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Recycling-oriented aquaculture system utilizing natural ecological functions of mangrove organisms

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Abstract. Model experiments of a recycling-oriented shrimp aquaculture using natural ecological function of benthic and planktonic organisms were carried out in Samut Songkhram, the Gulf of Thailand. Water and sediment qualities in the system deteriorated during shrimp aquaculture due to the wastewater of shrimp culture. Approximately 70-75 % of nutrients were purified when water circulated and up to 2.8 kg phosphorus and 48 kg nitrogen were reduced by means of the recycling-oriented aquaculture system. Survival rate and production of shrimps were the highest in the water circulated system. Total production of the water circulated system was approximately 30 % larger than that of the closed system and, as the results, the feed conversion ratio improved about 10 %. A total of 42 species/taxa of macrobenthic organisms, mainly Annelida, Mollusca and Arthropoda, were identified and we selected species suitable for inhabit the recycling-oriented aquaculture system. The recycling-oriented aquaculture system utilizing natural ecological functions of organisms was a feasible technology for sustainable aquaculture, although further investigation should be needed.

Key words: giant tiger prawn, *Penaeus monodon*, sustainable aquaculture, macrobenthos, Thailand

Introduction

In the Gulf of Thailand, shrimp aquaculture in coastal areas has rapidly developed and expanded since the middle of the 1970's, and the production of cultured shrimps has increased drastically (DOF 2003; Barbier *et al* 2004). During the 25 years from 1975 to 2000, shrimp farming areas increased from 129 km^2 to 811 km^2 and the number of farms increased largely from 1,544 to 34,979 (DOF 2003). The excessive intensive utilization of coastal areas has resulted in the destruction of many mangrove ecosystems and water pollution affecting the culture ponds and adjacent coral reefs. Recovery of mangrove ecosystems is of utmost importance for restoring the productivity of the coastal aquaculture and fisheries (Hogarth 1999; Barbier *et al* 2004).

In order to develop a rational and sustainable utilization strategy for mangrove ecosystems, we constructed a model plant of recycling-oriented aquaculture system in which environmental loading has been reduced due to the natural ecological functions of native organisms such as macrobenthos, plankton, algae, seagrass, mangrove trees, and so on. In this study, we demonstrated one of the experiments of shrimp culture to evaluate performance of the recycling-oriented aquaculture system.

Material and Methods

Model experiments of shrimp aquaculture by means of the recycling-oriented aquaculture system were carried out in experimental ponds of Samut Songkhram Fisheries Research Station (13°26.3'N, 100°03.5'E), Kasetsart University, along the Gulf of Thailand (Fig. 1). The aquaculture system consists of five main modules (see Fig. 4); that is, shrimp culture ponds, inlet channel, outlet channel, water treatment pond and reservoir pond. Every shrimp culture ponds were 40 m x 20 m in the upper area, 35 m x 15 m in the bottom area and 1 m water depth. The inlet and the outlet channels were about 400 m x 5 m, and the water treatment pond was 80 m x 80 m with convoluted water pathway. Area of the recycling-oriented aquaculture system from the outlet channel to the inlet channel was approximately 8,500 m^2 including the water treatment pond. Mangrove saplings, *Rhizophora mucronata* Lamarck were planted into outlet channel, water treatment pond and two shrimp culture ponds. Selected various kinds of benthic organisms (mollusks, polychaetes, algae, *etc.*) were selected and cultured depending on characteristics of every modules.

The experiments were started on February 25, 2005 with shrimp fry of 15 days of age (PL15) and cultured for 160 days until August 3, 2005 (Fig. 2). 13,000 fry of the giant tiger prawn (*Penaeus monodon* Fabricius) were stocked in each of 3 ponds (Ponds 1, 3 and 6) with a density of approximately 20 individuals per square meter (m^2), and 6000 fry in a mangrove planted pond (Pond 4). In Pond 1 and Pond 4, the water was pumped out biweekly into the outlet channel and supplied from the inlet channel through the water treatment pond. The control of the experiment was Pond 2, where no shrimps were cultured. Pond 3 was a closed intensive aquaculture without exchange of the water.

