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THE MANAGEMENT OF TRADITIONAL TIDAL PONDS FOR AQUACULTURE AND WILDLIFE CONSERVATION IN SOUTHEAST ASIA: PROBLEMS AND PROSPECTS

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Abstract

Despite the long history of tidal aquaculture ponds in Southeast Asia, they still undergo a largely traditional management with little fertilization, intensification or technology input. The recent appreciation of the conservation values of mangrove ecosystems calls for management protocols that can combine traditional exploitational use with wildlife conservation objectives. A case study on a Hong Kong tidal pond is described in which conflicts may arise when the same pond is managed simultaneously for aquaculture production and wildlife conservation. Sedimentation rate increases as a result of controlled water exchange in tidal ponds, leading to build-up in substrate level and changes in the type and amount of vegetation cover. Tidal ponds also support a different, and generally less diverse, fauna from the non-impounded areas, probably a result of the larger fluctuation in physical conditions. Water level management for shrimp and fish culture also conflicts with waterfowl use of the ponds. Wetland reduction, due to tidal aquaculture, reduces nursery areas for fish and crustaceans and makes serious inroads into mangrove swamps, which are a declining world resource.

INTRODUCTION

Tidal ponds excavated from mangrove areas are a historic and yet still flourishing landscape feature throughout Southeast Asia and in parts of South America (Macintosh, 1983; Knox & Miyabara, 1984; Nor, 1984; Terchunian *et al.*, 1986; Unesco/UNDP, 1987). The Indonesian version, the *tambak*, has a history of over 400 years (Schuster, 1952) and covered about 225 200 ha in 1984 (Cholik & Poernomo, 1987). This area has been increasing constantly and the Indonesian government is planning further development (Knox & Miyabara, 1984; Naamin, 1987*a*; Choong *et al.*, 1990). The Philippines had 206 000 ha of brackish water ponds in 1986 (Bureau of Fisheries and Aquatic Resources, 1986). In Southeast Asia, tidal ponds have many local variations in operation and composition of the cultured species. For example, ponds in southern China are mainly used for shrimp cultivation (Macnae, 1962), in contrast to the preponderance of fish and shrimp polyculture or fish (mainly the milkfish *Chanos chanos*) culture in the tambaks (Polunin, 1983). Growth of brackish water paddy has also been practised in some areas (e.g. the *bheri* in Bangladesh (Mahmood, 1987) and, until recently, in *gei wais* in the Pearl River Estuary, China (Irving & Morton, 1988)) to make full use of the land at different seasons. Management of most tidal ponds is still largely practised in the traditional manner, i.e. with little technological input, fertilization, or intensification (Fast, 1991).

Apart from being an important source for fishery products, mangroves have traditionally been exploited by man for forestry, including timber products for construction, charcoal, and non-timber products such as tannins, dyes and medicines (Jara, 1987; Saenger,1987). More recent attention on the mangrove ecosystem has, however, focused on their conservation (e.g. Johannes & Hatcher, 1986; Fortes, 1988; Gomez, 1988; Hatcher *et al.*, 1989). Conflicting uses of the mangals and similar wetland ecosystems have created management and policy problems in many countries (Bally & Branch, 1986; Nelson, 1986; Platt, 1987; Tompkins, 1987; Ewel, 1990). With increasing understanding of the ecology of mangrove ecosystems, their importance in shoreline stabilisation and wildlife protection has been recognised (Johannes & Hatcher 1986; Hutchings & Saenger, 1987; Saenger, 1987). The impact of such a traditional landscape feature as the tidal pond, totalling about 1·3 million ha in the Indo-West-Pacific in the 1980s (Macintosh 1983), on the conservation of the coastal wetland system thus deserves special attention.

This study considers the problems of managing such tidal ponds for both aquaculture and conservation using data on the ecology of an enclosure in Hong Kong and published information on other Asian examples.

