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Use of mangroves for treatment of wastewater from shrimp aquaculture ponds: Nitrogen and phosphorus budgets under increased area ratio of shrimp ponds

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Abstract: To assess the capacity of uptake of nitrogen and phosphorus by mangrove *Rhizophora mucronata* enclosures from shrimp *Penaeus monodon* aquaculture ponds, we carried out culture experiments at Samut Songkhram, Thailand. The area ratio of the shrimp culture pond to the mangrove enclosure was 1:1 in the previous study. Shrimp farmers hope that the area of the mangrove region can be reduced in view of effective economic management. In this study, an experimental area ratio between the shrimp aquaculture ponds and mangrove enclosures of 2:1 was conducted and the effect was evaluated. However, it was shown that the deterioration of the pond sediments could not be prevented in the case that the area ratio between the shrimp aquaculture ponds to the mangrove enclosure was 2:1. For sustainable pond usage, the necessity for increasing the area ratio of mangroves to shrimp culture ponds was indicated based on these results.

Keywords: *mangrove, shrimp aquaculture, treatment, budgets*

1. Introduction

Japan is the second largest shrimp importing country in the world and is importing more than 60% of the shrimp produced in brackish waters from Southeast Asian countries (HAMANO *et al.*, 2010). Therefore, shrimp aquaculture is an important export industry in these countries and the shrimp farming areas have been developed in order to acquire foreign currency. In these countries, however, mangrove trees have been cut down in order to construct shrimp aquaculture ponds (BARBIER and SATHIRATHAI, 2004), and the total area of mangrove in Thailand has decreased by more than 50% since the 1960's (BHODTHIPUKS, 1988; CLOUGH, 1993). Mangrove forests have an important role in the coastal tropical environment for purification of effluents from aquaculture and other terrestrial sources (ROBERTSON and PHILLIPS, 1995; RIVERA–MONROY *et al.*, 1999).

Intensive shrimp culture needs a large amount of feed and only 24% of nitrogen and 13% of phosphorus in feed input has been shown to be incorporated into the shrimp body (BRIGGS and FUNGE–SMITH, 1994). The remainder of the feed flows out into the surrounding waters or is accumulated in the sediment. After shrimp ponds are used for several years, they are disused and left (STEVENSON, 1997; OKUBO *et al.*, 2004) even if the sediment is removed

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after harvest.

In order to develop sustainable shrimp aquaculture practices, several methods have been proposed to decrease the impact of shrimp effluent (BOYD *et al.*, 1994; SANDIFER and HOPKINS, 1996; DIERBERG and KIATTISIMKUL, 1996; LIN *et al.*, 2003; TSUTSUI *et al.*, 2010). Although integrated mangrove–aquaculture systems have been initiated in Southeast Asia (RIVERA–MONROY *et al.*, 1999; PRIMAVERA, 2000; PRIMAVERA *et al.*, 2007; ALDON *et al.*, 2008), they are still at the verification and early dissemination stage and the use of mangrove areas for treatment of nutrients from intensive shrimp farming has not been widespread in tropical aquaculture regions (HAMANO *et al.*, 2010).

When shrimp culture density is high, disease outbreaks occur (SHIMODA *et al.*, 2005a), and the feed conversion ratio (FCR) also deteriorates and production efficiency decreases even if the shrimp remain healthy. Between the pond where water was circulated with mangroves and the control pond where water was not circulated, the production, survival rate and FCR were improved in the circulated pond, and therefore the aquaculture production efficiency was improved by the circulation with mangroves where the nutrients were utilized for enhancing mangrove growth. RIVERA–MONROY *et al.* (1999) suggested that an area of mangrove forest from 0.04 to 0.12 hectares is required to completely remove the DIN load from effluents produced by a 1 hectare pond. On the other hand, ROBERTSON and PHILLIPS (1995) reported that between 2 and 22 hectares of forest are required to filter the nitrogen and phosphorus loads from effluent produced by a 1 hectare pond. PRIMAVERA *et al.* (2007) suggested that 1.8–5.4 hectares of mangroves are required to remove nitrate wastes from 1 hectares of shrimp pond in the Central Philippines. GAUTIER *et al.* (2001) reported that the efficiency for effluent treatment as a biofilter using mangrove wetlands is less predictable than expected. However, these calculations are largely based on hypothetical theory because model experiments have not been carried out quantitatively.

The area ratio of shrimp culture ponds and mangrove enclosures was carried out at a ratio of 1:1 in the previous study (SHIMODA *et al.*, 2005b; SHIMODA *et al.*, 2007). Needless to say, shrimp farmers hope that the area of the mangrove region can be reduced in view of economic management. In this study, to develop sustainable shrimp culture methods, an experiment using an area ratio between shrimp aquaculture ponds and mangrove enclosures of 2:1, was conducted and the effect was evaluated in comparison to ponds of a ratio of 1:1 and a control of shrimp aquaculture pond only (no circulation to a mangrove enclosure).

2. Materials and methods

Experiments that involved the circulation of water between shrimp aquaculture ponds stocked with *Penaeus monodon* and mangrove enclosures planted with *Rhizophora mucronata,* were carried out at the Samut Songkhram Coastal Aquatic Research Station, Faculty of Fisheries, Kasetsart University, Thailand. Six ponds of 40×20 m for the upper level, 35×15 m for the lower level and 1.5 m depth were used for this experiment (Fig. 1). Shrimp were cultured in four ponds, and mangrove trees were planted in two. In Ponds 1, 2, 3 and 6, 12,500 shrimp larvae *Penaeus monodon* at the PL (post larvae) 20 days stage, were stocked (about 24 shrimp per m^2) and shrimps were intensively cultured for about 5 months from Friday, September 19, 2003. Totals of 476 one–year–old mangrove saplings *Rhizophora mucronata* had been planted in each of Ponds 4 and 5 in June, 2002.