Water temperature, salinity, dissolved oxygen (DO), hydrogen-ion concentration (pH) and turbidity were monitored by means of data logger and water quality checker. Nutrient concentration were analyzed by standard methods (Eaton *et al* 1995) using a spectrophotometer and a fluorometer. Benthic organisms were quantitatively core sampling method and line intercept transect (LIT) method.

Figure 1: Overview of recycling-oriented aquaculture system in Samut Songkhram Fisheries Research Station, Kasetsart University, Thailand.

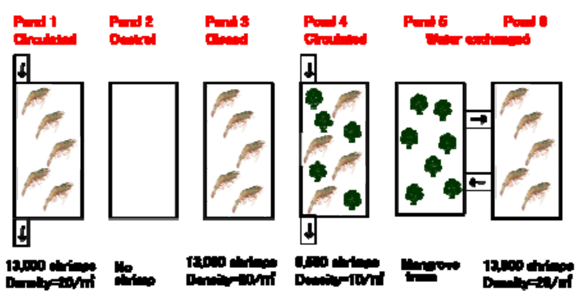

Figure 2: Experimental design of shrimp aquaculture.

Results and Discussion

Water quality during shrimp culture in Ponds 1-6 were compared in Fig. 3. Temperature fluctuated 24.3-33.9 °C in nighttime and 28.2-39.0 °C in daytime, and salinity decreased gradually because of the rainfall during rainy season. Biological oxygen demand (BOD), ammonia (NH_4) and turbidity increased gradually during shrimp culture. Water quality sometimes fluctuated because of soil erosion caused by heavy rain and phytoplankton blooming induced by strong sunshine. Water quality was stable throughout the experiment in the control pond (Pond 2), whereas, in the mangrove planted pond (Pond 4), the values fluctuated largely because of the shallow water depth (0.3 m). Dissolved oxygen (DO) decreased during the nighttime and increased in the daytime because of active photosynthesis by phytoplankton. In the daytime of fine days the rate of photosynthesis increased, and so DO and pH increased, and ammonia decreased, while the rate of photosynthesis decreased on cloudy or rainy days.

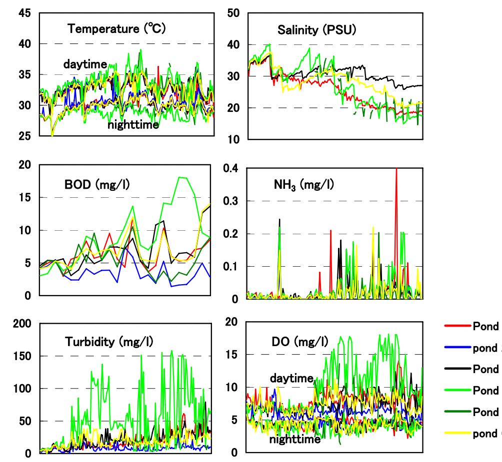

Figure 3: Water quality in experimental ponds during shrimp aquaculture.

Total nitrogen and total phosphorus were compared between before and after the shrimp culture in four modules of the recycling-oriented aquaculture system (Table 1). Before the shrimp culture, 0.001-0.010 mg/l phosphorus and 0.387-1.198 mg/l nitrogen were included in every modules. During the shrimp culture the nutrient increased gradually, and 0.150-0.483 mg/l phosphorus and 1.933-7.565 mg/l nitrogen were included when the shrimp culture terminated. Approximately 70-75 % of nutrient were purified when water circulated from the outlet channel to the inlet channel through the treatment pond; phosphorus reduced from 0.483 mg/l to 0.150 mg/l and nitrogen reduced from 7.565 mg/l to 1.933 mg/l. As the results, up to 2.8 kg phosphorus and 48 kg nitrogen were reduced by means of the recycling-oriented aquaculture system.