THE ECOLOGY AND MANAGEMENT OF A TRADITIONAL TIDAL SHRIMP POND IN HONG KONG

The study site

A detailed study of the production ecology and organic matter dynamics of a traditional tidal pond has been

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carried out in the Mai Po Marshes Nature Reserve in Hong Kong (Lee, 1988 1989*a,b*, 1990*a,b*, 1991). The marshes are a mangrove-dominated wetland in the Pearl River Estuary and have an area of about 300 ha. Of these, 200 ha comprise freshwater fish ponds and tidal shrimp ponds (*gei wais*) excavated from the native mangroves in the 1940s. The remaining 100 ha are relatively undisturbed tidal mangroves. Both the mudflat and the tidal pond mangrove communities are dominated by *Kandelia candel* (Rhizophoraceae), *Avicennia marina* (Avicenniaceae) and *Aegiceras corniculatum* (Myrsinaceae). The marshes are part of the larger Deep Bay ecosystem (112 km^2). A mudflat with maximum water depth <6 m at high tide is the most prominent component of this system. A total of over 250 bird species is recorded throughout the year from the Mai Po Marshes (Melville & Morton, 1983). This includes large populations of endangered species such as Saunders' gull *Larus saundersi*, Dalmatian pelican *Pelicanus crispus* and, in 1990, the oriental white stork *Ciconia boyciana* (Melville & Morton 1983; Melville, 1988). The marshes were declared a Nature Reserve by the Hong Kong Government in 1976 . Although traditional use, i.e. aquaculture, is still allowed, entry to the reserve is restricted.

The local tidal ponds are mainly used for the production of penaeid shrimps (*Metapenaeus ensis*, *Penaeus monodon*, *P. merguiensis* and *P. peniscillatus*). Fish production constitutes about 20-30% of the total annual economic return, the major species of economic importance being the yellow-finned bream *Sparus latus* (Sparidae), lady fish *Elops saurus* (Elopidae), striped mullet *Mugil cephalus* (Mugilidae) and *Therapon jarbua* (Theraponidae). Macintosh (1983) and Fast (1991) provide detailed descriptions of the general operation of tidal aquaculture ponds in Asia.

A study was started in 1985 on the ecology of one of the tidal ponds (9·1 ha) at the Mai Po Marshes. A diagram showing the location of the study pond and the reserve can be found in Lee (1989*a*). The pond is managed by World Wide Fund For Nature Hong Kong (WWFHK) in the traditional manner. The objectives of the study were (a) to investigate important factors influencing the production ecology of the tidal pond; and (b) how this may relate to the planning of future management strategies for the nature reserve. A model has been proposed to describe the pattern, stressing the importance of hydroperiod (draining and flooding regime) and water level management as regulators of organic matter flow (Fig. 1).

Management problems

The type and amount of vegetation cover

The Pearl River carries a high sediment load of $8{\cdot}6 \times 10^7$ t year^{-1} (Shen, 1983). As water exchange is only possible at particularly high tides, the ponds are flooded and drained for only about five days during each tidal cycle. This results in a high rate of sediment accretion, which was estimated in the study pond using sediment traps and found to be 1·7 cm year^{-1} (Lee, 1990*b*), equivalent to $8{\cdot}4 \pm 8{\cdot}8$ kg dry wt m^{-2} year^{-1}. This fast accretion rate strongly influences the floristics of the tidal pond.

Emergent macrophytes such as mangroves usually accelerate accretion (Turner, 1990). As the mangroves are progressively less frequently inundated, dispersal of viviparous (*K. candel*) and cryptoviviparous (*Avicennia* and *Aegiceras*) propagules is limited. The elevated mud surface also encourages the spread of otherwise less salt-tolerant species such as reed *Phragmites australis*, resulting in a change in the source of primary production and also the ratio of submerged to open areas (Lee, 1990*a*). Table 1 summarises the change in the amounts of vegetated and open areas in the tidal pond between dredging events, based on serial aerial photographs. The invasion by reed resulted in a loss of open area; its coverage increased from <25 to >40% between 1986 and 1988. Because of its high primary productivity (Lee 1990*a*), this probably raises the total primary productivity of the pond at the expense of the contribution from macroalgae (mainly *Enteromorpha* spp.). These represent more easily utilisable sources of organic carbon for detritivores (which are in turn preyed upon by birds) than the vascular plants.