Ponds 5 and 6 were connected, and the area ratio of shrimp culture pond and mangrove enclosure was 1:1. Ponds 2 and 3 where shrimp were cultured and Pond 4 where mangroves were planted, and they were connected so that the area ratio was 2:1 (Fig. 1). First, brackish water was added to a depth of 110 cm in the shrimp aquaculture ponds on the first Friday and water was removed from the mangrove ponds. Pond 1 was the control pond and shrimp were cultured in a closed system. In Ponds 4 and 5, every Monday, Wednesday and Friday, about 30% of the water in shrimp pond was transferred by siphon from the mangrove pond to the shrimp pond and the water was pumped

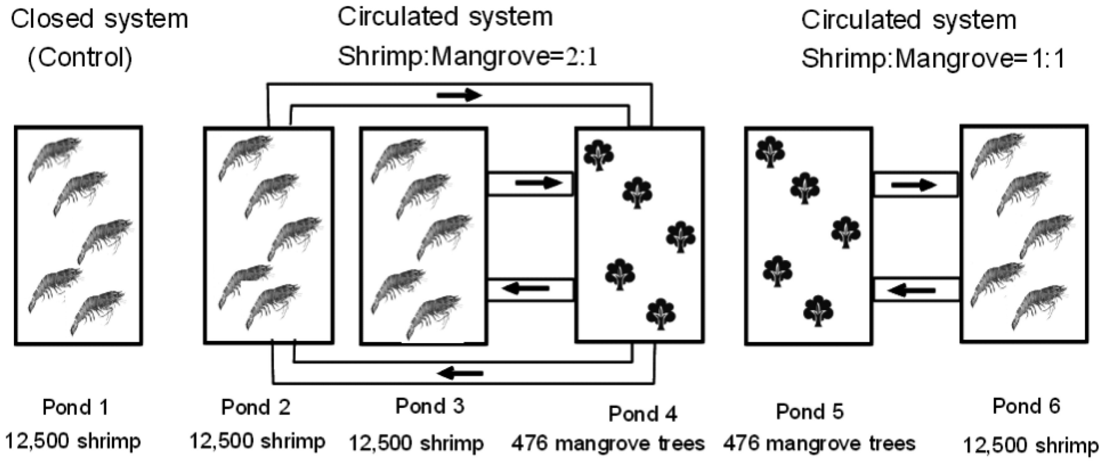


Fig. 1. Schematic outline of shrimp aquaculture ponds and mangrove enclosures used in the experiment.

back into the shrimp pond using a gasoline–powered water pump. In Ponds 2, 3 and 4, about 30% of the water in Pond 2 was transferred to Pond 4, every Monday. Water in Pond 4 was pumped back to Pond 2 every Wednesday. After that, about 30% of water in Pond 3 was transferred to Pond 4 on the same day. Water in Pond 4 was pumped back to Pond 3 every Friday. There was no standing water in Pond 4 from Fridays to Mondays.

Monitoring of the water quality and collection of water and soil samples were conducted weekly before circulation of the water by paddle wheels. The surface 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 from the center of each pond. The samples were immediately filtered through Whatman GF/F filters for the collection of chlorophyll *a* + phaeopigment (Chl. *a* + Phaeo.), particulate nitrogen and phosphorus. For Chl. *a* + Phaeo. analysis, the filters were soaked in *N, N*–dimethylformamide (SUZUKI and ISHIMARU, 1990), and then Chl. *a* + Phaeo. was extracted in solvent and analyzed with a fluorometer (Turner Designs TD–700). Particulate nitrogen was analyzed with an elemental analyzer (Fisons EA–1108). Particulate phosphorus was analyzed using the method of SOLORZANO and SHARP (1980b). The ammonia concentration was measured immediately after filtration using a method developed by SASAKI and SAWADA (1980). Nitrate, nitrite and phosphate (DIP) were analyzed by the standard method (PARSONS *et al.*, 1984) using a spectrophotometer (Shimadzu UV–1201). After potassium peroxydisulfate ($K_2S_2O_8$) was added to the samples, and digestion was carried out by autoclaving, the nitrate and phosphate concentrations were measured according to the method of SOLORZANO and SHARP (1980a) for total dissolved nitrogen and that of MENZEL and CORWIN (1965) for total dissolved phosphorus. Dissolved inorganic nitrogen (DIN) concentration was calculated from ammonia, nitrate and nitrite. Dissolved organic nitrogen (DON) and phosphorus (DOP) concentrations were calculated from TDN–DIN and TDP–DIP, respectively. Core–mud samples of 3-cm depth were collected from the surface using a syringe with 23-mm in diameter. The collected mud was dried, weighed, and crushed with a mortar. The nitrogen content in the sediment was analyzed with an elemental analyzer (Fisons EA–1108). The phosphorus content in mud was analyzed with the method developed by ANDERSEN (1976). *N, N*–dimethylformamide was added directly to the surface 1-cm depth mud sample for Chl. *a* and Phaeo. extraction. After centrifugal separation, the supernatant was analyzed.

