# Developments In Integrated Aquaculture In Southeast Asia

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## Abstract

Integrated aquaculture is inclusive of interactive utilization of resources and ecosystems in the artificial rearing of aquatic animals and plants. By the nature, purpose and scale of the operation, integrated fish culture can be categorized into five major modes. One is the traditional small-scale subsistence farming where fish are produced by recycling on-farm wastes in ponds or rice field, two is recycling of human excreta, three is the "industrialized" commercial operation by integrating medium and large-scale poultry or livestock farms with ponds for fish production, four is integration of aquaculture with natural ecosystems, e.g., shrimp culture with mangroves, cage and pen culture in lakes, cove culture in reservoirs. The fifth is environmental-oriented integration, where waste effluents from intensive aquaculture ponds are recycled to improve water quality and to grow filter feeder/ herbivores or macrophytes as secondary crops. This paper presents concepts and practical examples for some of these systems.

## Introduction

Integrated aquaculture systems have been widely practiced throughout Southeast Asia for centuries. The purpose of these systems is to maximize the use of finite resources for food production through recycling energy and nutrients. The traditional practices involving small-scale farms with crop/fish/livestock have received major promotion by many national and international agencies for rural development in Southeast Asia. A wealth of information has been documented by many institutes and organizations throughout the region. A large number of feature articles based on field observations and practices on integrated aquaculture has been published frequently in AARM Newsletter (AIT), Aquaculture Asia (Network of Aquaculture Centers in Asia, NACA), Asian Aquaculture (Southeast Asian Fisheries Development Center, SEAFDEC), Naga (International Center for Living Aquatic Resources Management, ICLARM), Aquaculture News (Food and Agriculture Organization, FAO), etc. However, relatively few quantitative description based on systematic experiments exist. To further improve and promote integrated crop/fish/livestock in the region requires multidisciplinary systems approach (Edwards, 1998). Dalsgaard and Oficial (1998) recently developed the ECOPATH model to illustrate the intricate interactions and quantitative expressions of energy flow and nutrient cycles of integrated aquaculture in context of various farming systems. Depending on the source of waste materials, fish production units are most commonly integrated with a variety of livestock, vegetable crops, rice paddies, household wastes, etc (Little and Muir, 1987). In general, fish productivity derived from on-farm low-input systems is relatively low and often considered as a subsistent practice. The rising trend in integrated aquaculture systems is to generate cash crop with either greater fish production or higher-valued species as economic incentive. For instance, in Thailand the integration of chicken, duck or pig with fish in medium or large-scale operations is an economically attractive business. This industrialized fish/livestock integration (Little and Edwards, 1999) has contributed a large quantity of relatively inexpensive freshwater fish raised in ponds. In Vietnam, integration of marine shrimp with rice (Binh and Lin, 1995) and with mangrove (Fitzgerald, 1997; Johnston *et al,* 1999) has become popular in the Mekong Delta. To mitigate environmental impact of intensive shrimp farm effluents, an integrated recycle system was initiated in Thailand using mollusks as filter feeder (Lin *et al,* 1993). Integration with herbivorous fish and seaweed are potential inclusions to utilize pond effluents.

In an attempt to increase economic incentive of integrated aquaculture and to mitigate environmental impact of intensive aquaculture, researchers at the AIT have developed integration of small-scale cage culture in ponds (Lin and Diana, 1995; Yi *et al,* 1996), and catfish (Lan, 1999) or freshwater prawn (Giap, 1999) culture in rice fields.

## Recycling Waste Effluents and Pond Mud from Intensive Aquacultures

With increasing demand of seafood product from aquaculture, intensive culture systems with high stocking density and protein-rich feed are becoming increasingly popular in Southeast Asia. The species commonly raised intensively in ponds are catfishes (*Clarias spp.* and *Pangasius spp.*), snakehead (*Channa spp.*), milkfish (*Chanos chanos*), tilapia (*Oreochromis spp.*), freshwater prawn (*Macrobrachium rosenbergii*) and penaeid shrimp (*Penaeus monodon*). As those species are typically raised with either formulated diets, trash fish or slaughterhouse wastes, water quality in culture ponds deteriorates rapidly and frequent water exchange is therefore required to prevent detrimental consequences from accumulated wastes. The effluent discharged from those ponds to surrounding waterways has become a major environmental concern as it accelerates eutrophication of natural waters (Beveridge, 1984; Ackefors, 1986; Lin, 1990).

