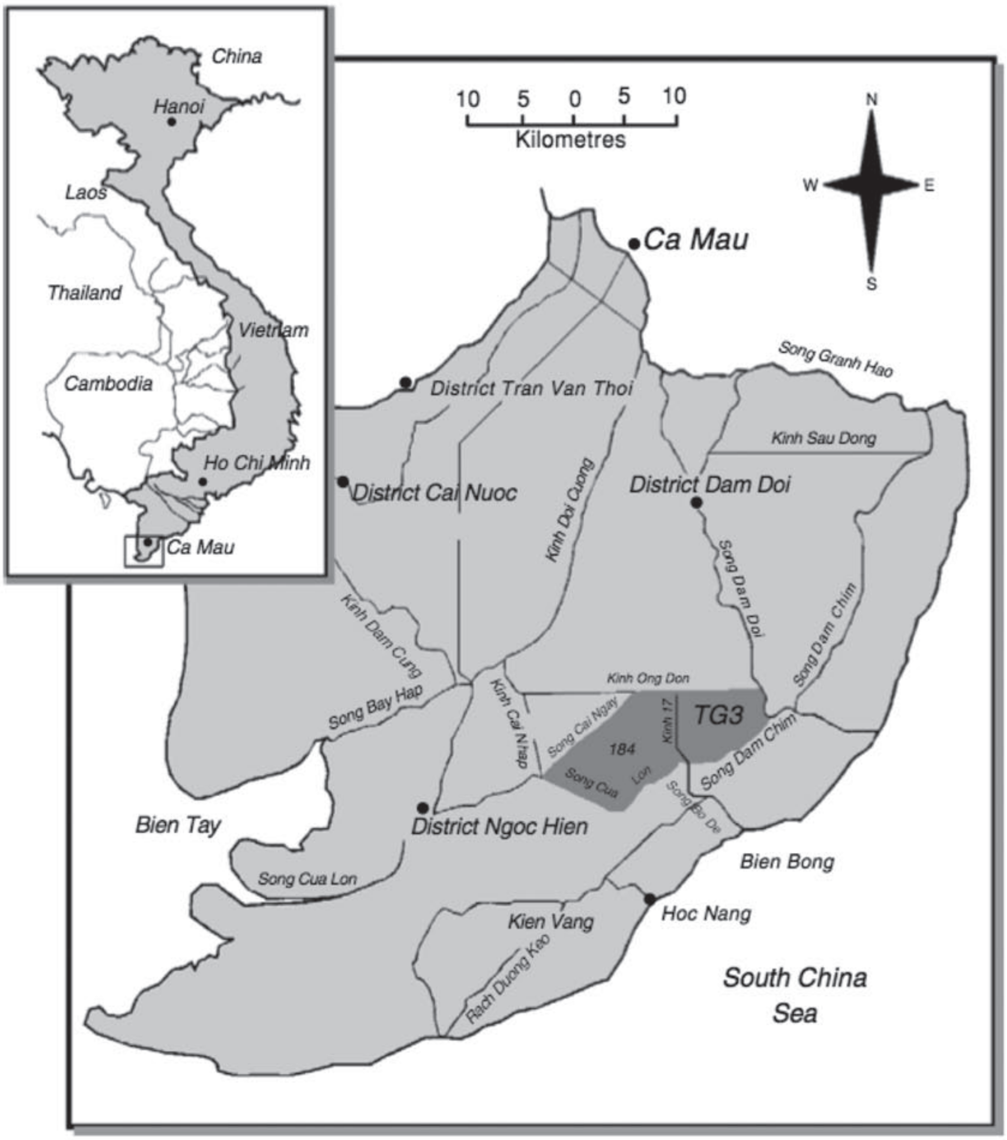
FIGURE 7
Map showing the location of two main Fishery-Forestry Enterprises – TG3 and SFFE 184, Ngoc Hien District, Ca Mau Province, focusing on aquasilviculture practices



Source: from Preston *et al.* (2003).

The two aquasilviculture systems in Ca Mau province are 1) mixed system and 2) separate system (Johnston *et al.,* 1999a; Clough *et al.,* 2002). The mixed system has channels dug through the mangroves with vegetated dikes or levees, whereas in the separate system the mangroves are grown separately next to the pond and levees are bare (Johnston *et al.,* 1999a). The systems can be classified into four different types, reflecting intensity and species focus, as follows: (1) the traditional mixed mangrove farming system relying on natural stocking (mainly *Metapenaeus ensis* and *M. lysianassa* and to some extent also *Penaeus indicus*). Secondary fisheries products in this system consist of fish (barramundi, mullet) and mud crabs. (2) Natural stocking and also hatchery reared shrimps. (3) Both hatchery reared shrimps and mangrove crabs (*Scylla serrata*). (4) Blood cockles (*Anadara granosa*) are added to the shrimps and the crabs (Minh, Yakupitiyage and Macintosh, 2001; FitzGerald 2002). In addition to the pond production and forest production, secondary cash crops are cultivated along the pond dikes (e.g. bananas, taro, pineapples, cherries, etc.). The natural food, developing from

Mixed shrimp-mangrove culture in Ca Mau, Viet Nam.

mangrove litter and materials and species being transported into the pond with the tides, is not sufficient to support higher stocking densities of hatchery reared larvae. To support additional stocking farmers add either fertilizers or supplemental feeds. However, the increased inputs can result in degradation of water quality and pond environment (i.e. increased organic matter and ammonia) (Johnston *et al*., 1999a). A higher production increases accumulation of solids in the ponds and channels, which have to be removed. Dumping the solids onto the vegetated flats and dikes leads to poor growth of mangroves from elevated farm area and to decreased tidal flushing (Primavera, 2000). In many areas of the Mekong Delta using such practices, has shrimp yields per unit area have declined (de Graaf and Xuan, 1998; Johnston *et al.,* 2000a). Low quality and quantity of seed may be resulting from poor pond management, overexploitation of wild stock, and disease outbreaks (Binh, Phillips and Demaine, 1997; Johnston *et al.,* 1999a: 2000a).

The production from different types of aquasilviculture systems in Ca Mau is presented in Table 7. Production is low for all systems, averaging some hundred kilograms per year, and even if accounting for the multiple products of fish and crustaceans they fall short when comparing with production per unit area from intensive culture of e.g. shrimps or fish. Johnston (2000b) showed that yields were significantly higher from extensive aquasilviculture farms compared to traditional farms, and that secondary integrated products, such as fish and mud crabs, increased total farm income by 14 percent. Binh, Phillips, and Demaine (1997) demonstrated that integrated mangrove– shrimp farms with a mangrove cover of 30–50 percent of the pond area had higher economic returns compared to farms where mangrove had been cleared. This comparison included only farms depending on natural productivity.

Even when production of various land crops and yields from the mangrove forest are included, both production and profits are still relatively low. However, mixed mangrove-aquaculture systems have been sustainable for a long time (FitzGeralds, 2002); while semi- and intensive shrimp pond farming have had limited lifetime due to their environmental impacts (Kautsky *et al.,* 2000). Further, clearance of mangroves, and degradation of the coastal environment involved with more intensive shrimp pond-farming in the intertidal zone leads to loss of various goods and services from the coastal zone (Rönnbäck, 2001), something that impacts negatively on other people

TABLE 7
Production from different mixed mangrove-aquaculture systems in Ca Mau, Viet Nam. Kg/ha/year

Production	Traditional	Hatchery reared shrimp	Hatchery reared shrimp/crab	Hatchery reared shrimp/crab and cockle
P. monodon		72 ± 85	107 ± 99	107 ± 99
Shrimps[a]	290-400	333 ± 111	425 ± 102	425 ± 102
Crabs[b]		24 ± 13	62 ± 50	62 ± 50
Cockle[c]				1.300
Fish[d]				
Mangroves[e]				

a) *Metapenaeus ensis* and *M. lysianassa* and to some extent also *P. indicus*
b) *Scylla sp.*
c) *Anadara granosa*
d) Fish mainly for household consumption
e) Contributing only with about 1 % of household selling

Sources: from Minh *et al.* (2001), Johnston *et al.* (1999a).

living within and from the coastal or adjacent inter-linked ecosystems (i.e. in the seascape). Hambrey (1996b) calculated that, due to low investment requirements, traditional activities such as mud crab fisheries and charcoal or pole production have a higher profit margin than any form of aquaculture developed in mangrove areas. Crop diversification on a farm also reduces the risks from income and food loss, something that is especially important for subsistence farmers. More intensive shrimp aquaculture depends on high capital investment and is susceptible to diseases (Clough *et al.*, 2002), which for most farmers imply high risks.

Aquasilviculture in Viet Nam has been developing towards maximizing production of higher valued species per unit area by means of increased inputs (feed and seed) (Clough *et al.,* 2002). In addition to shrimps, the mangrove crab is increasingly being farmed. This is not specific for Viet Nam but it is seen in other countries as well. The mangrove crab has been shown to be a good species for polyculture, particularly with finfish species (milkfish and tilapia) and seaweeds (*Gracilaria*). Crabs for grow-out are either stocked directly in the culture pond or in pens situated in the mangroves. The latter is being practised in the Philippines and Sarawak, East Malaysia (Primavera, 2000) (see below).

The development of intensive aquasilviculture practices in e.g. Ca Mau province may generate short-term benefits but results in the eventual loss of productive land (Clough *et al.,* 2002). This would indicate the need for proper land use planning and implementation of incentives for sustainable farming practices (i.e. enabling mangrove conservation) (Clough *et al.,* 2002). However, the question remains, what practices meet the sustainability criteria in a broader sense? The National Consortium for Forest and Nature Conservation in Indonesia reviewed five mixed mangrove – aquaculture systems, ranging from traditional to more intensive, and concluded that a single sustainability model could not be identified for all locations, since such models are highly site specific as well as subject to other local conditions that influence a system's sustainability (Anonymous, 1996b).

Case study 2 – Mud crab farming in the Philippines

Mud crab farming is argued to be environment-friendly, particularly to mangroves (Primavera, 2005). The culture of mud crabs *Scylla* sp. in mangrove pens can be conducted in such a way that mangroves are preserved both within and out-side the net pens. Feed usually consists of low-value fish, which may be questionable from a sustainability perspective in those cases where such fish constitute affordable and needed protein source for poor people. The interaction between mangroves and mud crab farming, both with respect to benefits from integration, and potential negative impacts on the mangrove ecosystem have not been sufficiently evaluated. Primavera *et al.*,

Mudcrab aquasilviculture, Aklan, Philippines.

TABLE 8
Summary of survival and production of wild *Scylla olivacea* with different feeding treatments in 200 m² mangrove pens in Zarraga, Iloilo

		No feeding	1 month supplem. feed	Fish	Pellets
BW (g)	Initial	65.9 ± 4.5	68.2 ± 6.9	65.1 ± 4.0	58.2 ± 2.7
	Final	114.5 ± 5.2	119.6 ± 5.2	129.3 ± 4.6	121.2 ± 4.6
Survival rate (%)		15.2	19.2	21.8	15.9
Total prod. (kg)		8.6	11.4	14	9.6

Source: from Primavera *et al.*, (in revision).

(in revision) studied how mud crabs pen systems (mixed of *Scylla olivacea*, *S. serrata*, and *S. tranquebarica*, stocked at 0.5–0.8/m² in 400/m² net pens) can benefit from mangrove production by comparing performance of different feed alternatives. The study also quantified impacts on mangrove macroflora from pen crab farming in the Aklan province, central Philippines. The different feeding treatments included no feeding (natural productivity), no feeding for 1 month + supplementary feeding, fish, low-cost pellets (2 percent fishmeal), and pellets + fish. Not surprisingly the crabs being fed fish had the highest production, but the difference in survival rates was not significant between the treatments (Table 8). The study showed that growth rates among different treatments, including crabs with no feeding, were similar during the two first months of cultivation. A sensitivity analysis, comparing fish with pellets + fish, showed improved economic performance for the latter.

The crab cultures did not affect mangrove trees, although it reduced species diversity and also numbers and biomass of seedlings and saplings (Primavera *et al.,* in revision). The authors recommended mud crab pen culture in mangroves with mature trees, but not in newly planted or newly colonized (wild) areas, and suggested that development of low-cost pellets can reduce dependence on local fish.

Mangroves as nutrient filters for shrimp pond effluents

Studies on aquasilviculture systems have mainly focused on production, and less on water nutrient quality (e.g. Johnston *et al.,* 2002; Primavera *et al.,* 2007). However, information about the role of mangroves for nutrient sequestration does exist, mainly in association with pond culture of shrimps (and sewage treatment). Thus another way to integrate aquaculture and mangroves is to discharge pond effluents into natural or planted mangrove forests. This approach is different from extensive aquasilviculture, and in addition to mangrove conservation it also aims at limiting the risk of eutrophication of adjacent open waters (Twilley, Chen, and Hargis, 1992; Robertson and Phillips, 1995; Massault, 1999; Rivera-Monroy *et al.,* 1999). The function of mangroves to act as nutrient sinks has been emphasized (Nedwell, 1975; Tam and Wong, 1993; 1995; 1996; Corredor and Morell, 1994; Wong *et al.,* 1995; Alongi, 1996; Tam, Yang and Wong, 2006). Specific processes studied were sedimentation, decomposition, nutrient uptake by plants and bacteria, nitrification-denitrification, and soil absorption of nutrients (Nedwell, 1975; Robertson and Phillips, 1995; Boyd and Tucker, 1998; Rivera-Monroy *et al.,* 1999). The use of mangroves as filters for absorbing effluents of intensive shrimp culture ponds is being recommended in countries like the Philippines (Primavera, 2000; Baliao and Tookwinas, 2002).