Table 1. Mean ± standard deviation of height, number of leaves and stalk diameter of mangrove trees *Rhizophora mucronata* at the beginning and end of the experiment in Ponds 4 and 5

	Height (cm)		Number of leaves (no.)		Diameter of stalk (mm)	
	Beginning	End	Beginning	End	Beginning	End
Pond 4	89.4±9.8	110.5±13.9	41.2±14.0	82.5±34.7	27.8±2.7	31.4±3.3
Pond 5	94.1±12.0	111.5±16.4	40.8±14.7	79.4±28.4	24.8±3.4	27.3±3.7

Table 2. Number of stocked larvae, shrimp total weight and individuals at harvest, survival rate, average shrimp size, the amount of feed during the experimental period and the food conversion ratio (FCR)

Pond	The area ratio	Stocked larvae		Harvest		Survival rate	Average size	Feed	FCR*
		(Individuals)	(/m²)	(kg)	(Individuals)	(%)	(g)	(kg)	
1	Control	12500	24	240.4	8273	66.2	29.1	352.8	1.47
2	Circulated with a ratio of 2:1	12500	24	194.6	7733	61.9	25.2	345.4	1.77
3	Circulated with a ratio of 2:1	12500	24	193.7	7652	61.2	25.3	320.6	1.66
6	Circulated with a ratio of 1 :1	12500	24	264.8	8971	71.8	29.5	400.1	1.51

*FCR= (We ight of fe ed) / (Weight of harvest−larvae)

The net nitrogen and phosphorus transport (NT and PT) from the shrimp ponds to the mangrove enclosures were calculated as follows:

NT or PT = (total quantity of nitrogen or phosphorus in water transported from a shrimp pond to a mangrove enclosure) − (total quantity of nitrogen or phosphorus returned from the mangrove enclosure to the shrimp pond).

The mean height, number of leaves, and diameter of the stalks of 10 mangrove trees were measured at the beginning and end of the experiment. At harvest, shrimp and other organisms in the ponds were sampled. The biomass, and their nitrogen and phosphorus contents were analyzed using the same method as that used for particulate nitrogen and phosphorus analysis.

3. Results

Table 1 shows mean± standard deviation of height, number of leaves and stalk diameter of mangrove trees *Rhizophora mucronata* at the beginning and end of the experiment in Ponds 4 and 5 for about 5 months from 19 September, 2003. All the values increased, showing that the mangroves grew. Table 2 shows the number of stocked larvae, shrimp total weight and individuals at harvest, survival rate, average shrimp size, the amount of feed and the food conversion ratio (FCR) during the experiment in Ponds 1, 2, 3 and 6. The shrimp total weight at harvest, survival rate and FCR were 193.7–194.6 kg/ pond, 61.2–61.9 % and 1.66–1.76 in Ponds 2 and 3 where the area ratio between shrimp aquaculture ponds and mangrove enclosure was 2:1, and they were 264.8 kg/ pond, 71.8% and 1.51 in Pond 6 where the area ratio was 1:1. In the control pond, they were 240.4 kg/ pond, 66.2% and 1.47. Therefore, aquaculture efficiency was better in Pond 6.

The water temperature decreased gradually from 30 to 24℃ (Fig. 2), and salinity increased from 13 to 31 in the aquaculture ponds. Though anoxic water did not occur in the shrimp aquaculture ponds, low level of dissolved oxygen were observed at the end of the experiment in Pond 4 that was a mangrove enclosure. The pH showed a tendency to decrease slightly and turbidity tended to increase.