Since the waste effluent from intensive culture ponds contain rich nutrients and abundant planktonic organisms material (Pillay, 1990; Edwards, 1991), it can be reused for raising herbivorous or omnivorous fish in ponds in an integrated fashion. In addition, the effluent can also be used for land crop irrigation (Seim *et al.*, 1997).

To illustrate the integration of intensive fish culture with various fish and land crop production systems a series of experiments were conducted recently at the AIT in Thailand.

## Fish-fish Integration through Caged Feeding in Ponds

A good example of fish-fish integration is the polyculture of several species with different feeding habits to maximize utilization of natural food as a result of recycling of wastes derived from artificial feed to certain high-valued species. However, in a mixed polyculture pond, the low-valued species may consume costly high protein diets, reducing economic return from fish production. The alternative approach is a cage-cum-pond integrated culture system whereby the high-valued species are raised intensively with artificial feed in cages within a pond stocked with species that depend on natural diets in open pond (Fig. 1). This system was developed using catfish-tilapia (Lin *et al.*, 1989; Lin, 1990; Ye, 1991; Lin and Diana, 1995) and in tilapia-tilapia integrated culture (Jiang, 1993; Yi *et al.*, 1996; Yi, 1997).

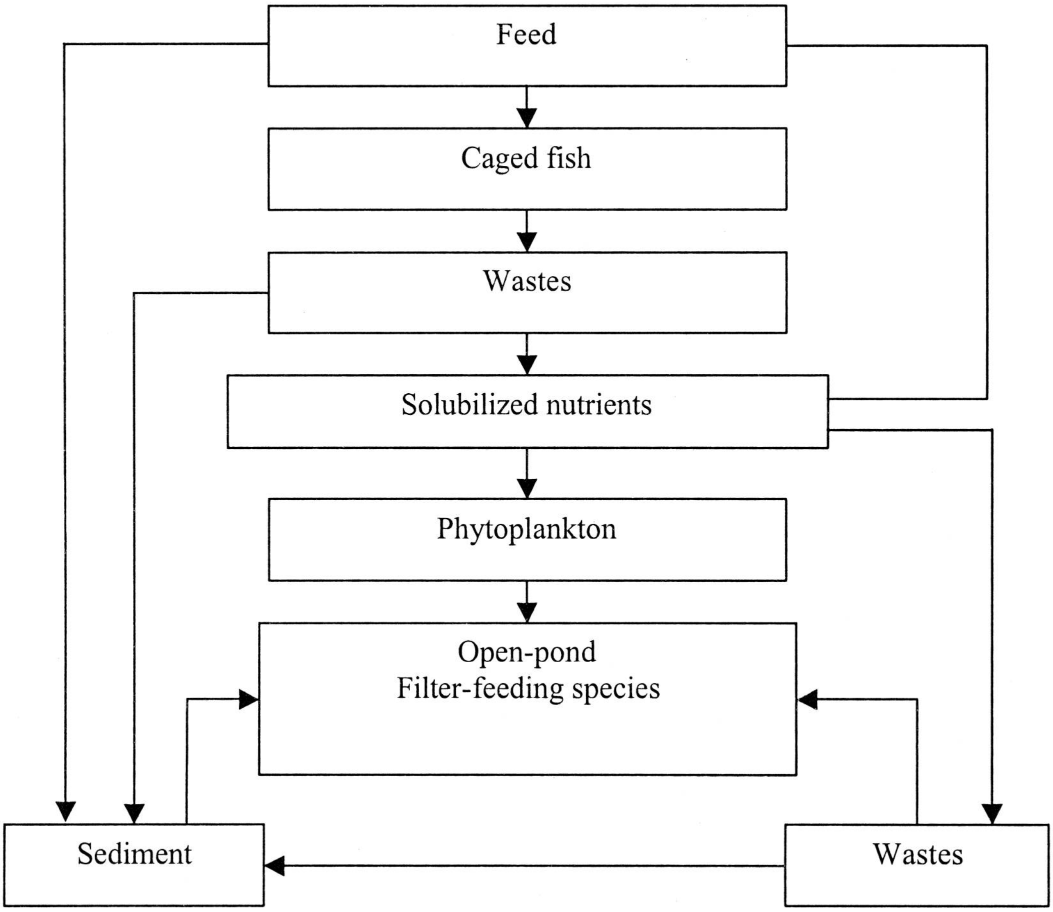

Figure 1. **Schematic diagram for integration of intensive cage culture in semi-intensive pond culture system**

### *Catfish-tilapia integrated cage-cum-pond culture*

Hybrid catfish (*Clarias macrocephalus* x *C. gariepinus*) and Nile tilapia (*Oreochromis niloticus*) are commonly cultured freshwater fishes in Thailand with an annual production of 41,700 and 91,000 mt, respectively (DOF, 1997). While the major production system for tilapia is semi-intensive with inorganic or organic fertilizer inputs, hybrid catfish are intensively monocultured at extremely high density (30-100 fish per $m^2$) with production of 12.5-100 mt in earthen ponds. The most common diets for hybrid catfish are chicken offal, trash fish or pelleted feed. Wastes as uneaten feed and metabolic products in the hybrid catfish ponds often result in excessive phyto- and zooplankton blooms. Although the hybrid catfish can tolerate low dissolved oxygen due to their air-breathing nature, water quality may affect their growth and survival (Diana *et al.*, 1988). To maintain favorable water quality, the pond water with rich nutrients and organic matter is periodically exchanged with new source water, causing pollution in natural waters (Lin and Diana, 1995). The nutrient load from intensive fish culture may have contributed to uncontrollable weed growth in most canals in central Thailand. In Northeast Thailand, the catfish pond effluents laden with overwhelming nutrients have