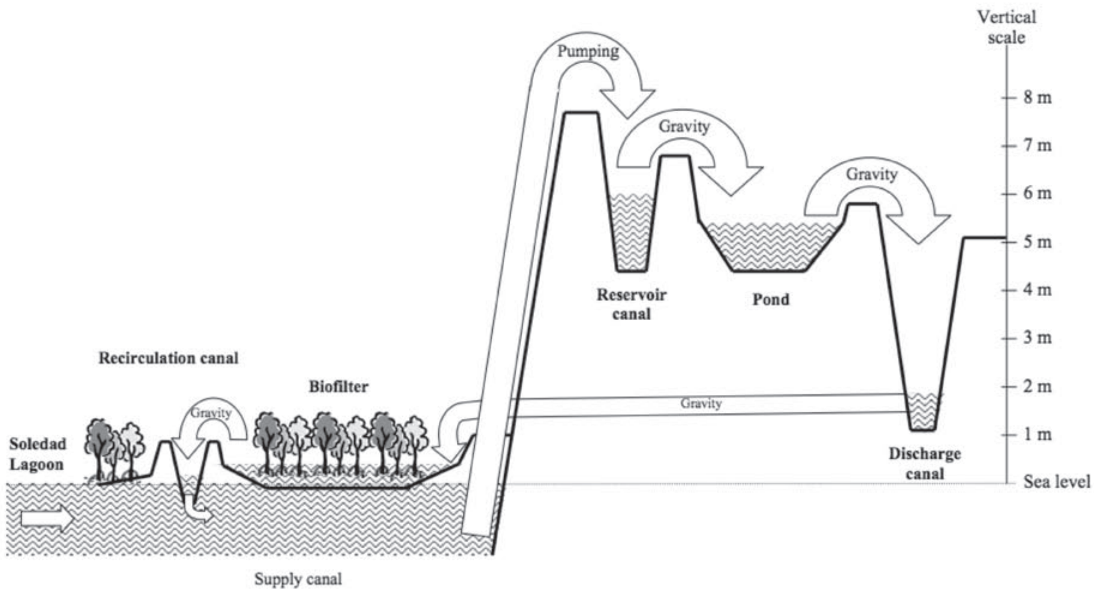
The discharge of aquaculture wastewater to the sea through mangroves is likely to benefit coastal fisheries and mangrove growth, and minimize coastal contamination (and thereby providing a higher-quality water supply for coastal aquaculture in general) (Boyd, 1997; Primavera *et al.,* 2007). There are, however, only a limited number of studies investigating how aquaculture farm effluent impacts mangrove nutrient absorption/transfer efficiency and productivity in the mangrove food web (Sansanayuth *et al.,* 1996; Massaut, 1999; Rivera-Monroy *et al.,* 1999; Rivera-Monroy, Twilley and Castañeda, 2001; Gautier, Amador and Newmark, 2001; Gautier, 2002; Valderrama and Engle, 2002; Primavera *et al.,* 2007). This is, however not surprising as measuring nutrient fluxes in coastal wetlands proved to be difficult (e.g. Boto and Robertson, 1990; Wattayakom, Wolanski and Kjerfve, 1990). Theoretical calculations show that 2–22 ha of mangrove wetlands are required to remove nutrients produced by 1 ha of semi-intensive shrimp pond (Robertson and Phillips, 1995) (Table 9). However, this calculation was based on uptake by the mangrove vegetation and did not take into account nutrient loss through denitrification, sedimentation, and soil absorption (Boyd and Tucker, 1998; Rivera-Monroy *et al.,* 1999). Theoretical calculations based especially on vegetation uptake data are complemented by actual trials using both natural mangroves (Boonsong and Eliumnoh, 1995; Gautier, 2002; Primavera *et al.,* 2007) and constructed or planted mangroves (Sansanayuth *et al.,* 1996; Ahmad, 2000) to treat shrimp pond wastes.

Based only on plant uptake Rivera-Monroy *et al.* (1999) found that 0.5–1.8 ha of Colombian mangroves were needed to remove dissolved inorganic nitrogen produced by 1 ha of semi-intensive shrimp pond. This ration dropped to only 0.04–0.12, once the denitrification capacity of the mangroves was also considered. Even though it is difficult to extrapolate to other areas due to large variability and complexity of mangrove systems, these findings suggest that some, but not all, mangroves can effectively treat aquaculture wastes. Denitrification was of only minor importance (< 1 percent of the total N budget) in a pristine mangrove forest comprised of *Rhizophora*

TABLE 9
Comparison of published ratios of mangrove: shrimp pond area, illustrating the areas of mangroves that are needed for total removal of nutrients released in shrimp pond effluents

Reference	System	Mangrove: pond ratio (area)	
		N	P
Boonsong and Eiumnoh, 1995	Intensive	9:1	8:1
Robertson and Phillips, 1995	Intensive	7:1	22:1
	Semi-int.	2:1	3
Kautsky *et al.*, 1997	Semi-int.	6:1	6:1
Primavera, 2005	Intensive	3-7:1	
	Semi-int.	2:1	

FIGURE 8
Construction and flows through a mangrove biofilter in Colombia. Water directed by concrete structures and several exits, allowing for controlling water residence time before being released into adjacent lagoon



Source: From Gautier (2002).

(Kristensen, 1997). Mangroves (a mix of planted and natural) only partially biofiltered shrimp wastes in an integrated semi-intensive system (*Litopenaeus vannamei*) and mangroves (dominated by *Rhizophora mangle*) Gautier (2002). Water flow through the 120 ha mangrove forest, which was surrounded by levees, was directed by concrete structures and several exits (allowed for controlling water residence time) within the mangrove unit before the water entered the adjacent lagoon (Figure 8). The mangroves decreased the suspended solid concentration, but concentrations of dissolved nutrients (SRP, TAN, and NO_3) increased after passing through the mangrove biofilter; this latter phenomenon being explained by production of guano by a large bird community.

The authors concluded that mangrove growth and regeneration constituted an important factor for nutrient storage, but that nutrient cycling within the mangrove system was still poorly understood and needed to be further investigated. The study did not examine sediment biogeochemistry or fauna within the mangroves. As no water exchange was allowed from the lagoon into the mangrove biofilter, the mangroves function as nursery and feeding ground was lost. This could have negative consequences for coastal fishery production in the area.

Valderrama and Engle (2002) used own data and results from Rivera-Monroy *et al.* (1999) and Rivera-Monroy, Twilley and Castañeda (2001) to estimate the potential nitrogen and phosphorus treatment capacity for mangrove forests receiving effluents from shrimp aquaculture ponds in Honduras. The largest mangrove area calculated was for total nitrogen removal (45 percent of farm) and this was in accordance to Rivera-Monroy, Twilley and Castañeda (2001).

Valderrama and Engle (2002) also calculated net returns for different Better Management Practices (BMPs) options and could show that natural and artificial mangrove biofilters involved the highest costs (Table 10). Construction of both settling basins and mangrove wetlands drastically reduced profit margins. The authors concluded that sophisticated mangrove biofilters could not be recommended for small farms in Honduras, and that financial incentives are required for farmers to adopt such practice. Valderrama and Engel (2002) (referring to work by Gautier (2002)) pointed out that such integrated system can result in significant savings if an effluent tax is

TABLE 10
Annual enterprise budget for an 85-ha shrimp cooperative in Nicaragua based on 2001 prices and costs. Two production cycles per year were assumed

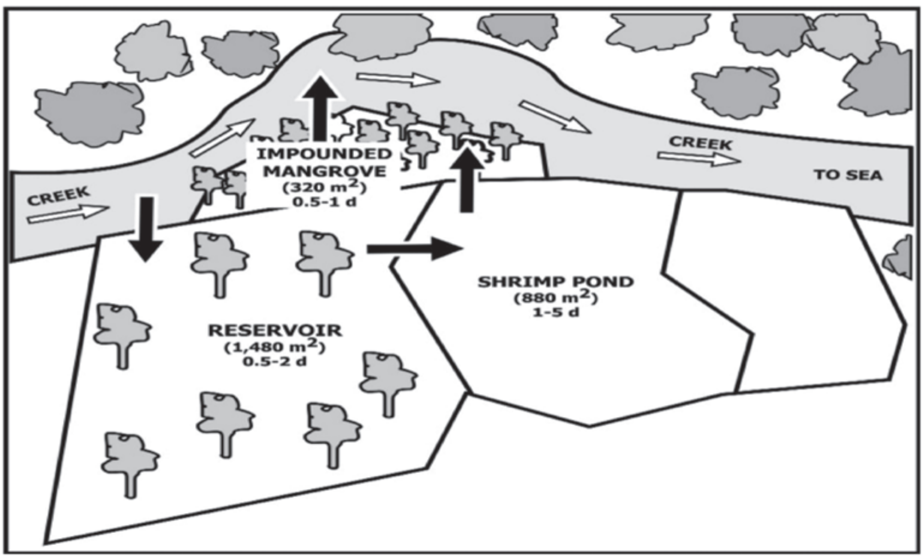
MBP	Net returns/ha in baseline scenario	Net returns/ha in BMP scenario (US$/ha)	Change	Description of change
Reduction in water exchange rates from 10-11% to 5%	483	648	34%	Total diesel cost decreased from US$7,701 to US$3,618
Application of entire ration of feed on feed trays	483	751	55%	Total feed cost decreased from US$24,753 to US$18,147
Combined BMP: reduced water exchange rates and use of feed trays	483	916	89%	Changes as above
Settling basin installation	483	244	-50%	Fixed costs increased by US$240/ha (annual amortized cost of basin)
Construction of mangrove biofilter – Natural forest	483	333	-31%	Fixed costs increased by US$150/ha (annual amortized cost of biofilter)
Construction of mangrove biofilter – Artificial forest	483	-442	-192%	Fixed costs increased by US$925/ha (annual amortized cost of biofilter)

Source: From Valderrama and Engle (2002).

practised. This, together with the fact that mangrove biofilters allow for partial or complete recirculation of effluent-waters, could be seen as something positive for a farmer.

In another study, Primavera *et al.* (2007) estimated that 2.2 and 4.4 ha of mangrove area were required to process nitrogen wastes from one ha of semi-intensive and intensive shrimp pond (*P. monodon* with milkfish being separated by a net pen), respectively. In Table 9 this ratio is being compared to ratios obtained in other studies (theoretical and actual experiments). Differently from the study by Gautier (2002) the mangrove filter studied by Primavera *et al.* (2007) allowed incoming tides into the experimental ponds. This facilitated the entrance of wild organisms which could utilize the mangrove area and could then return to adjacent waters (Figure 9). Thus, mangroves used in such way retained some of their natural functions. Generally, brackishwater

FIGURE 9
Schematic outline of aquasilviculture experiment conducted in the Philippines



Source: From Primavera (in revision).

pond aquaculture and mangroves are mutually exclusive since most fish and shrimps, require a permanent water column. In contrast, the growth and survival of mangrove trees, the dominant components of the ecosystem, require periodical water drainage by low tides. Therefore only a few animal taxa – mainly epifauna and infauna such as crabs and bivalves that bury in the substrate can be integrated in hydrologically-intact mangrove habitats (Primavera, 2000; Williams and Primavera, 2001). None of the above-mentioned studies were, however, conducted over a longer time period, and because the "mangrove filter" functions as a sedimentation pond, the long-term impact of effluents on mangrove ecosystem has yet to be assessed (Gautier, 2002).

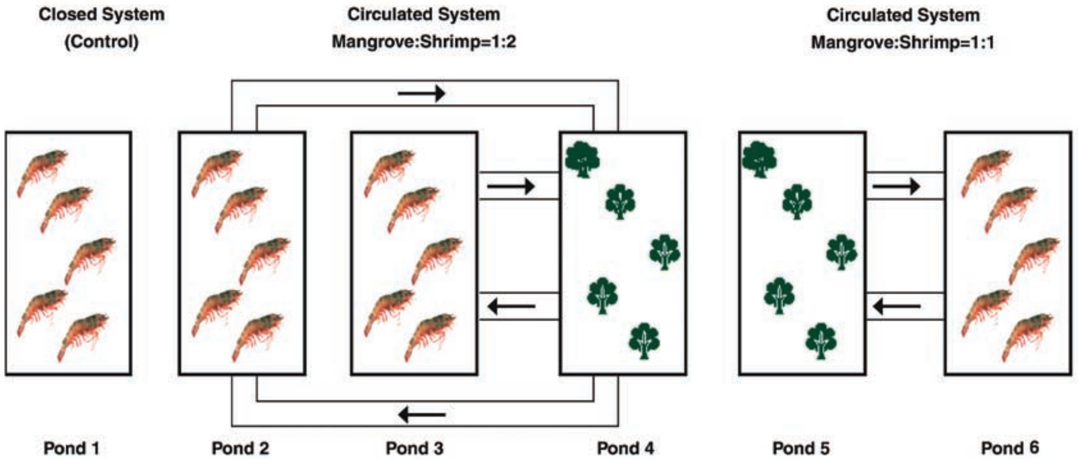
The use of constructed mangrove ponds (*Rhizophora mucronata*) to purify shrimp (*Penaeus monodon*) pond waste-water has been studied as part of a sustainable aquaculture research collaboration between the Faculty of Fisheries, Kasetsart University, Thailand, and Japan International Research Center for Agricultural Sciences (JIRCAS) (Fujioka, 2005; Fujioka *et al*., 2006; 2007). This effort was part of the research project "Studies on sustainable production systems of aquatic animals in brackish mangrove". Fieldwork at Samut Songkhram Fisheries Research Station, optimized mangrove pond and shrimp pond ratios (Figure 10), and measured the role of benthic organisms and shrimp production in mangroves receiving shrimp wastewater (Fujioka *et al.,* 2006). It was concluded that the mangrove system was overloaded if receiving shrimp wastes from shrimp farm area twice the size of the mangrove area. However, if areas allocated to shrimp and to mangrove were of similar size, bentic organisms were positively effected which also resulted in improved shrimp production (Fujioka *et al.,* 2006). There was no significant difference in nutrient concentrations between water in mangrove-shrimp ponds and single shrimp ponds (Fujioka *et al.,* 2006) Biogeochemical processes were, however, not studied in greate detail in these studies.

