems and I hope my discussion has contributed to that end. I also hope that it is apparent that the focus on alternate uses of mangroves is representative of the considerations to be faced in coping with coastal freshwater and wetlands management in general.

References

Alongi, D. M., 1990. Effect of mangrove detrital outwelling on nutrient regeneration and oxygen fluxes in coastal sediments of the Central Great Barrier Reef Lagoon. Estuar. coast. Shelf Sci. 31: 581–598.

Blaber, S. J. M., D. T. Brewer & J. P. Salini, 1989. Species composition and biomass of fishes in different habitats of a tropical northern Australian estuary: their occurrence in the adjoining sea and estuarine dependence. Estuar. coast. Shelf Sci. 29: 509–531.

Boto, K. G. & J. T. Wellington, 1988. Seasonal variations in concentrations and fluxes of dissolved organic and inorganic materials in a tropical, tidally-dominated, mangrove waterway. Mar. Ecol. Prog. Ser. 50: 151–160.

Chong, V. C., A. Sasekumar, M. U. C. Leh & R. D'cruz, 1990. The fish and prawn communities of a Malaysian coastal mangrove system, with comparisons to adjacent mudflats and inshore waters. Estuar. coast. Shelf Sci. 31: 703–722.

Jothy, A. A., 1984. Capture fisheries and the mangrove ecosystem. In J. E. Ong & W. K. Gong (eds), Productivity of the Mangrove Ecosystem. Proc. Workshop on Productivity of the Mangrove Ecosystem: Management Implications. University Sains Malaysia, Penang: 129–141.

Law, W. M., 1984. Productivity of the mangrove ecosystems: management implications for agricultural crops. In J. E. Ong & W. K. Gong (eds), Productivity of the Mangrove Ecosystem. Proc. Workshop on Productivity of the Mangrove Ecosystem: Management Implications. University Sains Malaysia, Penang: 121–128.

Martosubroto, P. & N. Naamin. 1977. Relationship between tidal forests (mangroves) and commercial shrimp production in Indonesia. Marine Res. in Indonesia 18: 81–86.

Morton, R. M., 1990. Community structure, density and standing crop of fishes in a subtropical Australian mangrove area. Mar. Biol. 105: 385–394.

Nixon, S. W., B. N. Furnas, V. Lee, N. Marshall, J. E. Ong, C. H. Wong, W. K. Gong & A. Sasekumar, 1984. The role of mangroves in the carbon and nutrient dynamics of Malaysia estuaries. In E. Soepadmo, A. N. Rao & D. J. Macintosh (eds). Proc. Asian Symp. on the Mangrove Environment – Research and Management. University of Malaya, Kuala Lumpur: 534–544.

Odum, E. P., 1983. Basic Ecology. Saunders College Publishing, Philadelphia.

Odum, H. T. & J. E. Arding, 1991. Emergy analysis of shrimp mariculture in Ecuador. Prepared for the Coastal Resources Center, Univ. of Rhode Island, 114 pp.

Ong, J. E., 1982. Mangroves and aquaculture. Ambio. 11: 252–257.

Rodelli, M. R., J. N. Gearing, P. J. Gearing, N. Marshall & A. Sasekumar, 1984. Stable isotope ratio as a tracer of mangrove carbon in Malaysian ecosystems. Oecologia 61: 326–333.

Sasekumar, A. & V. C. Chong, 1987. Mangroves and prawns: further perspectives. In A. Sasekumar, S. M. Phang & E. L. Chong (eds). Proc. 10th Annual Seminar Malaysian Society of Marine Sciences, University of Malaya, Kuala Lumpur: 10–22.

Thong, K.. L., A. Sasekumar & N. Marshall, 1992. Nitrogen concentrations in a mangrove creek with a large tidal range, Peninsular Malaysia. Hydrobiologia (in press).

Turner, R. E., 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. am. Fish. Soc. 106: 411–416.

Turner, R. E. & D. F. Boesch, 1987. Aquatic animal production and wetland relationships: insights gleaned following wetland loss or gain. In B. Hook (ed.), Ecology and Management of Wetlands: 25–39.

Turner, R. E. & N. May, 1977. An alternative evaluation of the fisheries value of tropical and subtropical wetlands. Proc. Fourth Internatl. Symp. on Tropical Ecol. 3: 836–852.

Twilley, R. R., 1985. The exchange of organic carbon in basin mangrove forests in a Southwest Florida estuary. Estuar. coast Shelf Sci. 20: 543–557.

Twilley, R. R., 1988. Coupling of mangroves to the productivity of estuarine and coastal waters. In B. O. Jansson (ed.), Coastal-offshore Ecosystem Interactions. Lecture Notes on Coastal and Estuarine Studies 22. Springer-Verlag, Berlin: 155–180.