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Attempt at Purification of Effluent and Sediment in Shrimp Aquaculture Ponds Using Mangrove Trees

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Abstract

Water was circulated between shrimp and mangrove ponds to process effluent from shrimp aquaculture using mangrove trees at the Samut Songkhram Research Station, Kasetsart University, Thailand. Shrimp growth was faster in the ponds circulated with water from mangroves during the first 63 days of culture, before mass mortality occurred. Mass mortality of shrimp occurred after 63 days of culture. Though a load reduction effect to the environment was observed in the nitrogen and phosphorus budgets, this experiment was terminated prior to completion due to mass mortality. Further experiments on processing effluent with mangroves are needed.

Discipline: Aquaculture
Additional key words: nutrient, denitrification, environment

Introduction

Brackish mangrove areas are very important for marine organisms. Productivity of the marine ecosystem in these areas is very high[9] owing to an abundant supply of nutrients from the land. Their complex geographical features and the shape of the mangrove tree also provides marine organisms with excellent shelter for spawning and nurseries, forming a diverse ecosystem. In some developing countries, mangrove forests have been cleared for aquaculture ponds[3]. Shrimp aquaculture has been developed in order to acquire foreign currency in these countries. In Thailand, mangrove areas have decreased by more than half in 30 years. As a result, the self-purification ability of the brackish waters has declined. Wastewater from aquaculture ponds has led to the deterioration of the coastal environment[13,19]. In addition, the deterioration of the water and sediment quality has had serious effects on aquaculture, causing disease outbreaks and the abandonment of ponds.

To develop a system of aquaculture, which is in harmony with the environment, several methods have been proposed to decrease the impact of shrimp pond effluent[2,5,14]. It is thought that the use of mangrove to treat effluent has been effective[12,13]. In Vietnam, mangrove trees are planted on the ocean side of shrimp aquaculture ponds and have been effective in reducing wave height, thereby resulting in the preservation of the coastal environment[7]. However, the use of mangrove to process effluent from shrimp aquaculture regions is still not generally practiced. In our study, water was circulated between shrimp aquaculture ponds and mangrove ponds to maintain water and mud quality and to supply feed from the mangrove pond using natural purification functions and high productivity in mangrove brackish waters. We aimed to clarify the purification ability from the nitrogen and phosphorus budgets in shrimp and mangrove ponds and the effectiveness of this aquaculture system.

Materials and methods

The experiment was conducted at the Samut Songkhram Coastal Aquatic Research Station, Faculty of Fisheries, Kasetsart University, Thailand, from August through December 2002. Five ponds with the size of 40 × 20 m in the upper level and 35 × 15 m in the lower level were used for this experiment. Shrimps were cultured in three ponds, and mangrove trees were planted in two ponds (Fig. 1). In Pond 1, 3,000 shrimp larvae (*Penaeus monodon* at the PL (post larvae)-20 stage) were stocked

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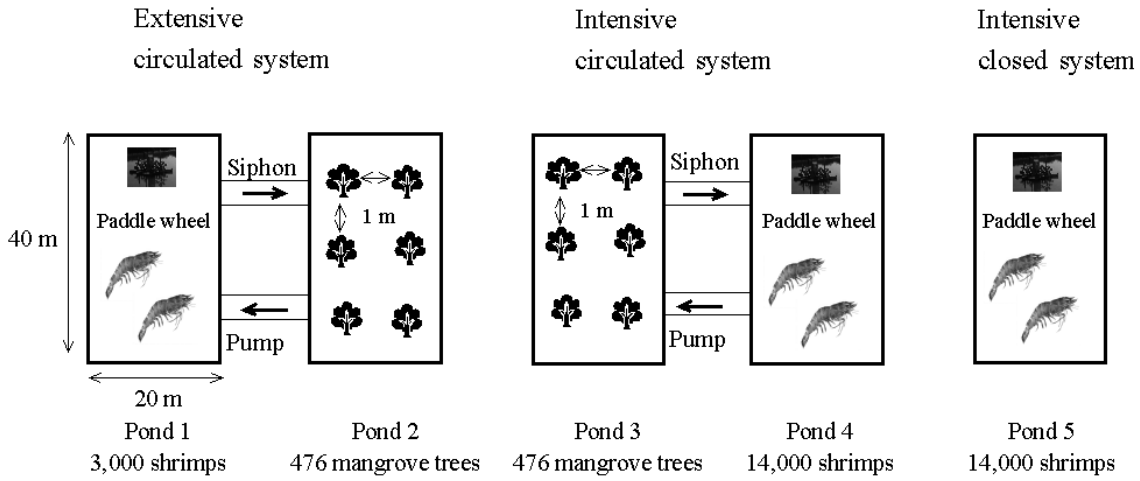