DIN concentration spiked occasionally but

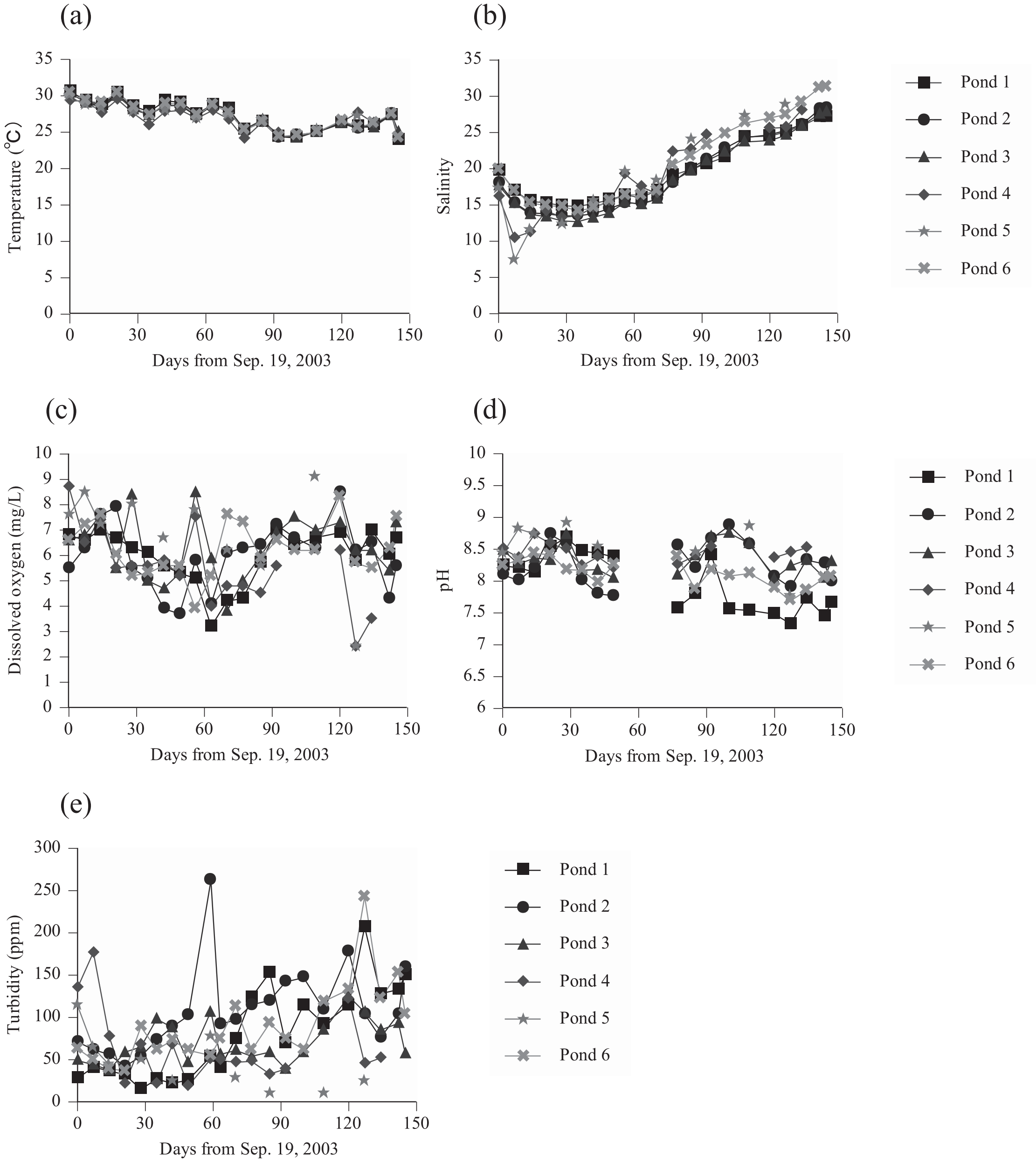


Fig. 2. Variations of (a) water temperature, (b) salinity, (c) dissolved oxygen, (d) pH and (e) turbidity during the experiment period.

the contribution to TN was small (Fig. 3). After an initial decrease in DON, it showed a tendency to increase. PN also increased in the culture ponds. As a result, the contribution of DON and PN was large to TN, and TN concentration increased from 2 mgN/L to 5 mgN/L on average in all aquaculture ponds. Though DIP concentration varied largely, both of DOP and PP concentrations gradually increased (Fig. 4). Contribution to TP was

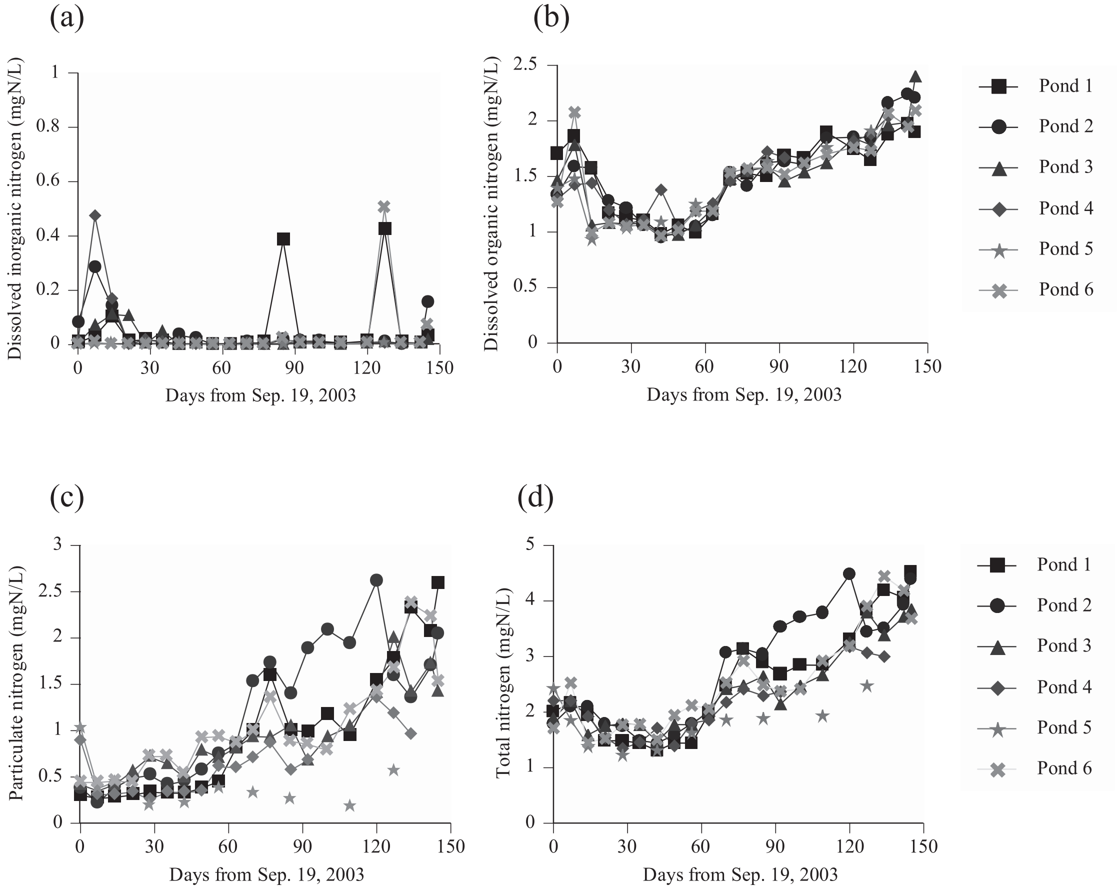


Fig. 3. Concentrations of (a) dissolved inorganic nitrogen, (b) dissolved organic nitrogen, (c) particulate nitrogen, and (d) total nitrogen.