Litter from the two dominant macrophyte producers *Kandelia candel* and *P. australis* decomposes at significantly different rates, and supports different macrobenthos assemblages (Lee, 1988, 1990*a,b*). These two macrophytes also have different degrees of spatial complexity. *K. candel* grows to about 7 m and has a more open understorey stratum whereas *P. australis* occurs typically as dense stands <3 m tall (shoot density >50 m^{-2}) of low spatial variation. As a result, the two plants also support different aerial consumer assemblages. Habitat quality therefore cannot be reflected merely by the maintenance of a high primary productivity.

Faunal composition

A total of 38 species of fish was recorded in the nature reserve for the period 1985–89, considerably lower than that recorded from open mangrove waters (e.g. Thong & Sasekumar, 1984; Pinto, 1987; Robertson & Duke, 1987; Thayer *et al.*, 1987). Of all the species present, highest densities were recorded from the tilapias *Oreochromis nilotica* and *O. mossambicus*. Due to their high reproductive rate and adaptability in the brackish

Table 1. Change in the amount of vegetation cover in the study pond with time (the last large-scale dredging took place in 1970)

Year	Vegetated area (ha)	% of total area
1975	0·855	9·4
1977	1·438	15·8
1979	2·129	23·4
1980	2·157	23·7
1982	2·202	24·2
1983	2·493	27·4
1986	3·531	38·8
1988	5·879	64·6