Fig. 1. Schematic outline of culture ponds used in experiment
Penaeus monodon larvae at the PL-20 *stage* were stocked in shrimp aquaculture ponds.
Rhizophora mucronata was planted in mangrove ponds.
Water was exchanged every day in the circulated system.

(about 6 shrimps per m^2), no feed was supplied and shrimps were extensively cultured. In Ponds 4 and 5, 14,000 shrimp larvae (about 25 shrimps per m^2) were stocked, feed was supplied and shrimps were intensively cultured. Unfortunately, mass mortality of the shrimps occurred in Pond 4, and the experiment was terminated 77 days after it began. In Pond 5, the experiment was discontinued and the shrimps were harvested at 84 days because the shrimps were swimming at the water surface and a small number of shrimps were confirmed dead. These events were considered to be predictive of mass mortality. Though the experiment had continued for about 4 months in Pond 5 mass mortality had not been confirmed. Yellow head virus was identified from the bodies of living shrimp (personal communication, N. Oseko, National Research Institute of Aquaculture, Japan). At the same time, yellow head virus was confirmed in small crabs that lived near the aquaculture ponds. It was suggested that those crabs were carriers of this virus. Dead individuals were collected and included in the budget calculations. Dead individuals were not included in the survival rate calculation.

A total of 476 one-year-old mangrove saplings (*Rhizophora mucronata*) had been planted in Ponds 2 and 3 in June 2002, respectively. First, the shrimp ponds were filled with water to a depth of 100 cm, and the mangrove ponds were filled to a depth of 30 cm. Then water in the mangrove ponds was pumped to the shrimp ponds using a gasoline engine water pump. The water was circulated by a paddlewheel, and the water in the shrimp ponds was returned to the mangrove ponds by a siphon every day. When the water volume decreased due to evaporation, well water near the ponds was supplied to the ponds.

Monitoring of water quality and collection of water and soil samples were carried out once a week before and after the circulation of the water in principle. Water temperature, salinity, dissolved oxygen, turbidity, and pH were measured with a TOA model WQC-20A water quality checker. Water samples were collected in two plastic bottles at the center of each pond. The samples were immediately filtered through Whatman GF/F filters for the collection of chlorophyll *a* (Chl. *a*), particulate nitrogen and phosphorus. For Chl. *a* analysis, the filters were soaked in *N, N*-dimethylformamide[17], and then Chl. *a* was extracted in solvent and analyzed with a fluorometer (Turner Design TD-700). Particulate nitrogen was analyzed with an elemental analyzer (FISONS EA-1108). Particulate phosphorus was analyzed by using the method of Solorzano and Sharp[16]. The ammonia concentration was measured immediately after filtration using Sasaki and Sawada's method[15]. Nitrate, nitrite, phosphate and silicate were analyzed by the standard method[11] using a spectrophotometer (SHIMADZU UV-1201). After potassium peroxydisulfate ($K_2S_2O_8$) was added to samples and digestion was executed by autoclaving, the nitrate and the phosphate concentrations, respectively, were measured according to the methods of Solorzano and Sharp[16] for total dissolved nitrogen and Menzel and Corwin[8] for total dissolved phosphorus. The surface 3 cm core mud samples were collected with a syringe 23 mm in diameter. The collected mud was dried, weighed and crushed with a mortar. The nitrogen content in sediment was analyzed with an elemental analyzer (FISONS EA-1108). The

phosphorus content in mud was analyzed by Andersen's method[1]. *N, N*-dimethylformamide was added directly to the 1-cm mud sample for chlorophyll extraction. After centrifugal separation, the supernatant was analyzed.