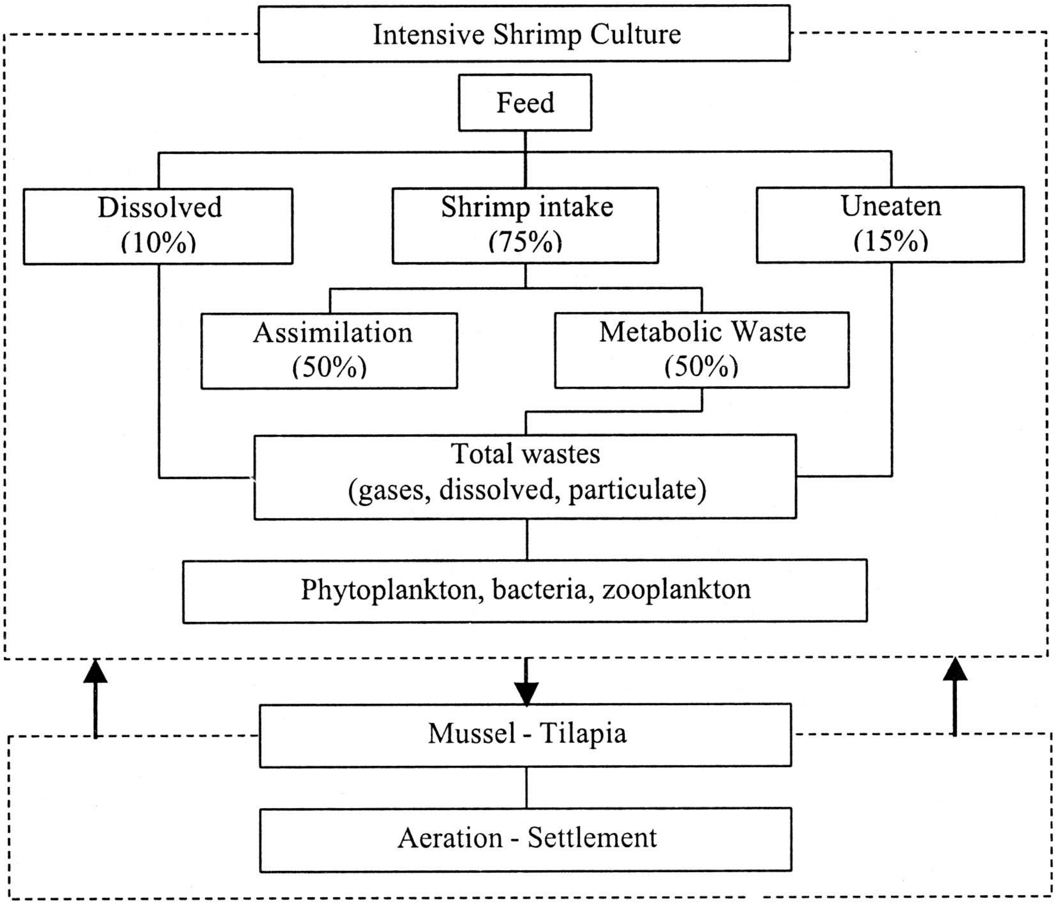

Figure 2. **Schematic diagram for integration of intensive aquaculture waste effluent with filter feeders**

damaged rice paddies, which eventually became wasteful artificial wetlands (C.K. Lin, personal observations).

To develop an integrated catfish and tilapia culture, a preliminary experiment was conducted in two 250-m$^2$ earthen ponds each with two 3.2-m$^3$ cages suspended 20 cm off the pond bottom near center of each pond (Lin *et al.,* 1989; Lin, 1990). Catfish fingerlings were stocked in cages and tilapia were stocked in open ponds. The final production of hybrid catfish ranged from 33.7 to 83.0 kg per cage in 146 days, and the open-pond tilapia production was 62.8-80.3 kg per pond with a mean weight of 367-408 g. The nutrient budget showed that 15% N and 21% P was recovered in the tilapia biomass from the wastes produced by caged catfish. Since the amount of nutrients generated from caged catfish depend on the stocking density, Lin and Diana (1995) conducted further experiments under similar culture conditions to determine the productivity and practical stocking ratio between catfish and tilapia of 2:1 and 4:1. Catfish fingerlings were stocked at a density of 275 fish per m$^3$, with a total of 880 and 1760 fish per pond in low and high