In Indonesia, Ahmad (2000) and Ahmad, Tjaronge and Suryati (2003) used natural mangroves in a "reservoir pond" to treat shrimp pond effluents. Water nutrient concentrations were lower in the mangroves than in the shrimp pond, but nutrient levels (particularly ammonia) slowly built up in both ponds. It was difficult to say anything about nutrient removal efficiency from the experiment as no controls were used. A separate tank experiment, to isolate nutrient uptake and water quality

PHOTO: YOSHIMI FUJIOKA

Integrated mangrove-aquaculture at Samut Songkhram Fisheries Research Station, Kasetsart University, Thailand.

FIGURE 10
Set-up of mangrove ponds (*Rhizophora mucronata*) to treat shrimp pond effluents (*Penaeus monodon*) in recirculation systems



Source: From Fujioka *et al.* (2006).

(i.e. microorganisms activity processes), did not result in any better understanding about efficiency. The potential benefits from mangrove production of bioactive compounds, acting as bactericides, was indicated by the findings that *Vibrio* spp. were always found to be lower in the mangrove reservoir water. However, the benefits to the shrimps from such reduction need to be studied in more detail, as shrimp are bottom dwellers and get exposed to bacteria populations in the sediments.

Special cases of integration

Farming herbivorous fish as feed for carnivore fish in polyculture

Polyculture where piscivorous fish species are used to control free spawning of targeted cultured fish species have been common practice in many tropical countries (i.e. for tilapia culture) (Guerrero, 1982; Mair and Little, 1991). Such practice reduces the risk of over-population and thereby increases economic performance. Variants of the practice include using larger predatory fish to control herbivorous fish in seaweed cultures (described earlier in text). Appendix 2 includes studies testing farming sea urchin on oyster ropes to control epiphytes (Lodeiros and Garcia, 2004), and Siganidae fish in cages with oysters to control epiphytes.

Poor Asian fish farmers often cannot afford good quality artificial feeds, necessary to farm higher valued fish species. A polyculture technique, where low valued inputs are transformed into high valued fish through intermediate production of low valued fish, has been applied by some farmers. Example of this practice can be seen in the Thai Ban Pho and Bang Pakong districts, were some farmers polyculture barramundi and tilapia in 0.6–1.6 ha ponds (personal observations, and personal communication Anocha Kiriyakit, AIT). The practice has been implemented in larger ponds in other districts. Water depth in such ponds is about 2–3 meters and they are prepared before stocking by draining, use of cyanide to get rid of snakehead fish (Channidae), and then dried for 3–4 days. Clean water is then pumped into the pond and chicken manure is applied 5–7 days before stocking takes place. Tilapia is stocked first, at about 40 000 fingerlings per hectare, and 3-4 months later 4 000 barramundi per hectare are added. The fish (i.e. mainly the tilapia) are then fed once a day with by-products (e.g. waste of soybean, waste from fish and chicken factory, rice bran, etc.). The type of feed added depends on availability and price. The carnivorous barramundis depend mainly on juvenile tilapias that are readily available from free spawning in the pond. The salinity of culture water depends on the seasons, and it is around 20 ppt during January to April, and then gradually decreases to 0 ppt in July. The harvesting of barramundi in polyculture usually takes place after about 10–12 months, mainly around August when demand and price of barramundi is at its maximum. Price of tilapia is more stable throughout the year. Yearly harvest per hectare of polyculture pond is around 2.1–4.2 tons of tilapia and 0.3–0.42 tons of barramundi.

Green water systems

"Biomanipulators" (e.g. all-male tilapia, milkfish, grouper, etc.) have been increasingly used, especially in shrimp farming polyculture (or practised as sequential integration) to "treat" the water (Wang *et al.,* 1998; Baliao, 2000; Yap, 2000; Corre, 2000; Fitzsimmons, 2001; Paclibare *et al.,* 2002; Lio-Po *et al.,* 2005; Tendencia, de la Peña and Choresca, 2006; Martinez-Cordero, Duncan and Fitzsimmons, 2004; Yi and Fitzsimmons, 2004; Yi *et al.,* 2004; Cruz *et al.,* 2007). Tilapia is often co-cultured with shrimps, in a wide range of salinity levels (from 0 to 30 percent), where the system either utilizes water from separate tilapia culture ponds and reservoirs, or tilapia are being stocked in cages inside shrimp pond or even mixed in the same ponds (Akiyama and Anggawati, 1999; Lio-Po *et al.,* 2005; Yi and Fitzsimmons, 2004). The excretion of nutrients from co-cultured species stimulates phytoplankton blooms, It is not exactly known what creates the positive qualities of the water (Leaño *et al.,* 2005), but for shrimp farming this methodology may tackle disease problems in multiple ways: 1) the treated water may be beneficial to the shrimps by reducing light intensity and thereby decreasing stress at the bottom where the shrimps stay most of the time, 2) by preventing the growth of benthic algae, 3) by helping oxygenate the water during the day, 4) by stabilizing water temperature, 5) by promoting the development of a favorable microbial community composition, 6) by removing potentially toxic faecal wastes and metabolites, and 7) by promoting enzyme enhancement (Martinez-Cordero, Duncan and Fitzsimmons, 2004; Izquierdo *et al.,* 2006). The "greening" effect of the culture environment can, however, also be achieved by other means than adding co-cultured species (Izquierdo *et al*., 2006).

Tilapia production in former shrimp ponds (with and without shrimp) has increased rapidly in many countries including Thailand, the Philippines, Honduras, Mexico, Peru and the inland desert of Arizona (Yap, 2000; Fitzsimmons *et al.,* 2003). Results from a survey carried out in twelve Provinces in Thailand (Yi and Fitzsimmons, 2004) indicated that 42.6 percent of the farms used a simultaneous tilapia-shrimp polyculture system, and 16.4 percent used shrimp monoculture water from reservoir stocked with fish. Among the farmers practising mixed farming, 76.9 percent released tilapia directly into shrimp ponds, and 23.1 percent stocked tilapias in cages suspended in shrimp ponds. Farmers practicing green water technology with fish stocked in a larger reservoir will have to reduce the shrimp pond area to fit within the culture site. Income losses from reducing shrimp production area can be compensated by the sales of fish raised in the reservoir, and a more stable water quality will result in higher shrimp production per area (from suppression of growth of pathogenic *Vibrio*).

In the Philippines a 1:1 ratio of shrimp culture to reservoir area is being recommended. The reservoir is stocked with fish (e.g. tilapia) at 3–3.5 tons/ha. This maintains blooms of beneficial microalgae like *Chlorella*, having a suppressive effect on *V. harveyi* (Corre *et al.,* 1999). The fish are also stocked in a cage inside the shrimp pond (Guerrero, 2006; Guerrero and Guerrero, 2006). In shrimp-milkfish polyculture, practised in areas where shrimp farming is no longer viable, the recommended area ratio has been 3:1 (Tendencia, de la Peña and Choresca, 2006).

Although today, fish are mainly being considered as a promoter of beneficial effects on water quality, in the future, alternative species groups such as seaweeds may function similarly. Seaweeds have been shown to inhibit aquaculture pathogenic bacteria (Nagahama and Hirata, 1990; He *et al.*, 1990; Pang, Xiao and Bao, 2006) and viruses (Tsutsui *et al.*, 2007).

Development, incentives and constraints

Biological methods for water treatment based on integration with non-microbial organisms have been investigated and implemented in many tropical countries. Several approaches and designs removed both particulate and dissolved wastes, and at the same time also generated additional aquaculture crops and benefited physiologically the main cultivated species (see Appendix 2). However, the systems that have actually been implemented by farmers have generally belonged to the "simpler" polyculture practices, either traditional or based on more recent scientific findings. The question is then why new practices and technologies, for example sequential farming techniques, both on land and in open waters, have not become implemented at any larger scale in tropical countries (or elsewhere). The answer is probably related to the greater skills required for multi-unit multi-species culture, as different species and different units require different culture conditions and protocols. This is different from polyculture, where organisms share and must tolerate the quality of a common culture unit. Polyculture is thus simpler, even though of course it limits the species that can be farmed together, considering competition for feed, oxygen, and space (Lutz, 2003).

In small-scale experiments it may be easier to show the efficient biofiltering capacity and growth of co-cultured species, but when the technology is adjusted to larger scale operations it may prove difficult to match the different species requirements and maximize their exposure to the wastes in question. This will involve issues like water movements and retention times, particle and nutrient densities, water temperature and salinity, etc. Bivalves, for example, may be sensitive to salinity fluctuations, which may cause problems during some parts of the year. Oyster growth may be depressed if cultured too close to the bottom dominated by particles with low nutritional value (Lin, Ruamthaveesub, and Wanuchsoontorn, 1993; Soletchnik, Lambert and Costil, 2005). Another aspect with respect to filter-feeders is the production of faeces and pseudo-faeces that can add to the sediment load in the system (Troell and Norberg, 1998; Smith, 1999). Further, the scaling up from small scale experiments may reveal unknown effects with respect to performance at commercial scale (Troell *et al.*, 2003).

This can be illustrated by preliminary experiments on polyculture of shrimps with sea cucumbers. Combining juveniles in culture tanks of 500–1 000 L the integration was successful suggesting that such integration was possible (Pitt *et al.*, 2004; Purcell *et al.*, 2006). However, when the integration was tested in ponds using shrimps and sea cucumbers of sizes likely to be reared together during commercial operations, the survival and growth of the latter were poor (Bell *et al.*, 2007).

A review of the potential of seaweeds for the removal of nutrients from intensive mariculture, focusing especially on possibilities within tropical aquaculture in general and shrimp aquaculture in particular, Troell *et al.* (1999), concluded that there was a lack of information on the feasibility of the approach. Even though more studies have been conducted since then there still seems to be a lack of knowledge or/and interest in what intuitively seems to be a straightforward environmentally benign practice. Briggs and Funge-Smith (1993) reviewed the possibilities of culturing seaweeds together with shrimps. Data on growth, physiological properties, economic values, etc., led them to conclude that seaweeds could favorably be used as biofilters in shrimp ponds, being cultured either as polyculture or in an adjacent sedimentation pond (of about 30 percent of the shrimp pond area in size). The measured benefits of the seaweeds were nutrient removal, and lessening of blooms and crashes of phytoplankton. The authors, however, pointed out the need for larger-scale experiments. Some seaweed species can be sensitive to salinity fluctuations, and can also suffer from light limitation in turbid and eutrophic pond effluents, as well as smothering by sediment and epiphytic microbial growth (Smith, 1999; Troell *et al.,* 1999). Indeed, poor seaweed growth in shrimp ponds has been linked to high epiphytic load and high water turbidity (Phang *et al.,* 1996; Nelson *et al.,* 2001; Marinho-Soriano, Morales and Moriera, 2002).

Integrated practices in open culture systems, characterized by a continuous exchange of water, which makes waste disposal difficult to control, have been rarely investigated in the tropics (Troell *et al.*, 1999; Troell *et al.*, 2003). The expansion of coastal cage farming (which is open by nature) in many tropical countries should provide opportunities to develop and study integrated practices, building upon experiences from temperate regions (China, Japan and Canada).

Issues related to sanitation, food safety, and environmental quality need to be considered in integrated aquaculture systems (Taylor, 2004). The predominance of regulatory regimes and instruments in aquaculture are relevant to monocultures much more than to integrated systems (Walrut, 2003). This implies that species produced in mixed cultures will be subject to the same regulations as those from monocultures, i.e. following regulations and standards specific for each individual species included in the culture, while positive or negative implications of the integration may be overlooked. From a European perspective, however, it is not likely that deployment of biofilter organisms should hinder development where a farm would be authorised under all other criteria (White and Pickering, 2003). Nevertheless, it has been argued that in many instances the development of multiple species culture may be subjected to further regulatory requirements in the future (White and Pickering, 2003). This will probably also be the case for integrated aquaculture in the tropics. Potential transmission of pathogens (or chemicals) from one species to another (Taylor, 2004; Etienne *et al*., 2006), not only within the farm practicing integration, but also spreading to neighbour farms may occur. A federal regulation in Canada restricted the harvesting of shellfish within 125 m of a source of organic waste. However, IMTA research demonstrating that fish-farm waste does not constitute the same health issues as human wastes, has changed this regulation (Taylor, 2004). However, there is a need for more research on this topic in e.g. the tropics, in light of promising results about these isssues from integrated systems in other climates (see refs in Neori *et al.* [2007]).

It is also important to recognize that one practice, developed for a specific system or place, may need to be tested before being transferred and implemented in a different region or locality. For example, the ability of biofiltering systems to improve water quality may vary depending on initial water quality. In shrimp pond farming, factors like pond soil type, quality of affluent water, stage of the grow-out season, and management practices can all influence water quality (Ziemann *et al.,* 1992 in Jones and Preston, 1999). It may also be difficult to generalize about economic performance (in those cases where it has been evaluated) because of the complexity of economic analyses.