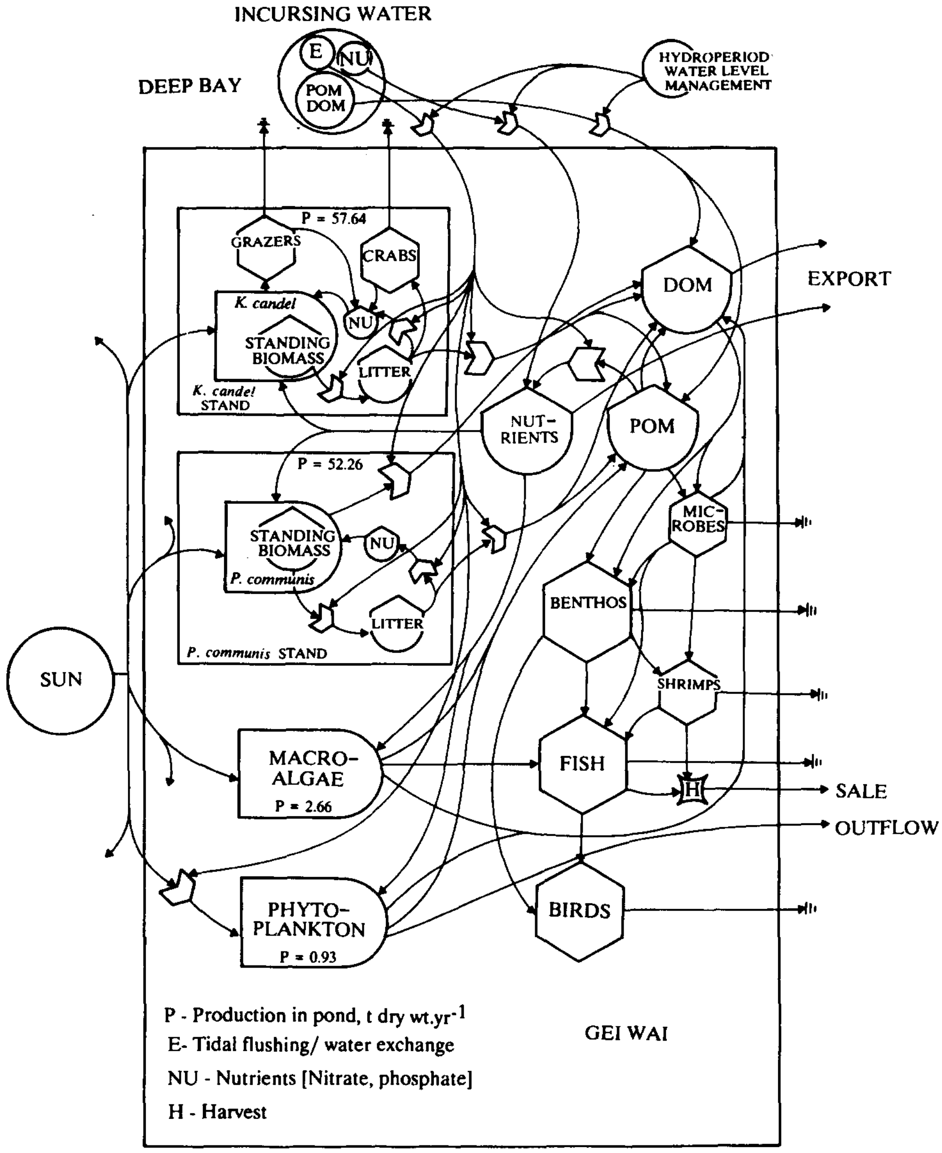

Fig. 1. A model for particulate organic matter flow in the study pond, using the energy language of Odum (1983). Water level and hydroperiod management are identified as the most important elements of management.

environment, the tilapias made up about 90% of all individuals of the fish community and 80% of the harvested biomass in the study pond (Table 2). The high density of 2·0 individuals m^{-2} also resulted in stunted growth, with most of the individuals attaining standard length <15 cm in the first year (Fig. 2). While the small size of the tilapias may benefit waders, their contribution to economic return is virtually nil. As omnivores, the tilapias also compete for food with the more economically important species such as the striped mullet and may prey upon the shrimp *Metapenaeus ensis*, the major economic species kept in the ponds.

Table 2. Production by the four dominant pelagic fishes in a Hong Kong tidal pond during the period September 1985 to January 1987

Species	Number of individuals	Mean wt (g)	Total wt (kg)	% Total by wt
Oreochromis spp.	36 406	66·99	2 429·93	77·9
Mugil cephalus	1 313	164·00	221·04	7·1
Sparus latus	1 564	152·31	238·21	7·6
Elops saurus	625	369·87	231·17	7·4
Total	39 908		3 120·35	100·0

The highest economic return from the fish catch was from yellow-finned bream, lady fish and striped mullet. Other species of commercial importance, such as *Therapon jarbua* and *Platycephalus indicus*, occurred in relatively smaller numbers.

Because of its restricted water exchange and shallow depth, the tidal pond amplifies natural fluctuations in water quality in the estuary (Table 3). Partial loss of the native mangrove forests, wide fluctuations in physical conditions and a lower spatial complexity mean that fewer species can survive in the tidal ponds. Many of the dominant animals on the tidal mudflat (e.g. the ocypodid crabs *Macrophthalmus convexum* and *Uca* spp., the mudskippers *Periophthalmus cantonensis* and *Boleophthalmus pectinirostris*) are either absent or occur only at much lower densities in the gei wai (Table 4).

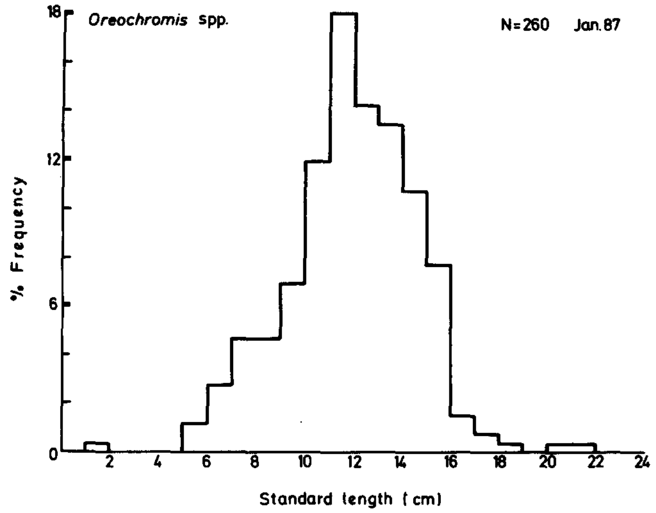

Fig. 2. Size frequency distribution of tilapias *Oreochromis* spp. from the study pond. Fish from the pond were last harvested in January 1985 so the population represents two years' growth. The tilapias probably have extended breeding periods in the pond environment, resulting in a large size-range for the individuals.