Mean height, number of leaves and thickness of stalk in the 10 mangrove trees were measured at the beginning and the end of the experiment. At harvest, not only shrimps but also the other main organisms in the ponds were sampled. The biomass and the nitrogen and phosphorus contents were analyzed using the same method as that used for particulate nitrogen and phosphorus analysis.

Results

Table 1 shows the height, thickness of stalk and leaf number in the mangrove trees at the beginning and end of this experiment. All numerical values increased, and the mangroves grew well.

Table 2 shows the outline of the shrimp culture indicated by the stocked larvae, cultured days, shrimp total weight and number of individuals at the end of the experiment, as well as the amount of feed and the food conversion ratio (FCR). The experiment was terminated halfway to completion because the shrimps were infected with yellow head virus and therefore the survival rate was very low. Dead shrimps were collected for nitrogen and phosphorus analysis, but they were not used for the survival rate and FCR calculations.

Fig. 2 shows the average weight of the shrimps before mass mortality in Ponds 4 and 5 and in the entire aquaculture period in Pond 5. During the first 63 days, before mass mortality occurred in Pond 4, the shrimp growth was the fastest in Pond 4 (analysis of covariance, $F_{2, 12} = 6.944$, $p = 0.01$), where water was circulated with the mangrove ponds and feed was given. Shrimp growth was second fastest in Pond 1, where water circulated from the mangrove ponds and feed was not supplied.

The water temperature was 25.1–35.1ºC and remained almost steady. The salinity ranged from 14.5 to 38.3 and exceeded 35 in Ponds 3, 4 and 5 at the beginning of the experiment because of the dry season. Well water was added to the culture ponds as needed to maintain the water level and salinity. Concentrations of nitrogen and phosphorus in well water were low compared to

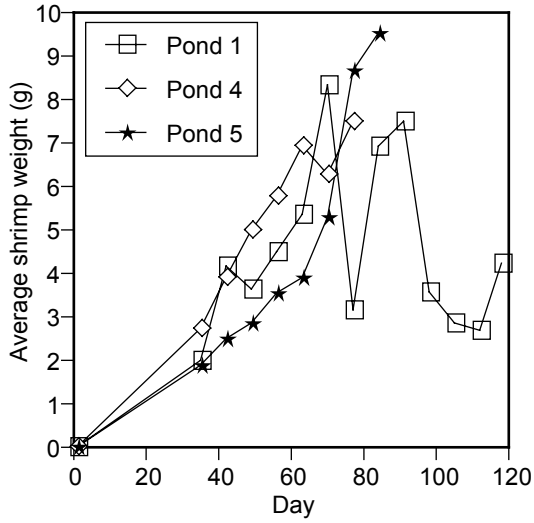

Fig. 2. Average shrimp weight during the aquaculture period

Table 1. The mean and standard deviation for height, leaf number and stalk thickness in mangrove trees, *Rhizophora mucronata*, at the beginning and end of the experiment in Ponds 2 and 3

	Height(cm)		No. of leaves		Thickness of stalk (mm)	
	Beginning	End	Beginning	End	Beginning	End
Pond 2	71.0 ± 8.1	81.4 ± 9.8	7.4 ± 1.3	18.0 ± 6.4	17.0 ± 0.85	21.2 ± 3.0
Pond 3	67.7 ± 6.8	73.7 ± 6.1	6.8 ± 1.0	10.4 ± 2.0	17.5 ± 1.2	20.1 ± 1.3

Table 2. The outline of the shrimp culture indicated by the stocked larvae, cultured days, shrimp total weight and number of individuals at the end of the experiment, as well as the amount of feed and the food conversion ratio (FCR)

Pond	Stocked larvae	Cultured days	Harvest		Average weight	Survival rate	Feed	FCR*
	(Individuals)	(day)	(kg)	(Individuals**)	(g)	(%)	(kg)	
1	3,000	126	0.8	237	3.4	7.9	0	–
4	14,000	77	26.5	3,535	7.5	25.3	90.3	3.4
5	14,000	84	49.6	5,180	9.5	37.0	86.6	1.7

*FCR = (Weight of feed)/(Weight of harvest – larvae).