Economic performance is probably a main reason for the low implementation rate, even after so many trials, of integrated designs and species combinations, especially of sequential practices in shrimp farming. Economic constraints in production and operating costs often make the treatment of farm wastes difficult to support (Muir, 1982), particularly in developing countries. This would also be true for more technologically integrated farming approaches (i.e. re-circulation) that may be more capital-intensive with higher labor costs for handling and harvest. The economic feasibility of most integrated practices experimented so far has not yet been demonstrated, especially at large-scale implementation (commercial). Thus, even though there are opportunities for integration, there is a need to clearly show and explain to farmers how resource use, space requirements, management, marketing, and economic issues could be solved. Existing monoculture farmers would otherwise be reluctant to move towards integrated systems (Hambrey and Tanyaros, 2003).

Incentives that could be used to promote integrated practices are of economic (increased profits) and regulatory nature. The economic incentives may be related less to short-term profits than possibly to risk management, disease management, market acceptability, and additional sustainability considerations. Drivers for practising IMTA are found at different levels. The most obvious, at a farm level, is the economic gain from producing an additional crop. Thus, if no net benefits are resulting from inclusion and subsequent sale of added extractive species, the farmers will have no immediate profitability incentive to practise IMTA. This may excludes many extractive species. However, when the costs of environmental degradation by monoculture are estimated, internalized by regulations and taken into account in the production costs, this could increase the value of extractive species as their environmental services are accounted for. Further, where limitations to nutrient emissions apply, production of the main farmed organism could expand thanks to nutrients recycling by extractive species (a concept of nutrient credits, similar to that of carbon credits). Thus, from a societal perspective, these incentives together with potential consumer preferences for species produced in IMTA systems provide a higher return for the additional biofiltering (extractive) crop. Today the benefits are seen almost exclusively from a corporate/farm level, but not from a broader more general societal perspective.

Even though wastes from certain types of aquaculture are now considered by society as having wider negative environmental impacts, the costs of their mitigation represent no monetary compensation to the farms. This situation stems in part from the complexities involved in the identification and quantification of environmental impacts. Before the costs of certain mitigation efforts can be determined, it is necessary to know what values (goods and services) are being generated from the impacted system – i.e. a natural coastal ecosystem (or freshwater system), and how they are affected from aquaculture wastes (to be separated out from all other potential factors). Even though the information is scarce, this perspective needs to be addressed to encourage the development of new integrated technologies. An accurate or better estimate of overall ecological and economic benefits should create incentives for joint financing by diverse stakeholders within the sector (i.e. governments and the aquaculture industry).

While the initial financial risks may be steep for integrated practices at a shrimp farm, the possibility to run a closed system with biofilters could eliminate many of the production risks that are beyond the control of most shrimp farm operators (e.g. affluent water quality, diseases, etc.). However, this objective may be achieved also by other means than integrating with macroscopic animals and plants, illustrated by the recent development of "flock systems" in shrimp farming (Fast and Menasveta, 2000; Moss *et al.*, 2001; Rosenberry, 2006).

In general, polycultures or other forms of multi-species systems have the possibility to reduce the financial risks, e.g. securing income if markets change drastically or if disease outbreaks affect one species. However, in practice, many farmers still prefer the simplicity of farming only one species. Thus, to promote changes in this widely adopted practice there is a need for developing economic incentives, or even implementing regulations to encourage greater diversity in aquaculture. Culturing more than one species should of course not be an ultimate goal for all farmers, but in situations when farmers choose to culture species in systems generating negative environmental impacts, integration should be promoted. Also farmers seeking quick returns from focusing on only one international "cash crop" species (risking significant market price fluctuations), may benefit from diversifying production. Certification systems, that include integrated approaches, could create incentives for farmers to adopt such practices. However, the many small-scale producers, that today operate some of the most efficient, environmentally sustainable, and socially equitable systems (extensive practices), may not be able to participate in certification schemes and traceable supply due to the different and costly standards that need to be met.

CONCLUSIONS

There have been many different mixed species aquaculture systems in study and in operation throughout the tropics, especially so in South-East Asia. Of significance are the many varieties of polyculture in earthen ponds, the mangrove-mixed cultures and the rice-shrimp systems. Extensive shrimp and fish polyculture ponds dominate integration. Single-pond extensive polyculture techniques, which entail low levels of skill, capital investment and operation costs, are more suitable to small-scale farmers compared with sequential practices. However, in many countries there seems to be a trend of intensification in aquaculture. In many cases, this means also implementation of monocultures, whose adoption of IMTA practices requires separation of the cultured species in place and/or time.

The integration of shrimp with mangroves is an innovative approach, but before this can be promoted at any scale more research will be needed. This is also true for the special form of mixed mangrove-aquaculture. However, in addition to focusing on pond engineering and management in these systems, it is important to also focus on socio-economic characteristics of such practice, including both farm level and overall coastal communities at large. Mixed rice-shrimp culture has been practised in large scale and for a long time in many countries (e.g. Bangladesh, Viet Nam, and India), and these systems could be potentially be improved further.

The many experimental studies carried out on tropical species and systems have investigated various aspects of polyculture and integrated aquaculture. Most research efforts have been on different species combinations and systems aimed at generating additional crops, improving the quality of e.g. effluents discharged from shrimp cultures and to improve the culture environment. This has involved integration with species like tilapia, milkfish, oysters, mussels, seaweeds, etc. However, the many experimental trials on shrimp farms seem not to have been carried out in a systematic way and no real promotion/adoption of such systems seem to have been achieved. This may reflect that no successful system has been developed that is simple and profitable enough to appeal to farmers, considering the added costs involving new skills, investments and operation. Industrial research has also been carried out to promote and develop new technologies for re-circulation involving new shrimp species (*Penaeus vannamei*) and microorganisms (i.e. bacteria), something that probably offers a more interesting alternative for large-scale farms compared to integration with larger species. To make good long-term profits such farms must recognize the complexities involved when managing multitrophic species systems and, if needed, involve appropriate expertise. This is especially important in the start-up phase.

Without a clear recognition of the aquaculture sector's large-scale dependency and impact on natural ecosystems and traditional societies, the aquaculture industry is unlikely to either develop to its full potential or continue to supplement ocean fisheries (Naylor *et al.,* 2000; Chopin *et al.,* 2001). Thus, to increase accessibility of seafood to economically depressed people, or even to maintain it at current levels, aquaculture development must be based on the right species choices and sound technologies. This is even more relevant to developing countries (Naylor *et al.,* 2000; Williams *et al.,* 2000). Thus, in solving the environmental problems associated with aquaculture the best available technology should be searched for; this may also involve extensive farming of low trophic species, in polyculture or monoculture, or more intensive re-circulation systems building on microorganisms as biological filters, or integration with larger extractive organisms. The choice of methods or systems may vary from place to place, and will depend on both the ecological as well as the social settings. Different systems may have somewhat different aims, some targeting high volume of low priced food species, some targeting export higher valued products, and some aiming mainly at providing income alternatives for poorer segments of the society. For some integrated techniques to develop there is a need for incentives that stimulate farmers to adopting certain practices that benefit the society at large. These may include rewarding systems for e.g. choosing extractive species that decrease overall nutrient loading to coastal waters, or tax systems that increase the attraction for choosing certain species. The concept of integration should also be extended to integration of aquafarms into the coastal seascapes. Thus, this would imply the integration of different farming alternatives at a more local/regional level.

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APPENDIX 1 – SOURCES

This study was mainly performed as a desktop review with interviews (by e-mail, letter, telephone and in-person) with key people. Besides standard search in common aquaculture journals, in electronic or print format, the study was complemented by visits to some key aquaculture centres in Asia. These include: Southeast Asian Fisheries Development Center (SEAFDEC), IIoilo, The Philippines; Asian Institute for Technology (AIT), Bangkok, Thailand; and Network of Aquaculture Centres in Asia-Pacific (NACA), Bangkok, Thailand.

Other sources of information included the Seaweb programme (www.seaweb.org); the aquaculture and aquatic resources management library in the Asian Institute for Technology in Bangkok, Thailand (AIT); the Web site of the Aquatic Health and Food Safety Committee of Baja California (CESAIBC, www.cesaibc.org); the Support to Regional Aquatic Resources Management programme (STREAM) Virtual Library (www.streaminitiative.org/Library/); the Western Indian Ocean Marine Science Association (WIOMSA) reference data base; and the Web site of the World Aquaculture Society (WAS).

APPENDIX 2

Brief overview of experimental work conducted on integrated mariculture in tropical regions

A= Polyculture, B= Sequential Integration, D= Mangrove Integration. Waste release Mitigation (WM), Increased Profits Multiple Species (IPMS), Treating culture water + culture env. (WT), Habitat preservation (HP).

System	Species	Country	Aims	Logistics of culture
P	• Sea bass (*Lates calcarifer*) • Seaweed (*Kappaphycus alvarezii*)	Philippines	IPMS	Seaweed cultured in 3 × 3 m bamboo rafts installed inside a 4 × 4 m floating net cage of sea bass (broodstock).
SI	• Shrimp (*Penaeus monodon*) • Mangrove (*Rhizophora mucronata*)	Thailand	WM	Effluents from Shrimp ponds (40 x 20 m) led into water treatment ponds with planted (1 stand per m^2) mangroves. Water re-circulated back. Also mixed ponds was studied. Role of benthic organisms in focus.
P	• Shrimp (*Penaeus monodon*) • Tilapia	Thailand	IPMS WM	Three brackishwater ponds were stocked with 1) only shrimp 2) shrimp and high-density tilapia 3) shrimp and low-density tilapia. Ponds were fed by either variable feed concentrations or fixed concentrations.
P	• Shrimp (*Penaeus chinensis*) *x O. niloticus* • Constricted Tagelus (*Sinonovacula constricta*)	China	IPMS WM	Three species were cultured in an net cage within an closed experimental pond.
P	• Shrimp (*Penaeus chinensis*) • Tilapia (*Oreochromis mossabicus x O. niloticus*) • Constricted Tagelus (*Sinonovacula constricta*) • Scallop (*Argopecten irradians*)	China	IPMS WM	Four species were co-cultured with shrimps in an net cage within an closed experimental pond. Treatments: Shrimp-tagelus (biomass ratio of 1:3), Shrimp-scallop (1:1), Shrimp-tilapia (1:1), Shrimp-tilapia-tagelus (1:0.3:2).
P	• Shrimp (*Penaeus monodon*) • Tilapia	Indonesia	IPMS WM	Tilapia initially stocked in cages inside in earthen shrimp ponds (1800-4000 m^2). Fish then released 60 days after shrimp were stocked. Shrimp stocked at 40 ind. m^2 and tilapia 0.3 ind. m^2
P	• Shrimp (*Penaeus monodon*) • Green mussel (*Perna viridis*)	Philippines	IPMS WM	Polyculture and monoculture of two species in experimental ponds for comparison of a variety of parameters (growth, water quality, etc.). Mussels grown on ropes hung from rafts in the pond.
S	• Shrimp (*Penaeus monodon*) • Green mussel (*Perna viridis*)	Thailand	IPMS WM	Intensive shrimp pond wastewater (stocking 30 ind. M^2 in 0.3-0.4 ha ponds) channelled into a drain with green mussels on bamboo sticks. Water exchange 10-13% daily.
P	• Milkfish (*Chanos chanos*) • Seaweed (*Gracilariopsis bailinae*)	Philippines	IPMS	Pond (18 m^2) and aquarium bi- and mono-cultures of both species. Fish stocking density 5000 ind. ha-1 and receiving feed pellets. Water replenishment once or twice fortnightly. Experimental period 16 weeks.
P	• Milkfish (*Chanos chanos*) • Seaweed (*Gracilariopsis bailinae*)	Pilippines	IPMS WM	Fine mesh nets submerged in earthen brackish water ponds (each 100 m^2). Three different fish-seaweed combinations tested: 30 fingerlings and 11 kg seaweed, 30 fingerlings and 112 kg seaweed, 30 fingerlings and no seaweed. Water exchange every spring tide (one-third of the pond water) and application of inorganic fertilizers. Two years study.
P	• Milkfish (*Chanos chanos*) • Spotted Babylon (*Babylonia areolata*)	Thailand	IPMS	Polyculture in 400 m^2 earthen ponds. Stocking density: 200 snails m^{-2}, 5 fish m^{-2}. Trashfish used for the snails and natural food + pellets for the fish. 50% of seawater exchanged at 15 days intervals.