largely in PP, and the TP concentration in the culture ponds increased from 0.16 mgP/L to 0.42 mgP/L on average. Chl. *a* + Phaeo. concentration in the water also increased (Fig. 5). Though nitrogen and phosphorus contents in mud (Fig. 6) fluctuated largely, they increased at the end of this experiment. The linear regression slopes between nitrogen content and Days were 1.194×10^{-3} $\mu gN/cm^2$/days, 5.300×10^{-3} $\mu gN/cm^2$/days, 3.862×10^{-3} $\mu gN/cm^2$/days, and 1.800×10^{-3} $\mu gN/cm^2$/days in Ponds 1, 2, 3 and 6, respectively. And the slopes between phosphorus content and Days were 1.387×10^{-3} $\mu gP/cm^2$/days, 8.996×10^{-4} $\mu gP/cm^2$/days, -1.307×10^{-4} $\mu gP/cm^2$/days and 2.510×10^{-3} $\mu gP/cm^2$/days, respectively. Though they were not significant statistically because of the large fluctuations, the slope for nitrogen was small and that for phosphorus was large in Ponds 1 and 6 where the aquaculture efficiency was better, and they showed the opposite trend in Ponds 2 and 3 where the aquaculture efficiency was worse.

The amount of transported nitrogen or phosphorus (Fig. 7) from Pond 6 that was a shrimp aquaculture pond to Pond 5 that was a mangrove enclosure, gradually increased during the experimental period. In Ponds 2, 3 and 4, the amount of transported phosphorus decreased temporally. The net nitrogen or phosphorus transports were large in Pond 6 where the area ratio between the aquaculture pond