Table 3. Comparison of the ranges for important hydrographic parameters recorded from the study pond and from inner Deep Bay (Environmental Protection Department, 1988)

Parameter	Study pond range	Inner Deep Bay
Surface dissolved oxygen (% saturation)	15·5–221·3	5·7–83·4
Surface salinity (ppt)	0–27	8·1–28·0
Surface temperature (°C)	10–40	19·7–30·4
pH	6·8–8·0	7·2–7·9
Secchi depth (m)	0·2–1·32	0·2–0·7
BOD_5 (mg litre^{-1})	5–75	1·1–16·0
Surface Chl *a* (mg m^{-3})	0·8–15·9	0·2–24·0
PO_4-P (mg litre^{-1})	1·09–9·72	0·05–4·20

Landscape, water level and hydroperiod management

Control of water level and hydroperiod are probably the most important elements of traditional gei wai fisheries operation. Good timing in draining and flooding not only maximises the influx of larvae of the cultured species but also enhances survival of the impounded juveniles. It is important that the general water level in the tidal ponds be kept high to minimise fluctuations in physical conditions such as temperature, in order to enhance survival of the cultivated species. There are, however, different water level management objectives in different seasons. The level in the pond was generally kept low (<1 m) during winter, as the farmers believe that exposing the mud to moderate insolation will facilitate shrimp and fish growth. Periodic exposure of the mud can stimulate algal growth to enhance fish production and this practice is widely adopted by tidal pond farmers throughout Asia (Macintosh, 1983). Higher levels (>1 m) prevailed during the summer period to avoid heating up of the shallow water.

Wading birds and their prey have incompatible water level requirements. Fish and other commercial species such as shrimps require relatively deep water to minimise temperature fluctuations. Feeding and roosting of most waders and other waterfowl, however, are only possible in shallow water (<50 cm deep). Thus, conflicts occur between the wildlife manager and the fish farmer.

To facilitate bird utilisation of the tidal ponds of the nature reserve, the water level in the ponds should be kept low during high tide periods in Deep Bay, allowing the birds to roost and forage for longer periods in the reserve. It has been found that one of the dominant resident bird species at Mai Po, the Chinese pond heron *Ardeola bachus* on average uses the gei wais for winter feeding for about 10–15% of the time (L. Young, pers. comm.). The same pattern of using the drained gei wais for winter feeding probably applies to many other waders, e.g. the little (*Egreta garzetta*) and great (*E. alba*) egrets. The landscape and hydrological regime of the other gei wais under WWFHK control have also been modified to facilitate bird use of the habitat. Water level is generally kept low to attract waders, but survival and growth of the cultured fish and shrimp species have been poor.

In addition to conflicting with the normal method of gei wai water level management (to flood during high tide and drain during low tide), such management is also conducive to drastic fluctuations in water quality as compared with the tidal areas. The pH of the water,

Table 4. List of animals and plants occurring at significantly different densities in the tidal pond and on the mudflat seaward to the ponds

Species with high densities in tidal pond	Species with high densities on mudflat
Animals	
Sermyla tornatella (Gastropoda)	*Boleophthalmus pectinirostris* (Osteichthyes)
Discapseudes sp. (Tanaidacea)	*Periophthalmus cantonensis* (Osteichthyes)
Oreochromis spp. (Osteichthyes)	*Macrophthalmus convexum* (Brachyura)
	Salinator sp. (Gastropoda)
	Uca arcuata (Brachyura)
	Uca acuta (Brachyura)
	Littorina melanostoma (Gastropoda)
Plants	
Phragmites australis (Gramineae)	*Avicennia marina* (Avicenniaceae)
Echinochloa crus-galli (Gramineae)	*Aegiceras corniculatum* (Myrsinaceae)
Macaranga tanarius (Euphorbiaceae)	*Acanthus ilicifolius* (Acanthaceae)

for example, is strongly affected by frequent exposure of the acid sulphate sediment to air and this probably results in the low fish and shrimp yields.