Colour codes

Colour codes
Mixed Mangrove Ponds/Pens
Tanks
Open Water
Earthen Ponds

Results and discussion	General conclusions	Comments	Reference
Total production of approximately 123 t (fresh) or 37 t (dried) ha-1 in the 5-month culture period.	Seaweed growth comparable, or somewhat higher, to commercial production in the Philippines.	No comparison was made with controls outside fish cages.	Hurtado-Ponce, 1992a
There was no significant difference in nutrient concentrations. Benthic fauna diversity, density and biomass were higher in mangrove ponds. Shrimp pond sediment deteriorated.	Mangroves overloaded if receiving shrimp wastes from shrimp area twice the size of the mangrove area. Similar size mangrove pond improved shrimp production but only extended time before deteriorated.	Experiment lasted between 50-147 days. Maybe to short time for all effects to be seen. Not enough replication	Fujioka *et al.,* 2006; Fujioka *et al.,* 2005; Fujioka *et al.,* 2007
Shrimp yield significantly higher in low-density fixed feed experiment, as opposed to mono- or high-density bi-culture. Tilapia growth was fast and independent of density suggesting not reached carrying capacity in system.	Greater yield of shrimp in low-density polyculture, diversification of production with addition of tilapia. Higher food conversion ratios and higher water quality. Net returns significantly higher in low-density polyculture with fixed feed. No difference between variable feed experiments. Tilapia enhanced water quality.	Optimal stocking density of tilapia for greatest return must still be assessed.	Yi *et al*., 2004.
Accumulation of N and P in the sediment of polyculture was 40% and 51%, lower than those of monoculture. DO and COD levels higher in polyculture and less fluctuating. Bacteria, phytoplankton and suspended organic matter in polyculture significantly lower.	Enhanced production, diversification of products. Benefits gained from co-culture and higher FCR. Tilapia and tagelus enhanced pond water and sediment quality, and reduced waste emission.		Tian *et al.,* 2001a; Tian *et al.,* 2001b; Qi *et al.*, 2001
The “shrimp-tilapia-tagelus” system raised the production by 28% and the utilization efficiency of input nitrogen by 85%.	All polyculture combinations superior to shrimp monoculture with respect to economic and ecological efficiencies.		Li and Dong, 2000.
Shrimp production level was increased by 20%. More stable water quality in polyculture.	Benefits gained from increased shrimp production and additional species. Tilapia believed to enhance water quality and increase biturbation.	High water exchange- 5-40 % two times a day.	Akiyama and Anggawati, 1999
Presence of green mussels only slightly improve water quality but enhanced growth rate and overall production of shrimp.	Benefits gained from increased shrimp production and additional species. To obtain a effective biofilter further studies of stocking densities are needed.	No significant differences.	Corre *et al*., 1997
Mussel growth 12 to 42 g in 18 weeks. Water quality in drainage channels stable and suitable for mussel growth.	Potential improvement of quality of shrimp pond waste water and production of additional product.	No measurement of nutrient removal capacity or changes in water quality parameters. Only mussel growth measured.	Lin *et al*., 1993
Both species had higher growth rates in polyculture than in monoculture, however, milkfish unable to control epiphytes on seaweeds. Seaweeds increased DO.	Successful integration but growth rates of both fish and seaweed declined over time. Declined seaweed growth probably due to epifytism (green algae).	Good replication. Short duration. No explanation for slower fish growth.	Alcantara *et al*., 1999
Milkfish growth unaffected by presence of seaweed. Fish growth similar to other studies on fish monoculture. Seaweed growth unaffected by tested stocking densities. Season and salinity had greatest effect on overall growth. Growth rates of seaweed similar to other studies in open water and brackishwater ponds.	Seaweed can act as biofilter and provide additional income. Due to seasonal changes it was difficult to maintain gracilaria production for extended periods. Night respiration increased with seaweeds but kept within tolerable limits.	No control for seaweed growth. No measurement of nutrients.	Guanzon *et al*., 2004
Polyculture is more economically beneficial than monoculture but further research is needed into efficiency Return on investment was 2.62.	Better economic returns from polyculture, potential use of earthen ponds that have been abandoned by shrimp farmers.	No comparison with monoculture. Beneficial effects from polyculture not investigated or discussed. No water quality parameters monitored. Economic calculations only including profits from snails.	Kritsanapuntu *et al.*, 2006a Kritsanapuntu *et al*., 2006b

System	Species	Country	Aims	Logistics of culture
SI	• Shrimp (*Penaeus monodon*) • Seaweed (*Gracilaria* sp.)	Brazil	IPMS WM	Shrimp effluent water from commercial shrimp pond culture drained into ditches with seaweed placed on frames. Seaweeds at 0.3 m below surface and 1.2 m above bottom. Shrimp stocked at 25 ind. Fertilization and pellet feeds. Five month study.
P	• Shrimp (*Penaeus monodon*) • Milkfish (*Chanos chanos*) • Mullet (*Mugil cephalus*)	Taiwan	IPMS	Culture of three species in inland ponds which receive water from deep salt water wells.
P	• Shrimp (*Penaeus monodon*) • Milkfish (*Chanos chanos*)	India	IPMS	Brackishwater pond (440 m^2). Stocking rate: 21000 shrimp per ha, 1000 milkfish per ha. Formulated feeds. 72 days study.
P	• Shrimp (*Penaeus monodon*) • Tilapia (*Oreochromis niloticus*)	Thailand	WM	Nine 200 m^2 earthen ponds. Three different shrimp: fish ratios (ind. per m^2) was investigated: 30:0, 30:0.25 and 30:0.5. Nutrients and solids quantified in pond water. Different draining schemes investigated.
P	• Shrimp (*Penaeus monodon*) • Tilapia (*Oreochromis niloticus*)	Thailand	IPMS WT	Nine 200 m^2 earthen ponds. Three different shrimp: fish ratios (ind. per m^2) was investigated: 15:1, 15:2 and 15:4. Culture period 133 days.
P	• Shrimp (*Penaeus monodon*) • Mullet (*Mugil* sp.)	Philippines	IPMS	Brackishwater ponds (21 x 171 m^2) polyculture to find optimal stocking densities for both species. Treatment ratios shrimp and mullet: 5000:0, 0:5000, 0:7500, 0:10000, 5000:5000, 5000:7500,5000:10000. 120 days trial.
P	• Sea cucumber (*Holothuria scabra*) • Shrimp (*Litopenaeus stylirostris*)		IPMS WM	Juvenile sandfish stocked at 0.8 and 1.6 individuals m^{-2} in hapas within 0.2-ha earthen shrimp ponds. Shrimp post-larvae stocked at 20 ind. m^{-2}.
P (SI)	• Sea cucumber (*Holothuria scabra*) • Shrimp (*Litopenaeus stylirostris*)	New Caledonia, (France)	IPMS	Shrimp and sea cucumber were co-cultured in experimental salt water tanks. Shrimp feed not accessible for sea cucumbers. Tanks, 500 L. Juveniles of both shrimps and sea cucumbers used.
P	• Shrimp (*Litopenaeus stylirostris*) • Sea Cucumber	Viet Nam	IPMS	Outdoor fibreglass tanks (1.15 m^3), 6 m^{-3} outdoor concrete tanks, high water exchange. Many different trials were carrier out, including different combinations and treatments.
P	• Shrimp (*Penaeus monodon*) • Tilapia (*Oreochromis niloticus*)	Pilippines	IPMS WM	all inoculation and tank experiment. Fish (500 g m^{-2}) in net-cages inside 3 m^2 outdoor tanks. Shrimps stocked at different densities (80 and 110 g m^{-2}) directly in the tank. Different feeding rates tested. Tank water inoculated with V. Harveyi. Incubation for 15-21 days without water exchange.
P	• Shrimp (*Penaeus monodon*) • Grouper (*Epinephelus coioides*) • Milkfish (*Chanos chanos*) • Tilapia (*Oreochromis niloticus*)	Pilippines	IPMS WM	Small inoculation and tank experiment. Fish (500 g m^{-2}) in net-cages inside 3 m^2 outdoor tanks. Shrimps (80 g m^{-2}) stocked directly in tanks. Tank water inoculated with V. Harveyi. Incubation for 21 days without water exchange.

Results and discussion	General conclusions	Comments	Reference
Seaweed growth rates varied between 1.8 to 8.8%. Silt accumulation on fronds removed every two days. High ammonia concentrations probably inhibiting seaweed growth after some time of culture.	Ammonia in excess may have had negative effect on red seaweed growth. High water turbidity impacting negatively on growth. Integration possible but more studies to find optimal design needed.	No information about water exchange given.	Marinho-Soriano *et al.*, 2002
Polyculture was more effective than any tiger shrimp monoculture. Higher shrimp growth rate in polyculture. Production: Polyculture-1.5 t shrimp + 13.75 t fish; Monoculture- 10.5 t shrimp. Less phytoplankton fluctuation in polyculture ponds.	The impact of inland ponds (10-20km) which use salt-water must be assessed - fresh-water salinization, water exchange, etc. Polyculture reducing risk of harvest loss.	Study summarised in Brzeski and Newkirk 1997. Higher stocking density of shrimps in monoculture resulting in more shrimps being produced. Poor relocation and no economic analysis.	Chiang *et al.*, 1990
High survival rate (>90%) for both shrimp and fish. Highest recorded production of shrimp compared to previous monoculture.	Polyculture showed upon greater returns than monoculture.	No replication. No detailed economic analysis. No monoculture experiments carried out within the study.	Thampy *et al.*, 1988
Results not revealing the different nutrient reduction capacities for the different treatments (with or without tilapia). Tilapia not affecting shrimp growth even if competing for feed. Higher feed input to polyculture did not result in higher phytoplankton abundance. Tilapia consuming phytoplankton and stabilizing water quality, and decreasing water turbidity. More nutrients bound in biomass in polyculture.	The present study showed that shrimp-tilapia polyculture is feasible technically, however, but not attractive economically. Economically viable to co-culture Tilapia with shrimps, but monoculture higher net return.		Saelee, 2004
Growth parameters of shrimp including total weight, survival rate, gross and net yields in the high tilapia density treatment were significantly poorer than those in the medium and low tilapia density treatments. Higher fish density resulted in less DO and higher TAN.	Not attractive economically with high fish density as survival of shrimps decreased. More research needed to optimize the tilapia-shrimp polyculture system. Survival and production of shrimps did not differ between the low tilapia densities.	No comparison was made between monoculture of tilapia and co-culture with shrimps. Only different densities of tilapia together with shrimps was evaluated.	Thien *et al.*, 2004. Thien *2003*
No competition between the two species, but intraspecific competition in highest fish density treatment. Highest total production in combination with shrimps and highest fish density, and lowest production in low density fish monoculture.	Diversification of products seems feasible using the co-culture of shrimps and mullet.	Abstract. Feeding? Nutrients?	Manzano 1982
Survival and growth of sandfish reared with shrimp significantly lower compared to monoculture. Increased shrimp stocking densities impacted negatively on sandfish survival. High stocking density of juvenile sandfish had no significant effects on growth and survival of shrimp.	Co-culture of larger individuals not viable but monoculture in earthen ponds seems promising.		Bell *et al.*, 2007
Growth of shrimp did not differ between monoculture and co-culture. Sandfish grew significantly slower in co-culture. Shrimps lowering water quality for sandfish (increased TAN). Sea cucumber add to turbation but don't significantly remove excess nutrients - not an effective biofilter,	Polyculture at the juvenile stage of both species seems possible. Co-culture may, despite slowed sandfish growth, be more financially sustainable compared to monoculture. Juvenile sandfish cannot be expected to be significant bioremediators for shrimp ponds. Further studies on waste discharge by larger sandfish at higher densities needed.	Researchers suggest seaweed as possible addition to system for biofiltration purpose.	Purcell *et al.*, 2006
Somewhat promising results but predation of sandfish by shrimps was a problem under certain conditions. Authors recommend more research needed before any conclusions can be drawn. Co-culture viable under certain conditions. Study only used many variations on stocking but few replicates.	Potentially co-culture of sandfish at no extra cost and no negative impact on shrimp growth. Harassment and predation of sandfish occurred under some conditions. Predation by shrimps under certain conditions. To high shrimp densities making sediment environment unsuitable for the sandfish. Successful co-culture means greater return for farmers using system.	No economic performance assessed in this study	Pitt *et al.*, 2004
Feeding enhances the antibacterial activity or improves the efficiency of tilapia to inhibit bacteria. Increased shrimp biomass (>80 g m^{-3}) resulted in decreased efficiency in tilapia to inhibit bacteria growth. Shrimp survival was lowest in control tanks without any fish.	Results explain discrepancies found in the use of tilapia to control luminous bacterial disease in shrimp ponds.	Small scale tank experiments conducted during short time.	Tendencia, de la Peña and Choresca, 2006
Tilapia and grouper decreased luminous bacteria levels resulting in increased shrimp survival. Milkfish had no such effect. Shrimp survival was lowest in control tanks without any fish.	Study proved that the presence of tilapia, grouper and milkfish positively affects shrimp survival (tilapia most effectively).	Small scale tank experiments conducted during short time.	Tendencia *et al.,* 2006, Tendencia *et al*., 2003, Tendencia *et al*., 2004, Tendencia *et al*., 2005

System	Species	Country	Aims	Logistics of culture
P	• Oyster (*Pinctada martensi*) • Seaweed (*Kappaphycus alvarezii*)	China	IPMS WM	Both lab. and open sea experiments. Glass container (20 L) used for evaluating seaweed nutrient uptake. Open water experiments: 1) both species cultured in offshore cages, 2) oyster growth in cages in seaweed farm, 3) seaweed grown in cages in oyster farm.
SI	• Oyster (*Pinctada martensi*) • Sea Urchins (*Lytechinus variegatus, Echinometra lucunter*)	Venezuela	WM	Two species of sea urchins were placed on oyster lines in order to attempt to control fouling on the lines and on the oyster.
SI	• Shrimp (*Penaeus monodon*) • Seaweed (*Gracilaria parvispora*)	Hawaii	IPMS WM	Two phase system: fertilization and initial growth of seaweed in ditches, periodically were filled with shrimp pond effluents, and then moved to floating cages in a lagoon for grow-out.
P	• Oyster (*Pteria, Ostrea nomades*) • Siganid (*Siganus canaliculatus, Siganus lineatus*)	Micronesia	IPMS	Oysters were grown on stringers which were placed in pens stocked with rabbit fish
P	• Shrimp (*Penaeus indicus*) • Milkfish (*Chanos chanos*) • Mullet (*Valamugil seheli*) • Sillago (*Liza macrolepis*)	India	IPMS	Polyculture of four species conducted in earthen ponds and coastal net-pens for comparison
SI	• Shrimp (*Penaeus monodon*) • Shrimp (*Fenneropenaeus merguiensis*) • Green mussle (*Perna viridis*)	Thailand	WM	Stable isotope analysis, treatment ponds with mussels
P	• Shrimp (*Litopenaeus vannamei*) • Oyster (*Crassostrea gigas*) • Black clam (*Chione fluctifraga*)	Mexico	IPMS WT WM	Earthen ponds. Monoculture of shrimps compared to polyculture. Growth as well as water quality studied. Study period nine month. Two oyster densities (10 and 16 m^{-2}), two clam densities (8 and 10 m^{-2}) and one shrimp density (30 m^{-2}) was investigated.
P	• Shrimp (*Litopenaeus vannamei*) • Shrimp (*Litopenaeus stylirostris*)	Mexico	IPMS	Earthen ponds
P	• Spotted babylon, (*Babylonia areolata*) • Sea Bass (*Lates calcarifer*)	Thailand	IPMS WM	Indoor tanks
P	• Tilapia (*Oreochromis niloticus*) • Shrimp (*Litopenaeus vannamei*)	Brazil	IPMS	Tanks 1 m^{-3}. Many different densities of both fish and shrimp tested, as well as different sizes fish of (50-200g). Cultivation period 120 days.
P	• Giant Clams (*Tridacna derasa*) • Trochus (*Trochus niloticus*)	Solomon Island	IPMS	Initial rearing of trochus in tanks, then open water cages for grow-out together with giant clams. Species produced mainly for re-stocking but the system could potential also be used for grow-out.