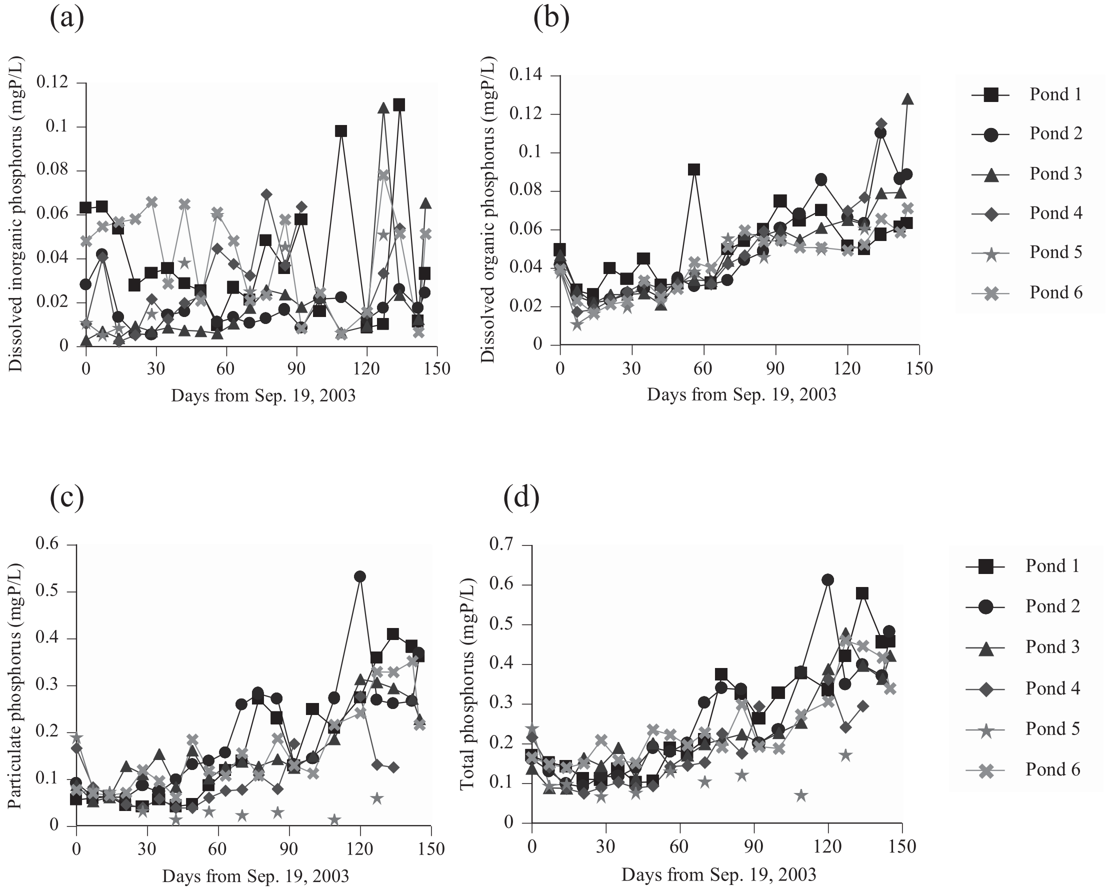


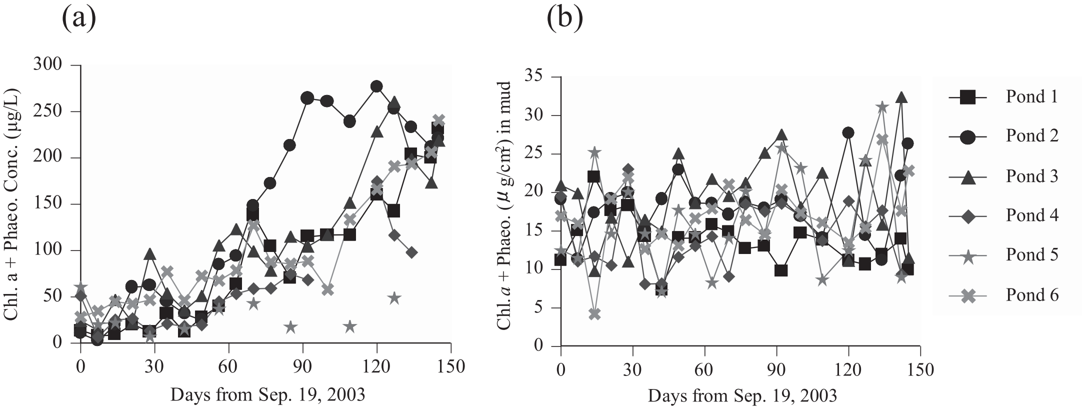
Fig. 4. Concentrations of (a) dissolved inorganic phosphorus, (b) dissolved organic phosphorus, (c) particulate phosphorus, and (d) total phosphorus.

and the mangrove enclosure was 1:1.

4. Discussion

Relative growth rate (RGR_H) (HUNT, 1982) of *Rhizophora mucronata* was not so high in comparison with some mangrove species and rates of 0.720±0.036 and 0.743±0.035 (mm/cm/mo) are reported in Thailand (Thampanya *et al.*, 2002). In this study, RGR_H was calculated with 0.621±0.208 in Pond 4 and 0.512±0.184 (mm/cm/mo) in Pond 5. Though mangrove saplings grew during this experiment, the growth rate was at a comparative level but slightly lower in the mangrove enclosures compared to saplings under natural conditions. Circulation of water between the shrimp aquaculture ponds and the mangrove enclosure simulated the level of water experienced during a tidal change. However, the weekly circulation of water might be insufficient to fully enhance mangrove growth.

The dry season of Thailand is from November to February and it doesn't rain around November and the temperature falls. Therefore, the water temperature fell and salinity rose during the experimental period, though salinity fell slightly immediately after the beginning of the experiment (Fig. 2). *Penaeus monodon* is euryhaline (0–52) (MOTOH, 1981) and the most suitable salinity is about 15 to 20 and ideal water temperature is thought to be 25–30 degrees (YOSHIDA, 1987). Therefore, the



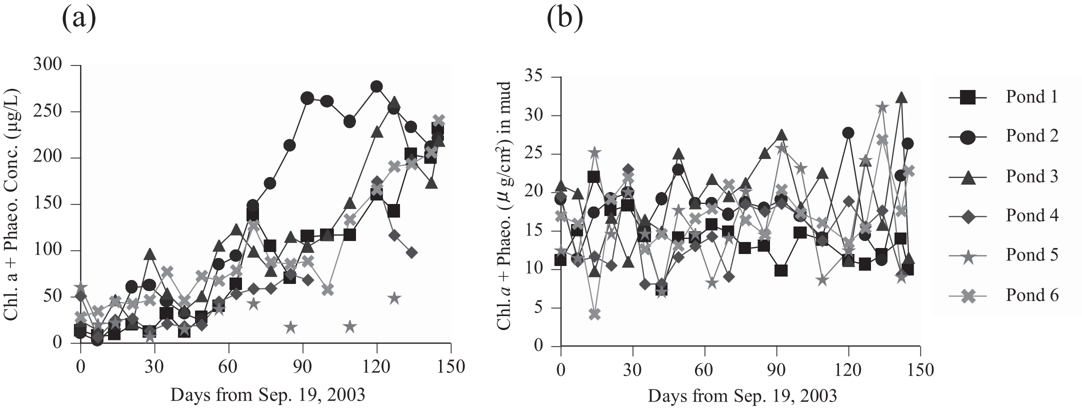


Fig. 5. Chl. a + Phaeo. concentration in (a) water and (b) mud.

water temperature and salinity were in a suitable range for *Penaeus monodon* during this experiment.

Though both DIN and DIP concentrations did not increase in all the ponds (Figs. 3 and 4), organic and particulate nitrogen or phosphorus increased in water. And Chl. *a* + Phaeo. concentration in water also increased in the shrimp aquaculture ponds (Fig. 5). Although their concentrations increased largely in the water, it was considered that water quality was kept within tolerable limits for shrimp growth during the experiment. Though Chl. *a* + Phaeo. concentration in the mud fluctuated largely, there was not an increasing trend. *Penaeus monodon* is omnivorous and can feed on benthic algae (YOSHIDA, 1987). It was considered they ate the benthic algae.