density treatments, respectively; and tilapia were stocked at 2 fish per m$^3$. The two catfish:tilapia stocking ratios did not significantly affect catfish growth with a mean weight gain of 2.16 g per fish per day, but did on tilapia growth with a

Table 1. **Summary of growth performance of caged catfish and open-pond tilapia in a catfish-tilapia integrated cage culture in ponds for 122 days (Lin and Diana, 1995)**

| | **Treatment A** | | **Treatment B** | |
|---|---|---|---|---|
| **Performance measures** | **Caged catfish** | **Open-pond tilapia** | **Caged catfish** | **Open-pond tilapia** |
| Water volume ($m^3$) | 3.2 | 220 | 3.2 | 220 |
| Cage number/pond | 1 | | 2 | |
| Stocking | | | | |
| Density (fish/$m^3$) | 275 | 2 | 275 | 2 |
| Total no. (fish) | 880 | 440 | 1760 | 440 |
| Total wt. (kg) | 12.6 | 3.1 | 26.4 | 3.0 |
| Mean wt. (g/fish) | 14.3 | 7.0 | 15.0 | 6.7 |
| Harvest | | | | |
| Survival (%) | 95.8 | 90.5 | 87.5 | 69.8 |
| Mean wt (g/fish) | 273.8 | 179.2 | 270.2 | 297.2 |
| Net yield (t/ha/year) | 26.1 | 8.1 | 46.9 | 10.3 |
| Gross yield (t/ha/year) | 27.6 | 8.5 | 50.0 | 10.6 |
| FCR | 1.94 | | 2.24 | |
| Waste loading rates (kg/ha/d) | 3.71 N and 1.01 P | | 8.06 N and 2.20 P | |
| Nutrient recovery rates (%) | 12.75%N and 14.27%P | | | |
| 7.42%N and 8.27%P | | | | |