**Not including dead shrimps in individuals.

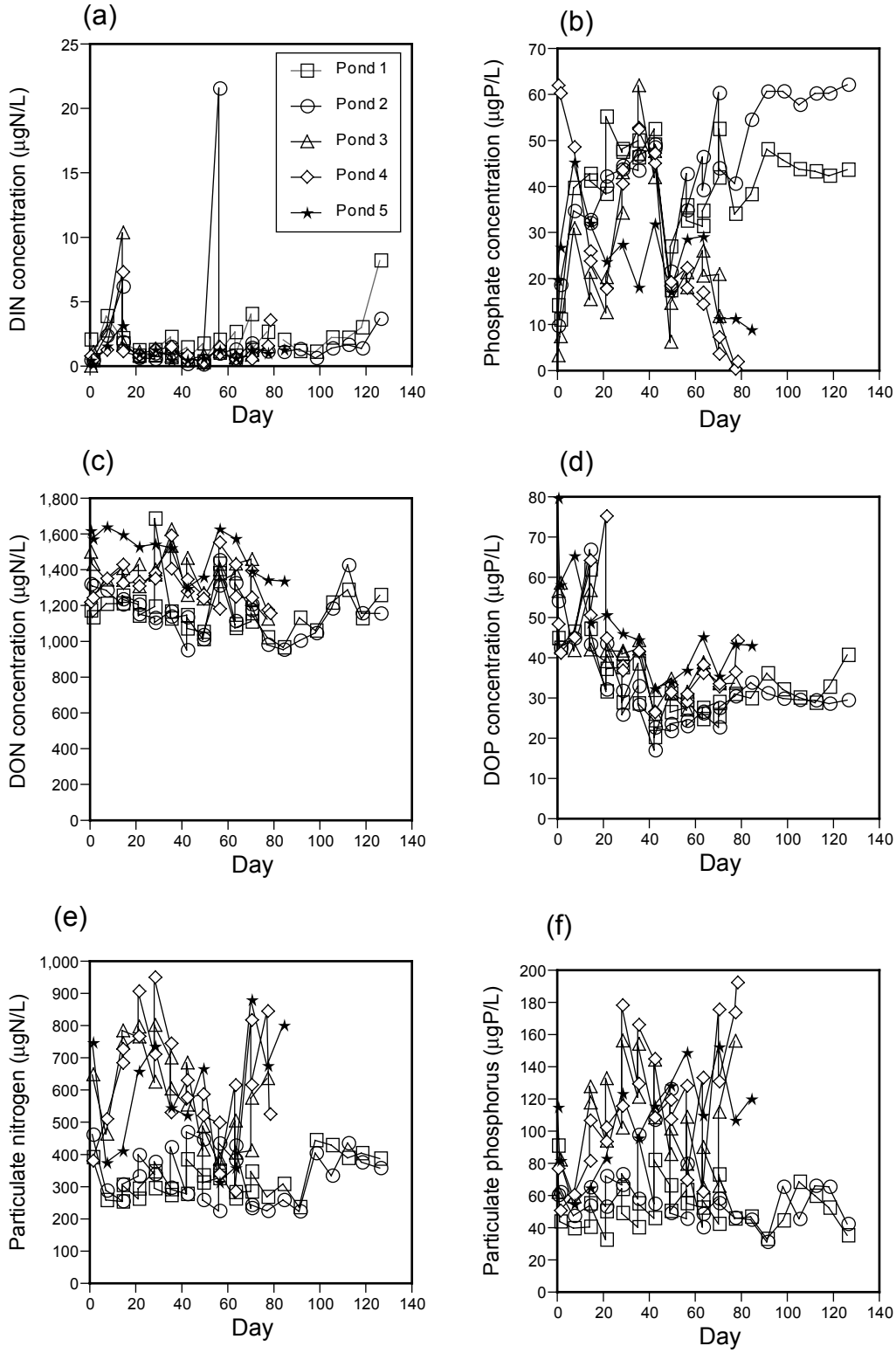

Fig. 3. Concentrations of (a) dissolved inorganic nitrogen (DIN), (b) phosphate, (c) dissolved organic nitrogen (DON), (d) dissolved organic phosphorus (DOP), (e) particulate nitrogen, and (f) particulate phosphorus during the experimental period

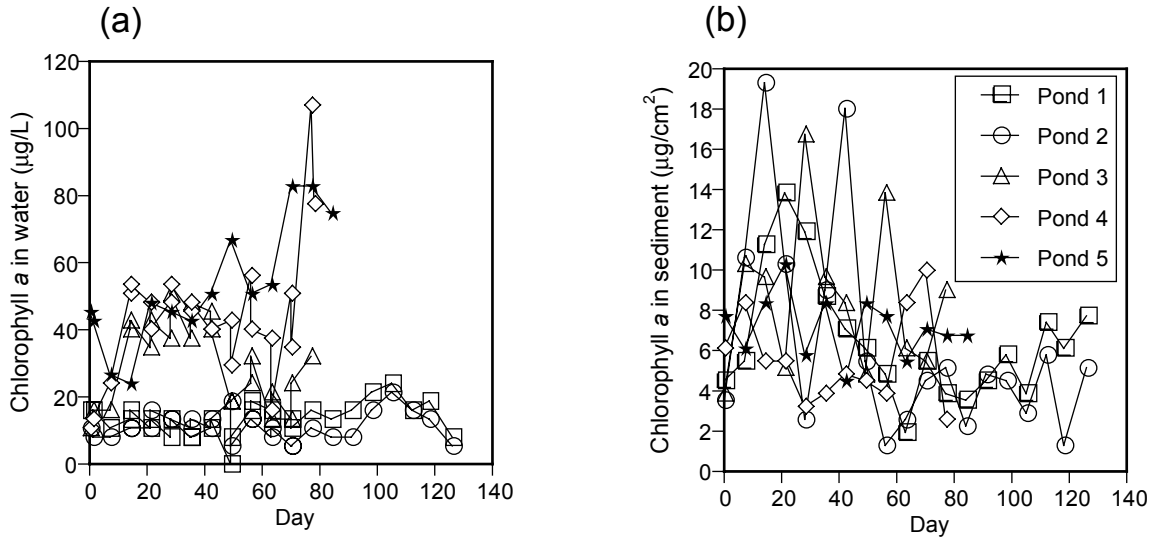

Fig. 4. Chlorophyll *a* concentration in water (a) and in sediment (b) during the experimental period