When water purified by means of mangrove enclosure, approximately 6.2-8.9 times of ponds was required to reduce the phosphorus (Shimoda *et al* 2005). While, in the recycling-oriented aquaculture system, approximately 5.3 times of areas are required to purify the wastewater, indicating that the system are considerably effective for promoting sustainable aquaculture.

Table 1: Nutrient in recycling-oriented aquaculture system. Total phosphorus and total nitrogen were compared among every modules before and after the shrimp culture. Unit: mg/l

	Total Phosphorus		Total Nitrogen	
	before	after	before	after
Culture pond	0.008	0.230	1.189	3.206
Outlet channel	0.010	0.483	0.610	7.565
Treatment pond	0.001	0.235	0.417	2.041
Inlet channel	0.007	0.150	0.387	1.933

A total of 42 species/taxa were identified from the recycling-oriented aquaculture system. The dominant species belong to three taxonomic categories; that is, (1) free-living nereid, *Perinereis* sp. and tube-dwelling spionid, *Polydora* sp. and some other polychaetes (Annelida), (2) gastropods such as *Cerithidea cingulata*, *Cerithium coralium*, *Sermyla riqueti*, *Stenothyra* spp. which live on the muddy or algal substrata (Mollusca), and (3) barnacles and some small arthropods such as ostracods, copepods, harpacticoids, amphipods and dipterans (Arthropoda) (Fujioka *et al* 2007). Diversity and biomass were the largest in the mangrove planted ponds and water treatment pond because of the diverse habitats associated with the mangrove trees. Whereas, they were smallest in the shrimp culture ponds because the cultured shrimps predated on macrobenthic organisms as food source.

Annelida, Mollusca and Arthropoda were the predominant and most diverse taxa in all the macrobenthic communities in the shrimp aquaculture ponds and the adjacent mangrove ecosystems (Barbier *et al* 2004; Hayashi *et al* 2005; Fujioka *et al* 2007). Since they play important roles under the natural ecosystem; that is, (1) as food for fishery resources in themselves, (2) in the purification of wastewater and sediments, and (3) in degradation, accumulation and circulation of organic materials, we utilize these organisms to maintain and improve the environment for sustainable aquaculture systems.

The results of the shrimp culture experiment were demonstrated in Table 2. During the experimental period, growth rate of shrimps differed largely among individuals from 4.5 g to more than 30 g. Survival rate and production of shrimps were the highest in the water circulated system (Pond 1). Total production of the water circulated system (Pond 1) was approximately 30 % larger than that of the closed system (Pond 2) and, as the results, the feed conversion ratio (FCR) improved about 10 %. In water exchanged system (Pond 6), growth rate of shrimps was very small possibly due to the insufficient improvement of water quality.

Cost performance of the shrimp culture experiment was also compared in Table 2. In the mangrove planted culture system (Pond 4), the artificial feed could be reduced. The profit/cost balance was the highest in the semi-intensive culture system with mangrove trees (Pond 4), followed by the water circulated system (Pond 1) and lower in the closed system (Ponds 3 and 6). Thus, effective aquaculture was achieved in the recycling-oriented aquaculture system such as Ponds 1 and 4.

Table 2: Results of shrimp culture experiment in recycling-oriented aquaculture system.