Results and discussion	General conclusions	Comments	Reference
Both species grew faster in polyculture than monoculture. Oyster nitrogen waste stimulated seaweed growth.	*Kappaphycus* can be used as a nitrogenous waste remover in pearl oyster farming and also stimulate pearl oyster production.	Unclear how oysters benefit from seaweeds as they compete with phytoplankton for nutrients.	Qian *et al.,* 1996 Wu *et al*., 2003
One species of sea urchin reduced fouling on lines and shells significantly, while the other only reduced fouling on the lines. Combination of both urchin species reduced fouling on lines and shells as well.	Sea urchins may be viable biocontrolers for fouling in bi-valve line systems. No difference in pearl oyster growth was, however, recorded and this is consistent with past research that oysters are not sensitive to fouling. Reduction in fouling on shells can reduce the amount of cleaning involved before sale, as well as increase overall value of bi-valve product.	No investigation of costs involved for cleaning the oysters and what the reduced fouling by sea urchins could imply from an economic point of view.	Lodeiros and Garcia 2004
Relative growth rates of effluent-enriched thalli in the cage system ranged from 8.8% to 10.4% day^{-1}. Growth of thalli fertilized with inorganic fertilizer was 4.6% $day^{-1.}$ Thalli in the effluent ditch had mean growth rates of 4.7% day^{-1}.	Enhanced growth of seaweed and the use of effluent from commercial shrimp farms as a resource.	Costs involved in maintenance (handling, transportation, etc.) not considered.	Nelson *et al.*, 2001
Siganids observed to eat algae which normally creates fouling, and more spat settled on nets when fish were present.	Cleaner equipment, decreased demand on labourers, greater production of oysters as a result of less fouling, and benefits of additional commercially viable species in rabbit fish. Enhances production, additional commercially viable product.		Hasse 1974
Mullet and Sillago showed better growth in net-pen, while milkfish showed better growth in pond. No difference between fertilized and unfertilized ponds in terms of growth.	Diversification of products. Benefits of multiple commercially viable products.	Abstract	James *et al.*, 1984
dC value suggesting that shrimp feed was the main food source for the mussels	Reduced particle load from biofilteering by the mussels.	Growth was not measured and no comparisons was made with monoculture outflow (i.e. biofiltering efficiency not made). Study just showing potential for co-culture. No economics considered.	Yokoyama *et al.*, 2002
Total ammonium nitrogen, total suspended solids and chlorophyll-a significantly lower in the ponds with the highest combined density of molluscs. Increased shrimp growth in Polyculture.	*Crassostrea gigas* showed not to be a good prospect for this polyculture (low survival (10-16%) due to high temperature).	No estimation of extra costs involved for farming multiple species.	Martinez-Cordova and Martinez-Porchas 2006
Litopenaeus vannamei and *L. stylirostris* exhibit some differences in their feeding preferences. Litopenaeus stylirostris is probably more carnivorous than *L. vannamei*, which can consume plant material quite well.	Lower FCR for polyculture, Higher production from increased growth (*Litopenaeus stylirostris*) and higher survival (both species). No economic analysis (even though data on FCR, growth available)		Martínez-Córdova and Pena-Messina 2005
Average growth, survival, FCR and total production of spotted babylon and sea bass from polyculture were not significantly different from those in monoculture.	Unclear. No obvious benefits. Decreased culture area could be one benefit from polyculture. No water parameters measured. No decreased resource usage.		Chaitanawisuti *et al.*, 2001
L. vannamei can be grown in association with tilapia *O. niloticus* in different combinations and receiving only one type of feed).	Polyculture showed upon similar growth and survival as monoculture.	Not evaluated but potential for more efficient resource utilisation and increased profits from an additional crop. Water quality not considered.	Candido *et al.*, 2005 *(In Spanish- abstract English)*
Trochus had no deleterious effects on the growth and survival of giant clams. Some indications of higher growth and survival of the giant clams at the highest stocking density of trochus. *Trochus* ineffective at removing larger species of algae.	Utilizing an existing culture facility (multiple crops). Growth and survival of the giant clams were improved at the highest stocking density of trochus, but this density was not optimal for trochus growth.		Clarke *et al.*, 2003

System	Species	Country	Aims	Logistics of culture
SI	• Shrimp (*Penaeus japonicus*) • Oyster, (*Saccostrea commercialis*) • Seaweed (*Gracilaria edulis*)	Australia	WM	Effluents from commercial shrimp ponds transferred to 11 indoor tanks. Biofiltration efficiency measured in a three-stage effluent treatment system consisting of sedimentation tank, oyster and seaweed. Close monitoring of suspended particles and dissolved nutrients. 24-48 hours experiments.
MI	• Shrimp (*Litopenaeus vannamei*) • Mangroves	Colombia	WM	Shrimp pond wastes from a 286 ha farmpartially recirculated through a 120 ha mangrove. Study conducted over three month period. Suspended solids and inorganic nutrients measured.
P	• Milkfish (*Chanos chanos*) • Siganid (*Siganus rivulatus*) • Seaweed (*Eucheuma denticulatum, Kappaphycus alvarzii, Ulva* spp., *Gracilaria crassa*) • Shellfish (*Pinctada margaretifira, Anadara antiquata, Isognomon isognomon*)	Tanzania	IPMS WM	Pond culture of milkfish and rabbit fish and two seaweed species (*Euchuema* spp.). Fish fed artificial feeds. 40000 m^{-2} large reservoir and and 300 m^{-2} treatment ponds. Study conducted over 8 month period.
SI	• Shrimp (*Litopenaeus vannamei*) • Oyster (*Crassostrea rhizophorae*)	Brazil	IPMS WM	Experiments carried out at two commercial shrimp farms. Oysters were cultivated on constructed beds after the sluice gate of the farm. Oysters harvested after 3 month. 4500 oysters per sluice gate (6 gates).
SI	• Shrimp (*Penaeus monodon*) • Tilapia (*Oreochromis niloticus*)	Thailand	IPMS WT WM	Shrimps grown in 5 m^{-2} concrete tanks with tilapia in cages within the tanks. No water exchange and experiment conducted for 60 days. Effects from different tilapia stocking densities on shrimp growth and water quality evaluated. Economic performance also evaluated.
SI	• Shrimp (*Penaeus monodon*) • Oyster (*Crassostrea belcheri*)	Thailand	WM	Lab. experiments to study oyster feeding. Field experiment where shrimp pond water was diverted into small tanks with Oysters. Part of the study also to qualitative and quantitative analysis of shrimp pond effluents (from 20 farms).
SI	• Shrimp (*Penaeus monodon*) • Mussel (*Perna viridis*)	Thailand	WM	Experiment 1: culture of mussels in drainage canal, testing culture methods; Experiment 2: 3 Litres tanks stocked with mussels received water from a commercial shrimp pond. Investigating filtration and biodeposition.
P	• Shrimp (*Penaeus monodon*) • Milkfish (*Chanos chanos*) • Siganid (*Siganus* spp.)	Indonesia	IPMS	Earthen ponds (> 1 ha). Testing growth performance and water quality under different species combinations (milkfish monoculture, shrimp-milkfish, siganid-shrimp).
P	• Milkfish (*Chanos chanos*) • Shrimp (*Penaeus monodon*)	Thailand	IPMS	Milkfish and shrimps reared in different combinations for 100 days in 500 m^{-2} earthen ponds.

Results and discussion	General conclusions	Comments	Reference
Detailed information regarding potential sedimentation and nutrient regeneration rates, oyster filtration rates, and nutrient uptake rates. Overall, improvements in water quality TSS 12%; total N 28% ; total P 14% ; NH 76% ; NO 30%; PO_4 35%; bacteria 30% ; and chlorophyll a 0.7%. High N content in the small unsettleable particles being removed by the oysters.	Showing upon the capacity to filter shrimp wastes using oysters and seaweeds.	Small-scale experiment difficult to really extrapolate to commercial conditions. Flow rate through the different treatment staged of great importance. Proper controls without biofiltering organisms.	Jones *et al.*, 2001
Phytoplankton and zooplankton density decreased passing the mangrove filter. Total and organic particulate removal rate in the biofilter was about 95% and 93%, respectively. Dissolved inorganic nitrogen and phosphorus increased (probably due to presence of large bird communities in the forest).	Possible use of mangrove wetlands as biofilters for effluent treatment will be less predictable than expected.	No replication or controls. No separation of dilution effects and true uptake/ transformation. Not known how long the biofilter function persists. Effects from permanent flooding of the mangroves also not known. Effects on forest functions not known. Supply water and biofilter exit close?	Gautier *et al.*, 2001
Water quality deteriorated significantly, with low DO and high ammonia levels. Poor seaweed growth in ponds but high growth in the channels.	Potential benefits of multiple commercially viable species. Water quality deteriorated potentially having an adverse effect on growth of cultured species and the environment.	Water quality deteriorated suggesting that this system may not be sustainable.	Mmochi *et al.*, 2002, Mmochi and Mwandya 2003
Decreasing Inorganic P and Chlorophyll a. No clear effect on dissolved N, some month decreasing concentrations in effluents and some month increasing.	Reduction of Chlorophyll and production of secondary crop. Potential for co-culture and potential for increasing farmers income.	Sometimes dissolved nitrogen increased. Not known if total particulate loading was effected as this was not studied. Growth was measured but no comparison with other cultivation methods performed and no overall economic analysis was carried out.	Oliviera and Brito 2005
Tilapia lowered dissolved N (but not significant) but increased Chlorophyll a. Tilapia regenerating N from shrimp wastes. No effect on dissolved P from integration. Competition between shrimp and tilapia for detritus. Tilapia increased economic returns only at lower stocking densities of shrimps (5-25 ind. per m^3).	Lowering dissolved N. Increasing economic return at low stocking densities of shrimps. Increasing phytoplankton densities, competition for detritus at higher stocking rates.		Yacoob 1994
More testing the suitability for using oysters fed shrimp waste water (feed quality (phytoplankton), optimal water velocities, pre-settling of waste water). Ammonia-N increased by 2.7 %, nitrite 10.1% and nitrate 4.6%.	A hypothetical 1 ha integrated farm could by using 5 % area for oyster units remove 21 % of total suspended solids, 9% of total N and 6 % of total P. This removal are based on 40% water exchange per day.	Very mechanistic study- difficult to extrapolate to commercial scale. Anticipated that it should be profitable under good management, but no economic calculations presented. Settling ponds removed more than double the amounts removed by oysters.	Tanyaros 2001
The experiment failed to say something about how efficient mussels can reduce particles in shrimp waste water due to logistical problems. Also changes in water nutrient concentrations could not be conclusive.	Mussels did grow but the growth period was to short (due to shrimp diseases) to be able to say something about the potential growth. They could utilize food in the waste water.	Mussels died twice due to salinity fluctuation. Problems with epiphytic growth on culture trays. Low water exchange caused stagnant water in canals- leading to low food availability and high temperatures. Experiments could not show upon effects on water quality form mussel filtration (due to design).	Buakham 1992
Lower production (biomass) in polyculture. Integration of shrimps and siganids successful- occupying different nisches (shrimp bottom feeded, siganids pelagic feeder).	Total production lower in polyculture but generating a higher value due to shrimp production (compared to milkfish monoculture).	Difficult to evaluate as different stocking densities and feed inputs been used.	Ranoemihardjo 1986
Negative impact on shrimps from milkfish but a positive effect from shrimps on milkfish.	If focus is on milkfish adding shrimps could increase fish growth. Water quality not changing in polyculture compared to monoculture but stocking densities very low (max 1 ind. per m^2).	Slow growth of shrimps if reared in higher densities due to insufficient feed (natural production stimulated by fertilisers).	Pudadera and Lim 1982, Pudadera 1980

System	Species	Country	Aims	Logistics of culture
SI	• Shrimp (*Penaeus monodon*) • Grey mullet (*Mugil cephalus*) • Siganid (*Siganus nebulosus*) • Seaweed (*Ulva* sp.)	Australia	WM	Earthen ponds (1 ha) and 10 m^3 tanks. Inclusion of vertical artificial substrates (VAS, AquaMatt™).
SI	• Milkfish (*Chanos chanos*) • Siganid (*Siganus rivulatus*) • Seaweed (*Ulva reticulata*)	Tanzania	WM	Gravity fed earthen ponds. Seaweeds suspended in fishnet cages in outflow channels. Low stocking density of fish. Only focus on seaweed performance.
SI	• Milkfish (*Chanos chanos*) • Siganid (*Siganus rivulatus*) • Seaweed (*Ulva reticulata, Gracilaria crassa, Eucheuma denticulatum, Chaetomorpha crassa*)	Tanzania	WM	Gravity fed earthen ponds. Seaweeds suspended in fishnet cages in outflow channels (except *Eucheuma* that was planted using 20-mm nylon ropes) . Low stocking density of fish. Only focus on seaweed performance.
P	• Shrimp (*Penaeus vannamei*) • Oyster (*Crassostrea virginica*) • Mullet (*Mugil cephalus*) • Tilapia (?)	USA	IPMS WM	Main focus on water exchange regime in shrimp pond farming. No-exchange ponds (600 m^2) were occasionally recirculated through a 0.1 ha pond containing oysters, mullet, tilapia and bait fish. Shrimps stocked at 38-78 PL per m^2. Manure and Urea supplemented. Pellet feed used as supplemental feeding for shrimps.
P	• Shrimp (*Penaeus monodon*) • Milkfish (*Chanos chanos*)	Philippines	IPMS	Eight 500 m^2 earthen ponds stocked with different combinations of fish and shrimps: 20,000 juv. shrimps with 2,000 milkfish fingerlings per ha; 20,000 juv. shrimps; 2,000 milkfish fingerlings per ha in monoculture. Natural production of food in ponds through fertilization. Experiment conducted for 109 days.
P	• Shrimp (*Litopenaeus vannamei*) • Seaweed (*Kappaphycus alvarezii*)	Brazil	IPMS WM HP	Experimental PVC cages (grow-out 100 shrimp per m^{-2}) with seaweed fixed in floating tubes and disposed inside. Experiment carried out for 103 days.
SI	• Shrimp (*Penaeus japonicus*) • Oyster (*Saccostrea commercialis*) • *Gracilaria edulis*	Australia	IPMS WM	Effluents from earthen shrimp ponds (6x1 ha) pumped into 15x34L oyster tanks (oysters on trays). Three different oyster densities: 24, 16 and 8 per tank. Controls with dead oysters included in the study.