Table 2. **Summary of nutrient budget in a catfish-tilapia integrated cage culture in ponds for 90 days (Ye, 1991)**

| | **Nitrogen (%)** | | **Phosphorus (%)** | |
|---|---|---|---|---|
| **Nutrients** | **2.5 catfish to 1 tilapia** | **5 catfish to 1 tilapia** | **2.5 catfish to 1 tilapia** | **5 catfish to 1 tilapia** |
| Feed | 100.00 | 100.00 | 100.00 | 100.00 |
| Nutrient gain | | | | |
| Catfish | 35.44 | 29.92 | 43.85 | 36.89 |
| Tilapia | 13.41 | 4.05 | 17.28 | 4.94 |
| Total | 48.85 | 33.97 | 61.13 | 41.83 |
| Nutrient lost | | | | |
| Sediment | 23.38 | 34.87 | 31.04 | 51.09 |
| Water | 11.94 | 6.86 | 4.92 | 4.09 |
| Other | 15.84 | 24.30 | 2.90 | 2.99 |
| Total | 51.16 | 66.03 | 38.86 | 58.17 |
| Nutrient recovery rates by tilapia | 20.77 | 5.78 | 30.77 | 7.83 |

mean weight gain of 1.41 and 2.38 g fish per day in the low and high density treatment, respectively (Table 1). Based on pond surface area, the extrapolated catfish production ranged from 30 to 50 mt per ha per year, an amount comparable to that in traditional intensive open pond culture systems, and tilapia production ranged from 8 to 11 mt per ha per year, which surpasses that in ponds fertilized with conventional chicken manure (Green, 1992) or chemical fertilizers (Diana *et al.*, 1991).

The nutrient budget in integrated catfish and tilapia culture system, as shown in Table 2, was estimated by Ye (1991) based on catfish:tilapia stocking ratios of 2.5:1 and 5:1. After the 3-month experiment, production of 1 kg catfish generated 48.0-60.0 g N and 10.0-12.5 g P as metabolic wastes; approximately 30-35% N and 37-44% P input from the feed were incorporated into catfish; 4-13% N and 5-17% P were incorporated into tilapia; 7-12% N and 4-5% P were remained in pond water; 23-35% N and 31-51% P were accumulated in pond sediment; 16-24% N and 3% P were unaccounted for. Among the nutrients in the wastes, tilapia recovered 6-21% N and 8-31% P.

### *Tilapia-tilapia integrated cage-cum-pond culture*

Nile tilapia are commonly grown in semi-intensive ponds based on fertilizers or on integrated systems with livestock (Boyd, 1976; Edwards, 1986, 1991; Diana *et al.*, 1991). However, fish harvested from those ponds are usually relatively small with an average of 200-300 g in five months (Diana et al., 1991), and it may take as long as five more months to rear the fish to 500 g under semi-intensive culture (Diana et al., 1994). In some countries such as Thailand, the market price of Nile tilapia increases with its size, resulting in a trend to culture the fish intensively in cages in rivers and lakes. Moreover, it has been shown that the most economically effective way to produce large size tilapia in pond culture is to start supplemental feeding at 100-150 g size (Diana *et al.*, 1996). The cage-cum-pond integrated culture system is based on a waste recycle concept to produce large size tilapia intensively in cages in ponds and meanwhile to nurse small fish in open ponds semi-intensively.