	Pond 1 Circulated	Pond 3 Closed	Pond 4 Circulated	Pond 6 Exchanged
No. of stocked (A)	13000	13000	6000	13000
Culture density (N/m^2)	20	20	10	20
No. of harvested (B)	4023	2987	1424	3142
Survival rate (%)(B/A)	30.9	23.0	23.7	24.2
Total production (Kg)(C)	58.6	41.5	24.8	25.4
Production (Kg/m^2)	0.10	0.07	0.04	0.04
Average weight (C/B)(g)	14.6	13.9	17.4	8.1
Feed (Kg) (D)	141.3	110.1	42.4	75.5
FCR (D/C)	2.41	2.65	1.71	2.98
Profit (Kg*140bahts)	8790	6225	3720	3803
Shrimp fry (n*0.11bahts)	1430	1430	660	1430
Fuel (Gasoline, Diesel Oil)	910	910	420	910
Feed (800bahts/25kg)	4520	3522	1356	2414
Profit/Cost	1.28	1.06	1.53	0.80

A considerable amount of leftover feed, exuviae and excrement of shrimps, and organic matter derived from the activities of plankton and benthos accumulated on the bottom of the aquaculture ponds and caused anaerobic conditions into the sediments. Cultured shrimp might be stressed by toxic organic materials such as hydrogen sulfide produced during shrimp culture. Such conditions are detrimental for the cultured shrimp and causes low yield of culture production and increase the susceptibility to outbreaks of disease (Barbier *et al* 2004). Controlling and minimizing the negative environmental impact by utilizing biofiltration treatment through the use of natural organisms such as mangroves trees, mollusks, polychaetes, barnacles, seaweeds and plankton is an important practical solution to maintain sustainable shrimp aquaculture.

Reducing the environmental impacts to shrimp ponds should be part of the overall issue of improving the sustainability of shrimp aquaculture. On the basis of a series of our study, we demonstrated a recycling-oriented aquaculture system in Samut Songkhram station as shown in Fig. 4. In this aquaculture model, wastewater circulated from the shrimp culture pond, though an outlet channel, to the water treatment pond. After being purified throughout the convoluted pathway in the water treatment pond, water is recycled to the shrimp culture ponds through the inlet channel. For control of DO, pH and ammonia, the density of phytoplankton should be controlled by means of a biofilter system set beside the inlet channel because they are related to the ability of photosynthesize by phytoplankton.

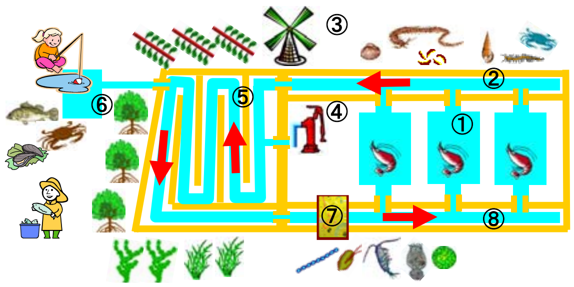

Figure 4: Recycling-oriented aquaculture model utilizing natural ecological functions of benthic and planktonic organisms. (1)shrimp culture ponds, (2) outlet channel, (3) windmill, (4) underground well, (5) water treatment pond, (6) reservoir pond, (7) biofilter, (8) inlet channel

We selected benthic organisms suitable for inhabit the recycling-oriented aquaculture system as follows: 2 mangrove (*Rhizophora mucronata* and *Avicennia marina*), 4 bivalves (*Perna viridis*, *Arcuatula arcuatula*, *Crassostrea belcheri*, *Mytilopsis adamsi*), 4 gastropods (*Cerithium coralium*, *Sermyla riqueti*, *Cerithidea cingulata*, *Stenothyra* spp.), 4 polychaetes (*Perinereis* sp., *Polydora* sp., *Mediomastus* sp., *Laonome albicingillum*), 1 barnacle (*Balanus* sp.), 1 seagrass (*Ruppia maritima*) and 5 algae (*Caulerpa lentillifera*, *Chaetomorpha* spp. *Rhizoclonium* sp., *Acanthophora spicifera* and *Solieria robusta*).

The recycling-oriented aquaculture system utilizing natural ecological functions of organisms was a feasible technology for sustainable aquaculture. For further subject, it is important to carry out the replicated experiments and improve the performance of water/sediment purification with careful screening of benthic and planktonic organisms suitable for this system.

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