Results and discussion	General conclusions	Comments	Reference
Mullet alone not resulting in significant N reduction (only 1.8- 2.4%), but contribute to control of macroalgal (*Ulva*) biomass. Mullet probably inhibit nitrification but process sedimented organic material.	Removal of algae and consumption of detritus. No significant effect on N removal and possible reduction of nitrification. Artificial substrate important for particle settlement.		Erler 2000 Erler 2004
Seaweed growth 4% per day under study period. TAN removal 65%. Controls without seaweeds also removing TAN – efficiently pH and oxygen level raised by seaweed.	Growth possible. Nutrients will be removed. Increased oxygen and pH	Study covered short period. Not clear if nutrient concentrations in outflow from fish ponds is representative for commercial practice. Special setting with gravity fed water to biofilter unit. This may not be applicable to most farms. The need for area will be large in commercial production and area in channels will probably not be sufficient. Controls without seaweeds also removed TAN efficiently.	Msuya *et al.*, 2006
Poor growth *Gracilaria crassa* and *Ulva reticulata* (1.5 and 1.2 %) but good quality with protein dry weight contents of 13%. *Eucheuma* and *Chaetomorpha* performed poorly in the fishpond effluents. Nutrient uptake (nutrient removal) based on nutrient content in seaweeds.	Growth possible for three of the investigated species. Removal of nutrients. Increased oxygen and pH	Study only covered short period. Not clear if nutrient concentrations in outflow from fish ponds represent commercial practice. Study mainly showing that the seaweeds can grow in present set-up. No. Special setting with gravity fed water to biofilter unit. This may not be applicable to most farms. The need for area will be large in commercial production and area in channels will probably not be sufficient.	Msuya and Neori 2002.
Good survival but somewhat lower in systems with no exchange of water compared to 15% exchange in monoculture. Trends towards higher production in ponds with exchange. Higher BOD in re-circ. system. No clear difference in dissolved nutrients but generally higher TSS in the re-circulation system. No significant difference in growth and survival rates between the different combinations.	Good water quality at used stocking densities, sufficient DO, extra crops and saving cost for water pumping. Water could also be reused. Reduction of effluents to the environment.	Results not clear and the two experiments indicate large variability in system performance. Potential lower production of shrimps in re-circ. system. Higher FCR in re-circ. System. Only pumping costs discussed and these decrease in re-circ. system. No other costs or profits included.	Hopkins *et al.*, 1997
No negative interaction between milkfish and shrimps. Good growth and survival in all treatments. Physio-Chemical Parameters similar between mono-polyculture.	Additional crop in polyculture systems with kept growth rates for individual species. No feed input.	Very low stocking densities (2 ind. per m^{-2}) with natural food in pond. Thorough economic analysis. Best economic return from polyculture. Economic feasibility with return on investment (ROI) valued at 45 percent for polyculture. Large land areas needed for increased production.	Kuntiyo and Baliao 1987
Floating cages are a viable alternative for rearing *L. vannamei* in open sea water and also with co-culture of seaweeds. Annual shrimp production 25-30 mt per ha. Rather poor seaweed growth (0.8-1.3% day^{-1}).	Multiple crops, nutrient reduction. Positive aspects from shrimps using algae as shelters and production of natural food need to be further investigated. Nutrient removal. Farming shrimps in open water reduce pressure on coastal land.	There were no negative interferences in culturing shrimps and algae inside the same cage. Cages seem to limit growth compared to rope cultures. Only profitable on small commercial scale. NO monoculture of seaweeds investigated. Why not seaweeds on surface?	Lombardi *et al.*, 2006, Lombardi *et al.*, 2001
Most effective oyster filtration (24 oyster treatment) could reduce concentration of TSS (49%), TN (80%), TP (67%), Chl. a (8%), bacteria (58%) in incoming water.	Reduction of particles, phytoplankton and total nutrients in effluent waters A 20% water exchange in a 1ha shrimp pond would need 0.12 ha oyster tanks (120000 oysters, 24 oysters per tank).	Not separating dissolved and particulate nutrients (possible build-up of NH4). Experiment short and limited period of the year.	Jones and Preston 1999

System	Species	Country	Aims	Logistics of culture
SI	• Shrimp (*Penaeus japonicus*) • Oyster (*Saccostrea commercialis*) • *Gracilaria edulis*	Australia	IPMS WM	Earthen shrimp ponds (1 ha), 1500 L concrete raceways , flow-through and re-circulation experiments.
P	• Shrimp (*Penaeus monodon*) • Sandfish (*Holothuria scabra*)	Viet Nam	WM	Earthen ponds (1.2 ha + 0.45 ha). Polyculture, 30 PL shrimps per m^2, and 50 and 100 g sandfish m^{-2}. Shrimp receiving artificial feeds.
SI	• Shrimp (*Penaeus monodon*) • Gracilaria (*Gracilaria fisheri, G. Tenuistipitata*)	Thailand	IPMS	Earthen ponds (800 m^{-2}) stocked with seaweeds receiving waste water from extensive shrimp ponds.
SI	• Shrimp (*Penaeus monodon*) • Cockle (*Scapharca inaequivalvis*) • Gracilaria (*Gracilaria* sp.)	Malaysia	IPMS WM	Shrimp pond wastes (5.5 m^3 per day) pumped into earthen ponds: one (30 m^{-2}) stocked with cockles and one (18 m^{-2}) stocked with seaweeds. System running for one month.
P	• Shrimp (*Penaeus chinensis*) • Tilapia (*Oreochromis mossambicus x O. Niloticus*)	China	IPMS	Net enclosures (5.0 x 5.0 x 1.8 m) with fish in a closed 1.7 ha seawater pond. Fish also stocked outside the cages. Stocking: 4.5- 7.5 shrimp and 0-0.32 fish per m^2. Fertilizers and pellet feeds added..
P	• Shrimp (*Penaeus monodon*) • Milkfish (*Chanos chanos*) • Seaweed (*Gracilaria lichenoides*)	Indonesia	IPMS	Earthen ponds (0.1 ha) . Different stocking combinations investigated. Three planting methods for seaweeds investigated.
P	• Shrimp (*Penaeus monodon*) • Tilapia (*Oreochromis niloticus*)	Philippines	IPMS	Monoculture was compared with polyculture two times during a year. Production 81-138 kg per ha for shrimps, Stocking 0.6 shrimps per m^2 (final weight 26-30 g per ind.), 0.4-0.6 fish per m^{-2}
MI	• Mud crab (*Scylla serrata*) • Mangrove (reforested)	Philippines	IPMS HP	Crabs held in 200 m^2 pens and effects of stocking density (0.5 or 1.5 m^{-2}) and feed (fish or mixture fish/mussel) was tested for 160 days.
P	• Shrimp (*P. Monodon, P. Japonicus, P. merguensis*) • Tilapia (*Tilapia Mossambicia*) • Milkfish (*Chanos chanos*) • Sidanid (*Siganus vermiculatus*)	Indonesia	IPMS	Sea water in earth fishponds (2000 m^2) on reclaimed mangrove areas. Chicken manure, brewery waste and sugar mill wastes used as inputs.
P	• Sea bream (*Acanthopagus cuvieri*) • Tilapia (*Oreochromis spilurs*)	Kuwait	IPMS	Different sea bream densities (3, 6, 9 ind. per m^2) stocked in twelve 1 m^3 floating cages with tilapia (200 ind. per m^2) to decrease competition over feeds with wild fish. Experiment was conducted over eight weeks.
P	• Shrimp (*Litopenaeus vannamei, juveniles*) • Tilapia (*Oreochromis niloticus, juveniles*)	Thailand	IPMS WT WM	Different densities of fish and shrimps in same outdoor tank (2×2.5×1.1 m^3). Shrimps stocked at 40 ind. per m^{-2} and tilapia: 0, 0.4, 1, 2, 3 fish per m^2. Shrimps fed pellets.
P	• Shrimp (*Penaeus monodon*) • Tilapia (*Oreochromis niloticus*)	Thailand	IPMS WT	Fish and shrimps stocked in same outdoor brackishwater tanks (fish: 30 ind. m^{-2}, shrimp PL 50 m^{-3}) (also using AquaMats). Shrimp was fed pellet feeds.

Results and discussion	General conclusions	Comments	Reference
Different oyster densities tested. Oyster filtration reduced concentration of TSS (29%), TN (66%), TP (56%), Chl. a (39%), bacteria (35%) of the initial concentration. Seaweeds of low quality in high density oyster treatment and in high particulate concentration. Settling ponds important for reducing TSS before oyster filtration.	Oyster survival sensitive to both oyster and seaweed densities, as well as particulate loading. Reduction of wastes from shrimp ponds by the tested approach feasible.		Jones *et al.*, 2002
Polyculture had lower conc. of bacteria H_2S, $N0_2$ and total organic compounds. Also sediment in polyculture had lower content of organic matter. Growth rate of shrimps increased in polyculture with sandfish.	Seems possible to culture shrimp and sandfish in polyculture or shrimp followed by sandfish. Increased quality of pond environment in polyculture, as well as increased growth of shrimps.		Ngoc 2006
Growth 37-40 % better in ponds receiving shrimp waste water. Growth rates between 2.6-3.1%.	G. fisheri could be grown all around the year, but *G. Tenuistipitata* only possible 6-7 month of the year (due to too high temperatures and low salinity).	Growth rates low compared to other cultures of gracilaria. Interfering epiphytic seaweeds making the cultured seaweeds float to the surface.	Chirapart and Lewmanomont 2004
An average reduction of 83% of phosphate; 61% in total phosphorus; 81% in ammonium; 19% in nitrite; and 72% in total nitrogen. Gracilaria out competed by green algae (*Enteromorpha* sp.).	Cockles could probably be exchanged by oysters that could be stocked in existing channels system at the farm. Seaweeds could be controlled by chemicals.	Short study. No controls identifying effects from the ponds themselves.	Enander and Hasselstrom 1994
Production of shrimps at 6 ind per m^{-2} was 514 kg per ha^{-1}. Optimum stocking density of shrimp and tilapia was 60,000 shrimp and 400 kg tilapia per ha.	Growth rate and survival of shrimp increased with increasing stocking density of tilapia. Tilapia maintained optimal and constant biomass of phytoplankton. Tilapia enhances water movement and nutrient cycling.	Tilapia competed with the shrimp for food if not separated in cages (or feeding grounds for shrimp surrounded by a net).	Wang *et al.*, 1998
Focus on addition of seaweeds to existing Tambaks. Seaweeds attached to bamboo screens resulted in best growth (ca 3% daily growth rate). Calculating with 25% seaweed cover in ponds result in 3000 Kg per ha per year.	Good seaweed growth when cultured with shrimps or fish. Seaweed growth decreased when cultured with both species. Decreased growth of shrimps when cultured with fish, and vice versa.	No control present and therefore difficult to say anything about the effects from the animals.	Sutika *et al.*, 1990
Higher growth of both shrimps and fish in combination 0.4 fish per m-2 compared to monoculture treatments.	Detailed economic analysis (in Samonte *et al.*). Two crops per year provided a 70% return on investment and a 1.2 years payback. This was higher return compared to monoculture using same densities .	Using data from Gonzales-Corre 1988 to perform a detailed economic analysis.	Gonzales-Corre 1988, Samonte *et al.*, 1991
Growth was not significantly affected by stocking density or feed types.	The integration of crab aquaculture within natural mangroves is feasible, providing both immediate and long-term commercial and environmental benefits. Return on capital investment of 49–68%.	Not showing how mangroves are effected by this kind of culture.	Trino and Rodriguez 2002
Shrimp performance was compared and *P. monodon* had highest survival and growth rate. The other shrimp species could possibly survive better in more sandy soils.	Polyculture of *P. monodon* and fish possible.	Performance and interaction with fish difficult to access as different stocking rates was used and no controls.	Gundermann and Popper 1977
No effect on tilapia production. Placing sea bream monoculture cages close to tilapia cages could potentially minimize interaction from wild fish.	No benefits that not could be obtained from placing sea bream cages in the vicinity from tilapia cages (no need to be inside).	Thorough economic calculation. Potentially can sea bream feed being utilized by tilapia.	Ridha and Cruz 1992
Tilapia stocking significantly improved P conversion rate but the N conversion and shrimp growth rates decreased with high tilapia stocking. Net income was not significantly different between mono and polyculture.	Integrated system with a low tilapia–shrimp ratio (the ratio of 0.01 and 0.025) were effective to improve the nutrient conversion rate to culture animals without lowering shrimp growth.		Muangkeow *et al.*, (in press)
Tilapia increased shrimp survival but decreased growth.	Potential improved water quality in co-culture with tilapia but decreased shrimp growth. Questionable if fish production can compensate for lower shrimp yields		Ngo 2000