A series of experiments were conducted in fifteen 330-m$^3$ earthen ponds with 4-m$^3$ cages suspended 20 cm off the pond bottom to develop a tilapia-tilapia cage-cum-pond integrated rotation system, in which large size tilapia can be fattened in cages and small size tilapia can be nursed by utilizing cage wastes and then can be removed every three months to restock the cages (Yi et al., 1996; Yi, 1997). In the first experiment, the optimal stocking density of caged tilapia was determined as 50 fish per m$^3$ with a total of 200 caged fish per pond. Results of the second experiment indicated that the appropriate number of cages per pond was 2 cages per pond. To make this system rotate every three months, the third experiment was conducted to determine the optimal density of open-pond tilapia. The results showed that the optimal stocking density of open-pond tilapia was 1.4 fish per m$^3$, and also indicated that the carrying capacity and growth performance of caged tilapia could be enhanced by lowering the stocking density of open-pond tilapia. The fourth experiment was conducted to compare the growth performance of both caged and open-pond tilapia between the integrated cage culture and the traditional mixing-size pond culture. Results revealed that the growth performance of both caged and open-pond tilapia was significantly better in the integrated cage culture than in the traditional mixing-size pond culture.

In the optimized integrated cage-cum-pond rotation culture, large size tilapia (124 g) were stocked at 50 fish per m$^3$ in two 4-m$^3$ cages suspended in 330-m$^3$ earthen ponds with the surface area of 313-393 m$^2$ and water depth of 1-1.2 m, and small size tilapia (16 g) were stocked at 1.4 fish per m$^3$. Final production of caged tilapia was 91.9 kg•cage$^{-1}$ with an individual weight of 465 g and daily weight gain of 4.06 g•fish$^{-1}$ in the 86-day experimental period (Table 3). The final mean weight of open-pond tilapia production was 124 g with mean daily weight gain of 1.35 g per fish per day. The extrapolated tilapia production was approximately 6.7 mt per ha per year. The nutrients incorporated in caged

Table 3. **Summary of growth performance and nutrient efficiency of both caged catfish and open-pond tilapia in a tilapia-tilapia integrated cage culture in ponds for 86 days (Yi, 1997)**

| Performance measures | Caged tilapia | Open-pond tilapia |
|---|---|---|
| Water volume ($m^3$) | 4 | 330 |
| Stocking | | |
| Density (fish/$m^3$) | 50 | 1.4 |
| Total no. (fish/pond) | 400 | 462 |
| Total wt. (kg/pond) | 49.4 | 7.2 |
| Mean wt. (g/fish) | 124 | 16 |
| Harvest | | |
| Survival (%) | 98.8 | 92.0 |
| Mean wt (g/fish) | 456 | 124 |
| Net yield (t/ha/year) | 18.2 | 6.2 |
| Gross yield (t/ha/year) | 24.9 | 7.1 |
| FCR | 1.22 | |
| Waste loading rates (kg/ha/d) | 1.75 N and 0.37 P | |
| Nutrient recovery rates (%) | 20.52% N and 27.98% P | |

tilapia accounted for 36.41% N and 45.47% P of the total nutrient inputs. The nutrients in the wastes fertilized the ponds at a rate of 1.75 kg N and 0.37 kg P ha per day, giving a N:P ration of 4.73. Open-pond tilapia recovered 20.52% N and 27.98% P contained in the wastes produced by caged tilapia.

### *Fish-fish integration through water recycling*

Recycling nutrient-rich water from intensive fish culture ponds to semi-intensive units can be done through recirculation. Water recirculation can also facilitate mixing in intensive ponds, minimizing ammonium accumulation and undesirable anaerobic zones in the pond (Avnimelech *et al,* 1992). An experiment was conducted to recirculate nutrient-rich water from intensive catfish tanks to tilapia tanks once every 3 or 7 days (Sethteethunyahan, 1998). Water recirculation significantly increased daily weight gain of individual catfish, but did not result in significant differences in survival and yields. The extrapolated tilapia production in the 7-day recirculation treatment was 6.5 t per ha per year, which recovered 3.1% N and 4.5% P of the nutrients from the catfish wastewater.

### *System-system integration through circulating pond water to rice fields*

Wastewater from fish culture can also be reused for fertilizing agricultural crops, but such integration between aquaculture and agriculture farming systems have seldom been practiced. This system may lead to community sustainability and environmental enhancement (Huat and Tan, 1980; Edwards, 1993). An experiment was conducted in Vietnam using wastewater from intensive hybrid catfish culture ponds to irrigate and fertilize rice fields in comparison to regular chemical fertilizers (Lan, 1999). No significant differences were observed in grain yields between those two treatments. But, the grain yields from the wastewater treatment was improved with inorganic fertilizer supplement. This experiment indicated that it is feasible to use the wastewater from the intensive fish culture effluent for rice crops, but the N:P ratio needs to be adjusted using phosphorus fertilizer to achieve better rice performance.