DISCUSSION

The use of tidal ponds for aquaculture has been developed in Southeast Asia and South America because it provides a relatively cheap way of tapping a rich resource. No fry or fertilizers need to be added, as stocks of larvae and nutrients are carried by the water into the mangrove environment. Such traditional management requires the minimum amount of manpower but has only limited productivity. Knox and Miyabara (1984) suggested that tambaks in Indonesia provided about 12% of the total fish production by value, with good employment opportunities because of their large area. Exploitation of mangrove forests for aquaculture also seems to be more profitable than forestry or capture fisheries (Ong, 1982; Hatcher *et al.*, 1989). It is therefore likely that more such ponds will continue to be built and operated in the traditional manner. Tidal pond construction is now the major cause for mangrove destruction in Latin America (Terchunian *et al.*, 1986; Lahmann *et al.*, 1987) and throughout Asia (total area $>4{\cdot}5 \times 10^5$ ha in 1980s) (Kapetsky, 1987; Naamin, 1987*b*). The area of tambaks in Indonesian mangroves, for example has been steadily increasing, from about $1{\cdot}7 \times 10^5$ ha in 1978 to $2{\cdot}25 \times 10^5$ in 1984 (Polunin, 1983; Cholik & Poernomo, 1987; Naamin 1987*a*).

Nevertheless, recent studies on various methods of brackish water pond shrimp or fish culture have indicated that such systems are not economically feasible except under semi-intensive or intensive conditions (Ong, 1982; Chiu *et al.*1987; Fast, 1991). Kapetsky (1987) has therefore suggested ways of improving tidal pond aquaculture which also prevent further destruction of mangroves: intensification, development of non-destructive forms of aquaculture and better management protocols. These, however, can only be of limited use if excavation is still seen as an easier option.

Intensification seems to be the main direction of development in tidal pond aquaculture. However, ecological problems such as eutrophication, introduction of exotic species and of bioactive compounds (e.g. antibiotics) to the natural environment are common consequences (GESAMP, 1991). Highly intensified establishments can be located outside wetland areas and thus minimise their destruction.

The tidal pond, with its levees and sluice control of the hydrological regime, should facilitate management of wetlands as wildlife habitats. Problems, however, arise when the same pond is to be managed for conservation and aquaculture production, as can be seen in the Hong Kong example. Unlike the Hong Kong gei wais, in many countries mangroves are cleared when tidal ponds are built, giving a monotonous appearance as in the Indonesian tambaks (Polunin, 1983). The construction of these and other similar ponds therefore has drastic effects on mangal landscapes (Lahmann *et al.*, 1987), often decreasing their value as wildlife habitats. The undesirable impact has been recognised by the Indonesian government and there are plans to reafforest the disused tambaks (de la Cruz, 1984; Choong *et al.*, 1990).

Although these ponds can provide a rapid, short-term, economic return, a vicious circle leading to increased and accelerated wetland destruction may result. Turning mangroves into aquaculture ponds decreases nursery sites for offshore species, causing a decline in capture fisheries, and therefore encouraging more ponds to be built.

Traditionally, attention has centred on the integration of different types of consumptive uses of natural systems (e.g. rice/fish farming in Malaysia (Ali, 1990); fisheries/aquaculture (Kapetsky, 1987)). A concept of integrated management for aquaculture and conservation is now needed as outlined by Desaigues (1990). This requires (a) more research on the impact of various traditional landscape and operation practices on the use of mangroves for wildlife conservation; (b) various management alternatives to be explored, and negotiated solutions achieved through a suitable decision process; and (c) a suitable regulatory instrument to be established to ensure correct implementation.

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