In Pond 6 where the area ratio between the shrimp aquaculture pond and mangrove enclosure was 1:1, the shrimp total weight, the number of individuals harvested and the survival rate were high, and FCR was low. However, in Ponds 2 and 3 where the area ratio was 2:1, the shrimp total weight, number of individuals harvested and the survival rate were low, and FCR was high. Though the aquaculture efficiency was higher in Pond 1 than Ponds 2 and 3, the previous use history as a shrimp aquaculture pond might have influenced the nutrient budgets. From the nitrogen and phosphorus budgets (Table 3), the difference (In–Out) of nitrogen was –0.36 kgN/ pond/ experimental period in Pond 6. This means that nitrogen was not accumulated into the mud in Pond 6, and it was thought that nitrogen was released by denitrification and ammonia evaporation (BRIGGS and FUNGE–SMITH, 1994). On the

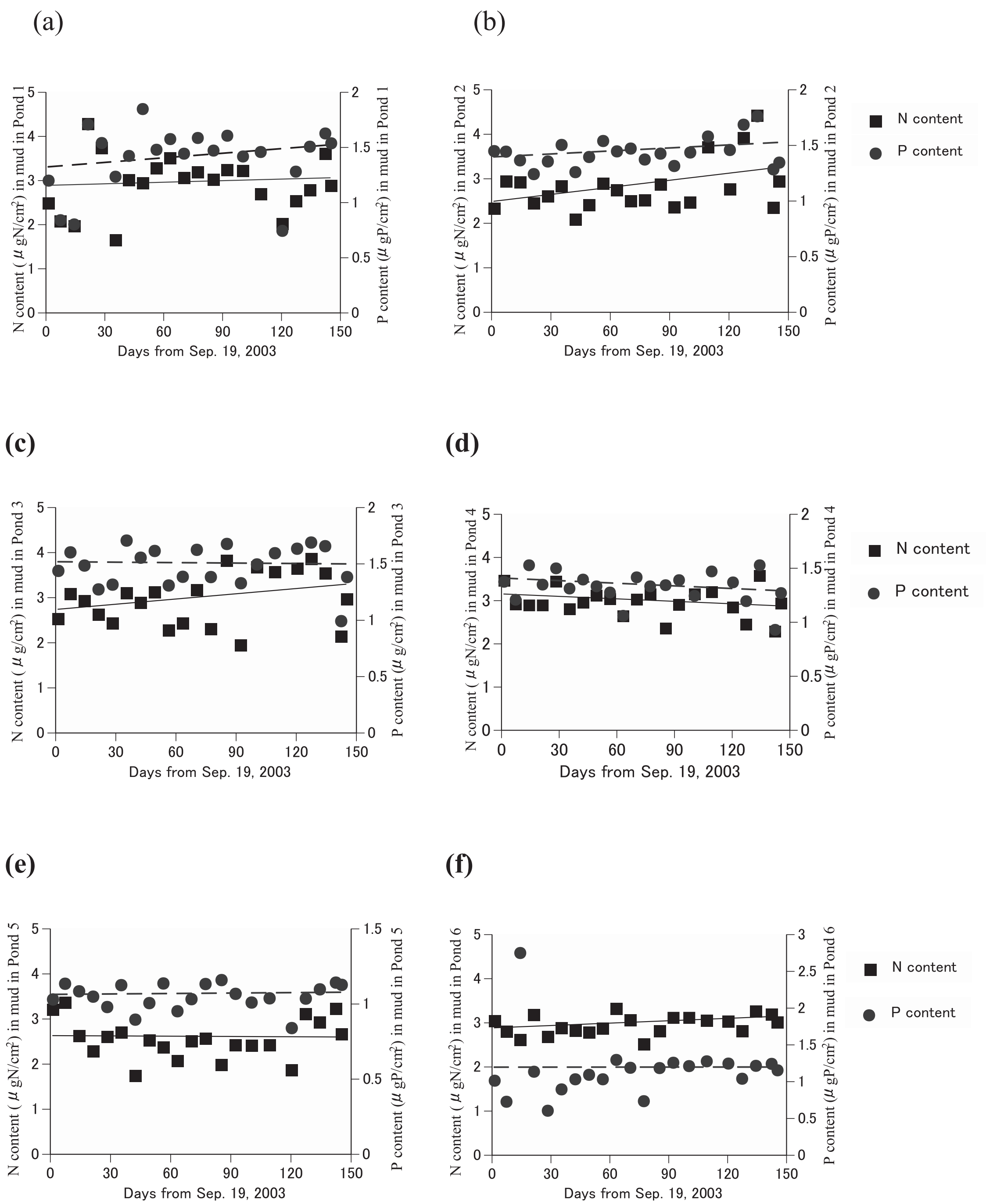


Fig. 6. Nitrogen and phosphorus contents in mud in Ponds 1 (a) –6 (f). The solid and broken lines show the regression line of nitrogen and phosphorus contents in mud, respectively.