### *System-system integration through extracting mud nutrients by rooted crops*

The nutrient distribution in bottom mud of fish ponds accounted for about 70% of total N and 35-40% of total P in intensively manured tilapia ponds (Green and Boyd, 1995), 23-35% N and 31-51% P in a catfish-tilapia integrated cage-cum-tank culture (Ye, 1991), 20-29% N and 27-45% P in a tilapia-tilapia cage-cum-pond culture (Yi, 1997). Pond mud is a major sink for phosphorus and the adsorption capacity is related to mineral composition and clay content of pond mud (Shrestha and Lin, 1996). In rice-fish integrated culture, most nutrients end up in sumps and trenches with limited benefit to rice fields (Giap, 1999).

As sediments function as phosphorus sink in ponds, regeneration of adsorbed P from mud to water is minimal. Thus, the sedimentary nutrient loss and its reuse has become a major concern. The traditional techniques to recycle those trapped nutrients are to apply the pond mud for land crop cultivation (Muller, 1978; Delmendo, 1980; Brown, 1983; Hu and Yang, 1984; Zweig, 1984; Little and Muir, 1987; Christensen, 1989). In a preliminary experiment, cowpea (*Vigna unguiculata*) and taro (*Colocasia esculenta*) were cultivated with mud or mixture of mud and sand taken from AIT's fish ponds. Cowpea recovered 6.4% N and 1.0% P from pond mud and 7.8% N and 1.6% P from mud-sand mixture, and taro recovered 13.9% N and 3.3% P from pond mud and 13.4% N and 3.6% P from mud-sand mixture (Shrestha, 1994). However, removing pond mud is labor intensive and its practicability is questionable (Edwards *et al.,* 1986).

The alternative method to recover those nutrients is to grow rooted aquatic plants in ponds, since aquatic macrophytes can mobilize and extract them effectively (Denny, 1972; Boyd, 1982; Smart and Barko, 1985). The aquatic macrophytes selected for planting in pond together with fish especially between two fish crops should have comparable economic values with fish culture. For example, lotus (*Nelumbo nucifera*) with high-value edible rhizomes is a suitable candidate, being an emergent macrophyte commonly planted in fields or ponds with nutrient-rich mud and having a growing season of 100-150 days.

### *Marine shrimp culture*

In recent years, effluents discharged from intensive marine shrimp farming have caused serious deterioration of water quality in coastal environments (Phillips *et al,* 1993). In Thailand, shrimp pond effluents annually contribute an estimated 187,500 t of organic matter, 13,050 t of nitrogen and 4,200 t of phosphorus to the environment (Lin *et al.*, 1993). To reduce or alleviate the pollution load from those wastes, a closed or integrated recirculation system has been developed (Chien and Liao, 1995; Lin, 1995). An idealized model for integrated recirculation shrimp farming is presented in Fig. 2. A number of filter feeding fish, (e.g., species of tilapia, milkfish, mullet), bivalves such as the green mussel (*Perna viridis*) in combination with seaweed are potential candidates to be integrated. In a pilot scale demonstration farm, green mussel was grown in wastewater canal in a recirculation unit for 113 days, during which mean weight of mussel increased from 12 to 42 g. However, the major problem of integrating multiple species in the same culture complex is their compatibility of environmental requirements.

## Conclusions

Integrated aquaculture has been extended from traditional on-farm closed systems to reuse of wastes from intensive aquaculture based on off-farm resources.

The development of recycling of wastewater from intensive aquaculture to semi- intensive culture or other agriculture crops is still in the artisanal stage.

A systems approach is needed for further development of integrated aquaculture, which requires proper engineering design, quantitative information on physical conditions, nutrient budgets and biological comparability among cultured species and systems.

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