System	Species	Country	Aims	Logistics of culture
SI	• Shrimp (*Penaeus monodon*) • Mussel (*Mytilus* sp.) • Seaweed (*Gracilaria fisheri*)	Thailand	WT	Indoor 200 L tanks stocked with different combinations of species. Experiments conducted over 12-48 hours.
P	• Mudcrab (*Scylla serrata*) • Milkfish (*Chanos chanos*)	Philippines	IPMS	Different stocking densities of milkfish and crabs was tested in polyculture in three 0.1 ha earthen ponds (subdivided by bamboo screens). Culture period 130 days.
SI	• Shrimp (*Penaeus vannamei*) • Oyster (*Crassostrea virginica*) • Clams (*Mercenaria mercenaria*)	USA	IPMS	Shrimp and biofilter ponds 0.1 ha in re-circulation. Treatment pond with oysters on trays or directly on pond bottom, and clams directly on bottom. Shrimps stocked at 60 ind. per m^{-2}.
P	• Shrimp (*Penaeus monodon*) • Milkfish (*Chanos chanos*)	Philippines	IPMS	Earthen ponds, 500m^{-2}, three different stocking combinations; monoculture milkfish, low (4000 ind. per ha) and high (8000 ind. per ha) shrimp polyculture. Only fertilizers used as input.
SI	• Shrimp (*Penaeus vannamei*) • Oyster (*Crassostrea virginica*)	Thailand	IPMS	Two flow through tanks (310 L) receiving waste water from commercial semi-intensive shrimp ponds. Oysters stocked on trays and pond water flowed downward through each of two seven tray stacks. Experiment lasted for 268 days.
SI	• Shrimp (*Litopenaeus vannamei*) • Constricted tagelus (*Sinonovacula constricta*)	China	IPMS WM	Two systems containing six shrimp ponds (tot area 0.93-1.3 ha), one mollusc pond (0.67-1.20 ha) and a a reservoir was run in recirculation mode. Culture period 81–106 d^{-1} for shrimps, and 240–350 d^{-1} for tagelus. Shrimps stocked at 128-135 ind. per m^2. Natural foods in the water from the shrimp ponds used for tagelus, being stimulated by adding fertilisers . Daily circulation rate was 10%–20% of the total water volume of the system (excluding reservoir volume) in early stage, 20%–30% in middle stage, and 40% in late stage. System also included artificial biofilm.
P SI	• Shrimp (*Penaeus monodon*) • Seaweed (*Gracilaria changii*)	Malaysia	IPMS WM	Gracilaria was cultured on i m^2 frames on lines, at 15 cm interval from the surface. The frames were placed in the middle of a shrimp pond and also in irrigation canal. A third treatment was seaweeds placed in ponds in the mangroves. Growth was studied during 12 weeks and repeated 3 times.
SI	• Shrimp (*Penaeus monodon*) • Mangrove (*Rhizophora mucronata*)	Indonesia	WT	Mangroves in a natural “reservoir pond” receiving shrimp pond effluents from 12 2500 m” earthen ponds. Artificial pellets, stocking rate 40 per m^2.
P	• Sea bass (*Lates calcarifer*) • Seaweed (*Gracilariopsis heteroclada*)	Philippines	IPMS WT	Seaweeds on ropes suspended at different depth in Sea bass (fingerlings) cages. Empty fish cages used as controls. Polycultue with fish mainly as biological control (predation on herbivorous fish).
P	• Grouper (*Epinephelus* sp.) • Seaweed (*Kappaphycus alvarezii*)	Philippines	IPMS WT	Seaweeds on ropes suspended at different depth in Grouper (juveniles) cages. Empty fish cages used as controls. Polycultue with fish mainly as biological control (predation on herbivorous fish). Different culturing techniques of seaweeds were tested.

Results and discussion	**General conclusions**	**Comments**	**Reference**
Ammonia-nitrogen decreased 67% in seaweed treatment, but increased in mussel and mussel/ seaweed with over 600%. between 8-54% in all treatments during 48 hours. Treatment had no significant effect on suspended solids. Chlorophyll a and BOD+COD decreased (20-100%) in all treatments ($P<0.05$) during 48 hours.	Variable results depending on duration of incubation.	Small scale and short term experiments (indoor) which makes it difficult to extrapolate to outdoor conditions. Large variation within treatments.	Chaiyakam and Tunvilai 1992, Chaiyakam and Tunvilai 1989, DOF 1992
Net production of crabs was higher in polyculture at both stocking densities (5 and 10 000 per ha). For milkfish the opposite was observed.	Fish may 1) increase food availability for the crabs, and 2) their presence may reduce movement of crabs and thereby minimizing interactions between crabs. .	FCR given but no information about feeding.	Lijauco *et al.*, 1980
Growth and survival of shrimps not effected by bivalves. Good growth of bivalves with the exception during the warmer period. High mortality of clams only immediately after stocking. Oyster survival high only for oysters in trays.	Only ammonia-N decreased (30%) in polyculture ponds. Not possible to grow oysters directly on bottom. Fairly high infestation of oyster shell mud blister (caused by *Polydora* sp.).	No costs or profits included. Mentioning of low investment costs for co-culture but potentially higher costs for handling. Difficult to explain the decrease in ammonia-N and that only minor differences was found in particle conc.	Hopkins *et al.*, 1993
Highest combined milkfish and shrimp production in high shrimp density treatment. Shrimps had a positive effect on milkfish production. Mean survival rate ranged from 90 to 96% for milkfish and was about 50% for shrimps; it did not differ significantly with treatment.	Extensive system reaching max. 380 kg milkfish and 116 kg shrimp per ha per 4 month culture period.		Eldani and Primavera 1981
Mean oyster growth rate was 2 g $week^{-1}$ (up to 3.7 g wk^{-1} in upper layer certain period) and survival was 79%. It was concluded that the prospects for shrimp and bivalve co-culture appear promising.			Jakob *et al.*, 1993, Wang *et al.*, 1990
Tagelus pond decreased the concentrations of suspended matters and PO_4-P, and also COD and inorganic nitrogen to certain extent. TAN reduced by 19-64% and suspended solids by 45-90%.	The water quality in the ponds was maintained at a desirable level and no viral epidemics were discovered. Income from mollusc culture accounted for 22.1% of the systems total, the profit accounts for 52.6% of the total.	Probiotics (mostly nitrifiers) and fertilizers applied in tagelus ponds. Low profits from shrimps due to late stocking (small sizes). No controls used to isolate the filter feeding effects from pond effect (sedimentation etc.).	Wu *et al.*, 2005
Seaweed growth rate was three times higher in the irrigation canal compared to the shrimp pond and the natural mangrove (8.4, 3.6 and 3.3%, respectively). The seaweed cultivated inside the shrimp pond were heavily epiphytised and grazed upon (by fish). Seaweed growth best at the surface.	Seaweed growth was limited by epiphytes and high water turbidity. This could to some extent probably be solved through better placing in the pond , i.e. towards the edge of the pond. No quality measurement (i.e. Agar) was done on seaweeds cultured in the shrimp pond or in irrigation canal.		Phang *et al.*, 1996
Water nutrient concentrations were lower in the mangrove reservoir pond but e.g. NH_4 followed the slowly build-up experienced in the shrimp ponds. Tank experiment with mangroves showed upon large uptake capacity of mangroves (70% of NO_3, NH_4).	Difficult to say anything about nutrient removal efficiency as no controls were used in pond experiment, and no details were given about the tank experiments. Only 7 week experiment.		Ahmad *et al.*, 2003
Specific growth rate of seaweeds significantly influenced by the fish. Probability from predation of small herbivore fish. Best growth at 25 cm depth. Approx. 172 g (dry) m^{-2} $month^{-1}$ was produced.	Presence of fish not increasing seaweed growth all month (not in April when seaweed growth was highest).	Not studied how fish growth is being impacted by the presence of seaweeds.	Hurtado-Ponce 1992c
Better growth using horizontal technique (ca. 5%).	Illustrates the potential to co-culture the seaweed with groupers in cages.	No comparison was made with cages without fish. The potential positive effect from either increased nutrients or prevention of grazing could therefore not be studied.	Hurtado-Ponce 1992b

System	Species	Country	Aims	Logistics of culture
SI	• Mangroves (impounded, predominantly *Avicennia rumphiana/A. officinalis/ Nypa fruticans*) • Shrimp (*Penaeus monodon*)	Philippines	IPMS WT HP	Wastes from intensive shrimp ponds (with milkfish in net-pens) diverted into natural mangrove stand. Shimp stocking density 10-30 shrimp postlarvae per m^2.
P MI	• Mangroves (predominantly *Avicennia marina*) • Mud crab (*Scylla olivacea, S. Serrata, S. Tranquebarica*)	Philippines	IPMS HP	Mud crabs stocked at 0.5-0.8 m^{-2} in 200 m^2 net-pens. Different feed combinations evaluated.
SI	• Green mussel (*Perna viridis*) • Spiny rock lobster (*Panulirus ornatus*)	Viet Nam	IPMS WM	Investigating growth of lobster fed different feed combinations-one being mussels farmed outside cages. Also measuring how integration effected different environmental quality parameters.
SI	• Green mussel (*Perna viridis*) • Seaweed (*Kappaphycus alvarezii*) • Grouper (*Epinephelus fuscoguttatus*) • Abalone (*Haliotes asinina*)	Viet Nam	IPMS WM	Grouper in 9 m^2 cages, mussels and seaweeds hanging on long lines outside cages, abalone kept in baskets inside fish cages. The weight ratio of cultured grouper, green mussel and alga was 3:1:12. Dissolved oxygen measured weekly and NH_3-N, NO_2-N, PO_4-P, Chlorophyll once a month. Grouper was fed on trash fish and experimental period lasted 10 month.
SI	• Giant Clams (*Tridacna derasa, T. Gigas, T. Maxima, T. Squamosa*)	USA	IPMS WM	Clams stocked in indoor raceways (2.5 x 0.3 m) receiving waste water from fish culture. Clam sizes between 32- 87 mm. Two month experiment.
SI	• Giant Clams (*Tridacna derasa*) • Snails (*Astrea tecta*)	USA	IPMS WM	Clams stocked in two indoor tanks (300 L) receiving waste water from fish culture (0.01 kg fish (snappers) per L) in re-circulated system. Clam sizes between 4.5 - 11 cm. Six month experiment. Herbivorous snails added to control biofouling.

Results and discussion	General conclusions	Comments	Reference
Mangroves reduced wastes by 64.2% for TSS, 34.0% for sulphide, 24.8% for NH_3 and 18.7% for NO_3 in the first 6 h. Night-time draining resulted in net production of nutrients from the mangroves. Growth of saplings and trees was 2.5 times greater in the treated mangroves compared to controls.	Based on overall findings it was estimated that a 2.18-4.36 ha of mangroves would be needed to treat N wastes from one ha of shrimp pond.		Primavera *et al.*, 2007
S. olivacea had low growth and low survival rates in all treatments.	Crabs have no impacts on adult mangrove trees, only on seedlings and saplings. Economic analysis showed that crab culture in mangrove pens using a combination of fish biomass and pellets is viable.		Primavera *et al.*, in press
Lobsters fed on mussel had higher survival rate than those fed by-catch. Growth rate the same. Organic matter in the deep water and sediment was lower under the combined culture compared to monoculture of lobster. Also bacterial densities decreased.	The results suggest that mussel and lobster co-culture potentially can lessen dependence on capture fishery resources, increase lobster growth reduce negative environmental impacts.	Preliminary results without statistical analysis.	Pham *et al.*, 2004, Pham *et al.*, 2005
No significant difference between polyculture and monoculture systems with respect to environmental factors. Fish growth not different between monoculture and integration. Mussel growth low (0.007 cm day^{-1}), seaweed daily growth rate 3.91% but showed signs of ice-ice infection at the end of the farming period. Abalone grew fast (0.016 cm day^{-1}.	The profits from polyculture system was 21.23% higher compared to monoculture. Investments and total production costs were only 9% and 17.5% higher, respectively.	Surprisingly low mussel growth!	Khanh *et al.*, 2005
Three of the species had high survival , but *T. Gigas* had 50% mortality. Only *T. derasa* grew faster in fish effluent water, the other clam species showing no growth. Clams able to remove some nutrients e.g. nitrogen and phosphorus concentrations lower in treatment tanks.	Nutrient reduction capacity not enough for integration with food fish aquaculture but possible for ornamental fish aquaria's.	Short term study and only on juveniles! No controls with only shells.	Sparsis *et al.*, 2001
Significant higher survival and growth rates for clams in fish effluent water. Nutrients measured but no uptake calculated. 2.5 times higher zooxanthellae density in clams in fish effluents.	Nutrient reduction capacity not enough for integration with food fish aquaculture but possible for ornamental fish aquaria's.		Lin *et al.*, 2001