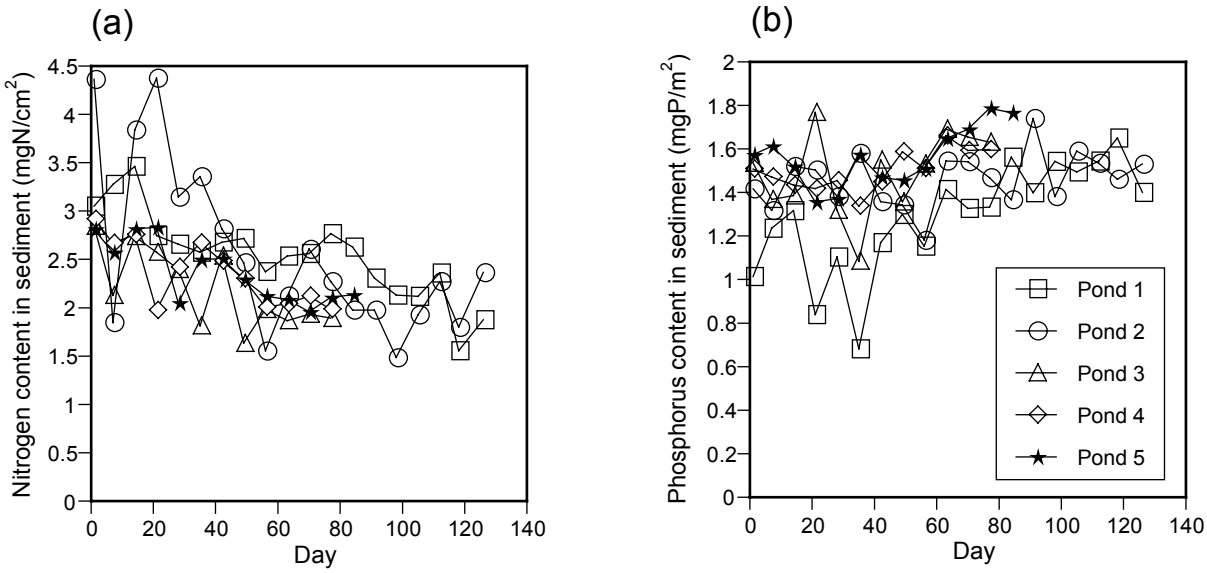

Fig. 5. (a) Nitrogen and (b) phosphorus contents in the sediment during the experiment period

those of water in the ponds. Dissolved oxygen concentration was 4.7–12.5 mg/L and anoxic water was not observed. The pH was about 8.5 and stable in all ponds during the experimental period. Turbidity was 3–210 mg/L and increased after water exchange, especially in the mangrove ponds. Though water exchange between the shrimp and mangrove ponds affected turbidity, no tendency of the turbidity to rise during the experimental period was observed.

Nearly all of the nitrogen in water existed in the form of dissolved organic or suspended matter in each pond (Fig. 3). Since the Chl. *a* concentration in the water increased greatly in the shrimp culture ponds (Fig. 4), it was suggested that the dissolved inorganic nitrogen (DIN) was consumed by phytoplankton as soon as the organic matter decomposed to inorganic matter. Dissolved organic nitrogen and particulate nitrogen were higher in Ponds 3, 4 and 5 than in Ponds 1 and 2. The phosphate level in the aquaculture ponds, which were provided with feed, showed the tendency to decrease gradually as the Chl. *a* concentration increased. The phosphate concentration was high in Ponds 1 and 2 (Fig. 3) though no feed was provided. Dissolved organic phosphorus tended to decrease in all the ponds. Particulate phosphorus and Chl. *a* increased in the aquaculture ponds where feed was supplied.

The nitrogen content in sediment decreased and the phosphorus content in sediment increased in all ponds during the experimental period (Fig. 5). Table 3 shows the nitrogen and phosphorus budgets in shrimp aquacul-

ture ponds during the experiment period. The main organisms in ponds, primarily small fish, snails, and barnacles were collected and quantified. Moreover, the increment of nitrogen and phosphorus in water and sediment was calculated. The change in nitrogen in the water column was small compared to that of sediment. As a result, in the nitrogen and phosphorus budgets in each aquaculture pond, nitrogen decreased greatly while phosphorus increased more than the input of feed. In other words, nitrogen disappeared and phosphorus appeared from somewhere. Phosphorus increased in all ponds, including Ponds 1 and 2, where feed was not supplied.

Discussion

During the first 63 days, before mass mortality occurred, shrimp growth was faster in the ponds circulated with water from the mangrove ponds (Fig. 2). It was thought that the productivity in the mangrove ponds would allow the shrimps to grow faster for at least about 2 months. However, after 2 months, a decrease in the mean size occurred in Pond 1 since comparatively large individuals died from a food shortage or virus.