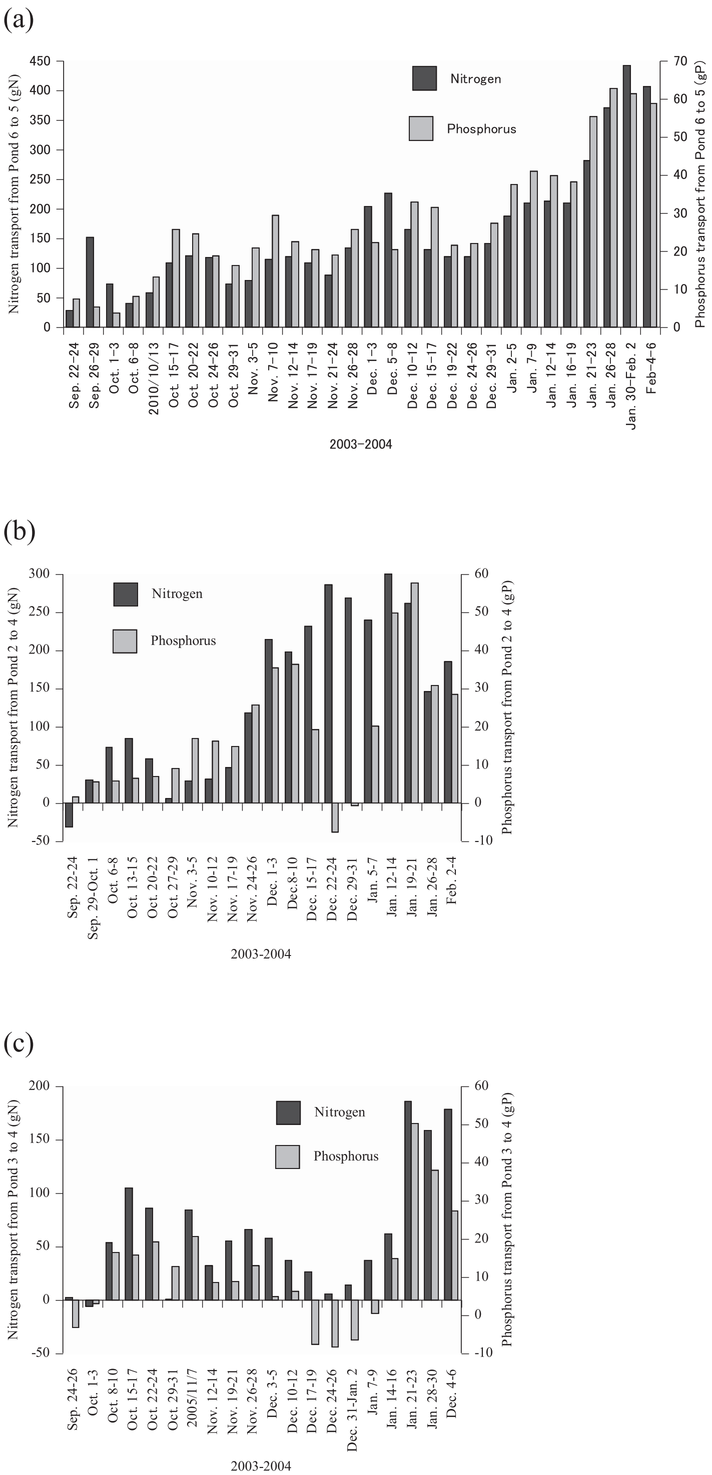


Fig. 7. Nitrogen and phosphorus transports (a) from Ponds 6 to 5, (b) from Ponds 2 to 4 and (c) from Ponds 3 to 4.

Table 3. Nitrogen and phosphorus budgets in the shrimp aquaculture ponds during the experimental period.

	Pond 1	Pond 2	Pond 3	Pond 6
In				
N supplied from feed	21.25	20.60	19.00	24.10
Initial N content in shrimp at stocking	0.01	0.01	0.01	0.01
Out				
N accumulated in shrimp at harvest	6.70	5.01	5.43	7.29
N accumulated in snail	1.91	3.41	2.89	0.19
N accumulated in barnacle	0.21	0.20	0.22	0.17
N accumulated in water	1.53	1.59	1.82	1.87
N accumulated in mud	6.40	9.48	6.77	−0.36
N transport to mangrove encclosure		2.78	1.24	4.83
N differences (In−Out)	4.51	−1.86	0.64	10.12

(kgN/pond/experimental period)

	Pond 1	Pond 2	Pond 3	Pond 6
In				
P supplied from feed	4.41	4.28	3.94	5.00
Initial P content in shrimp at stocking	<0.01	<0.01	<0.01	<0.01
Out				
P accumulated in shrimp at harvest	0.64	0.48	0.47	0.69
P accumulated in snail	0.12	0.21	0.16	0.19
P accumulated in barnacle	0.02	0.02	0.03	0.12
P accumulated in water	0.18	0.20	0.17	0.11
P accumulated in mud	5.35	−1.61	−0.90	2.25
P transport to mangrove encclosure		0.38	0.24	0.83
P difference (In−Out)	−1.89	4.60	3.78	0.81

(kgP/pond/experimental period)

other hand, the difference of nitrogen was −1.86 −0.64 kgN/ pond/ experimental period in Ponds 2 and 3. This shows that nitrogen accumulated in the bottom and it means that the sediment environment deteriorated. The difference of phosphorus was negative in Pond 1 that was the control, and the difference of phosphorus was low in Pond 6 where the area ratio was 1:1 compared to 2:1. Phosphorus content in mud decreased in Ponds 2 and 3 while it increased in Ponds 1 and 6. This means phosphorus desorbed from the bottom in Ponds 2 and 3 where phosphorus had accumulated in the past. The results showed that the deterioration of mud of the ponds could not be prevented in the case that the area ratio between the shrimp aquaculture ponds and the mangrove enclosure was 2:1. The necessity for increasing the area ratio of the mangrove region to the shrimp culture pond was indicated based on these results for sustainable ponds usage.

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