Phosphate concentration in water (Fig. 3) was high and stable in the no-feed culture pond with water circulated from the mangrove pond, though the initial concentration was low. Though dissolved oxygen was not low, there was the possibility of sediment in aquaculture ponds becoming anoxic. It was thought that an anoxic condition in the sediment could have occurred and released phosphorus[6,18], but no increase in Chl. *a* occurred (Fig. 4) because there was no nitrogen supply from feed.

From the phosphorus budget (Table 3), phosphorus appeared from somewhere and increased. It was supposed that phosphorus was released from the depths of the bottom of the pond to the water column due to anoxic conditions in the sediment and was then carried to the bottom surface again by phytoplankton uptake and particulate adsorption. Though the phosphorus budget in Pond 4, 0.06 kg was only slightly lower than that in Pond 5, 0.09 kg, the increment in the phosphorus content in the sediment was 0.47 kg/pond in Pond 4 and 1.01 kg/pond in Pond 5. Hence, the effect of preventing environmental deterioration to the aquaculture pond was recognized for phosphorus in Pond 4 where water circulated from the mangrove pond.

On the other hand, nitrogen decreased greatly in the budget. It was suggested that denitrification besides the uptake by the mangrove ecosystem greatly played a part in the decrease of nitrogen[4,10]. The amount of nitrogen decrease, 11.84 kg, in the sediment in Pond 4 circulated with water from the mangrove pond was higher than the 5.81 kg decrease at Pond 5 without circulated water. A load reduction effect for nitrogen was recognized in the pond sediment. Though deterioration in the water and sediment in respect to nitrogen was not observed in Pond 5, where water was not circulated, data in the last phase of aquaculture is necessary when the amount of feed increases, because the daily ration is generally increased

Table 3. Nitrogen and phosphorus budgets (kg/pond) in shrimp aquaculture ponds during the experimental period

	Nitrogen			Phosphorus		
	Pond 1	Pond 4	Pond 5	Pond 1	Pond 4	Pond 5
Inputs						
Feed	0.00	4.57	4.38	0.00	1.19	1.14
Shrimp stock	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Outputs						
Shrimp harvest*	0.01	1.02	1.12	0.00	0.11	0.12
Small fish	0.03	0.06	0.06	0.01	0.01	0.01
Snail	0.82	1.18	0.94	0.09	0.08	0.06
Barnacle	0.10	0.19	0.12	0.01	0.03	0.02
Increase in water in shrimp pond	0.08	0.24	−0.11	−0.02	0.04	0.00
Increase in water in mangrove pond	−0.04	−0.05	–	0.00	0.01	–
Increase in soil in shrimp pond	−6.17	−4.90	−3.56	2.03	0.47	1.01
Increase in soil in mangrove pond	−10.49	−4.99	–	0.60	0.51	–
Outputs – Inputs	−15.67	−11.84	−5.81	2.73	0.06	0.09

*Including dead shrimps.

in the last phase of aquaculture.

Robertson and Phillips[13] estimated that 22 ha of mangrove forest for 1 ha of shrimp aquaculture pond was necessary. Rivera-Monroy[12] supposed that 0.04–0.12 ha of mangrove forest was needed to process the effluent from 1 ha of shrimp aquaculture pond using the DIN concentration in effluent. The results of both papers differed greatly. In this paper, though the area of aquaculture and mangrove pond was 1:1, the amount of nitrogen decrease was larger and the increment of phosphorus content in sediment was less than half in the ponds circulated with water from the mangrove ponds, and a load reduction effect on the environment was observed. However, because nitrogen decreased and phosphorus increased in the budget, the area ratio between shrimp and mangrove ponds of 1:1 was adequate in respect of nitrogen, but was insufficient in respect of phosphorus.

Shrimp aquaculture usually continues for 4–5 months. However, this experiment was terminated owing to the occurrence of yellow head virus. Moreover, in Pond 1 where water circulated with the mangrove pond and shrimps were cultured extensively, the decrease in nitrogen and increase in phosphorus were larger than the ones that were calculated in Ponds 4 and 5. Though nitrogen might decrease by denitrification, it was not easy to think that phosphorus increases permanently under a situation in which feed was not supplied. Therefore, further experiments are needed.

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