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Harvest Draining Associated Mass Discharged from Intensive Shrimp Culture Pond: A Case Study of Commercial Shrimp Farms in Chachaengsao, Province of Thailand

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Abstract

This study was conducted to evaluate effluent and solid waste management practices used by shrimp farmers in Thailand and to assess nutrients and solid waste loading to the external environment associated with harvest draining. In this study, 24 shrimp farms were selected in the Chachaengsao province, Thailand. One pond from each farm was randomly selected for effluent and sediment analysis. Effluent samples during harvest draining were collected at three depths namely, when pond water level was between 100-50 cm (surface), 50-30 cm (middle), and 30-0 cm (bottom) and were assessed for effluent quality. After harvest draining, sediment samples (10 cm depth) were collected from each pond for nutrients and organic carbon analysis.

Effluent quality at harvest varied largely among the 24 shrimp farms surveyed. Total ammonia nitrogen in effluent ranged from 0.0 to 1.1 mg l^{-1}, but was not significantly different among the three pond depths. Total nitrogen and total phosphorus ranged from 2.3 to 9.7 mg l^{-1} and from 0.2-1.3 mg l^{-1}, respectively; and the values were significantly higher at the bottom effluent than at the surface effluent. Organic matter and total solids content in effluent ranged from 0.7 to 1.0 g l^{-1} and 3.3 to 3.8 g l^{-1}, respectively, and the values were not significantly different among the three pond depths.

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Total settleable matter, total volatile solids and total suspended solids in bottom effluent were significantly higher than effluent from the surface and middle of the pond. The results showed that pond sediment contained about 74% nitrogen and 78% phosphorus of the total outputs compared to only 9% nitrogen and phosphorus contained in the effluent water. The study suggested that retaining bottom effluent (30 cm) and sediment (10 cm) at harvest can significantly reduce nutrient loading to the external environment and thus, minimize the negative impacts of intensive shrimp farming.

Introduction

Shrimp farming is one of the most important economic agricultural activities in Thailand. The Thai shrimp farming sector grew at an average rate of 20% during the last two decades as production reached 494 thousand tons in 2006 (DOF 2007). Thailand is historically positioned as the world's largest shrimp exporter with shrimp exports reaching a net worth of US$ 2.2 billion in 2007 (TFFA 2008). The shrimp-farming sector not only generates national foreign exchange earning but also has greater social implications for the Thai society as the sector comprises of large number of small-scale shrimp farmers. Despite its value and popularity, shrimp farming is one of the most controversial forms of aquaculture in the world. Rapid expansion of marine shrimp culture and difficulty in managing shrimp farms without causing environmental degradation have caused environmental problems throughout the coastal areas in Thailand and other shrimp producing nations in the world (Phillips et al. 1993; Smith 1999; Naylor et al. 2000). Discharge of untreated pond effluents not only leads to environmental problems; it also imposes economic loss to the shrimp farm through wastage of costly nutrients, and thereby reducing farm profitability (Smith et al. 2002). Obviously, detrimental impacts of effluent and sludge generated by shrimp farms on the environment are the most serious concerns for the sustainability of the shrimp aquaculture. These impacts must be reduced to ensure the environmental, social, and economic sustainability of the industry.

Since majority of the shrimp produced in Thailand is meant for export, shrimp importing nations have greater leverage in influencing changes in the shrimp sector. In recent times, environmental problems associated with shrimp aquaculture have become more pressing, which has led to increased international pressure on shrimp producing nations to implement and regulate responsible management practices to protect the environment. Boyd (2003) observed that effluent regulation is going to be a reality for aquaculture practice in most of the countries and thus, the shrimp growers must act to devise proper effluent management strategy to meet effluent standards and minimize the environmental impact of shrimp farming. In its recent report on the aquaculture sector, Greenpeace has also warned against irresponsible action of aquaculture operations, particularly on the impacts of waste disposal on wider environment (Allsopp et al. 2008). In order to comply with the environmental standards, shrimp farms must apply management measures to reduce effluent discharge and treat the waste on farms before being discharged to the natural waters.

Research has been conducted to minimize the concentration of pollutants in effluent water by physical, chemical and biological treatment methods (Chaiyakum and Tunvilai 1992; Yahiya 1994; Tookwinas 1996; Songsangjinda et al. 1999). Pond sediment is one of the important sources of pollution loading from shrimp ponds. Surasawait (2000) observed that pond sediment deposited at the pond bottom during the grow-out period were high in organic matter, nutrients and solids, which can be easily drained to the external waters during harvest draining. Considering the volume of discharge generated by shrimp pond harvest and economy of scale of production, it is essential to devise a practical approach to minimize the pollutant loading from shrimp pond. Despite efforts of the Thai Department of Fisheries to implement nationwide programs to regulate environmental standards for sustainable shrimp farming it remains a challenging task for the Thai shrimp farming sector to develop cost-effective management measures to comply with the standards (Thakur 2007).

To minimize the risk of disease contamination in recent years, many shrimp farmers in Thailand have switched to low daily water exchange or zero water exchange shrimp culture systems. Though close shrimp culture system reduces the net effluent discharge to the external environment compared to water exchange system, it results in the build-up of nutrient and organic matter wastes within the pond over the culture period; and thus, it may pose a greater risk to the environment if harvest effluent are discharged directly to the public water. Hence, it is required to reduce mass discharge of substance from closed shrimp ponds by retaining maximum possible nutrient in the pond to be used for the next production cycle. Lin et al. (2001) reported that appropriate management in pond draining and fish harvest can minimize the environmental impacts of aquaculture. The means of minimizing environmental impacts of pond effluents include minimizing the use of nutrients, managing drainage to retain most nutrients in the pond system, and maximizing the use of surplus materials in both water and sediment (Lin and Yi 2003). Moreover, development of strategy for effluent and solid waste management for shrimp farm would require knowledge of existing effluent management practices and clear understanding of harvest draining associated loading to the external waters. The study was conducted to seek information on effluent management practices commonly used by commercial shrimp farms in Chachoengsao province of Thailand and to assess nutrients and solid waste loading to the external environment associated with harvest draining.

Materials and Methods

Study Site

Chachoengsao province was selected for this study since the province has the highest number of shrimp farms and shrimp culture area in Thailand (DOF 2007). Chachoengsao is located on the bank of Bang Pakong River, 24 kilometers upstream from the mouth. Chachoengsao is administratively divided into ten Amphoe (Districts), 93 Tam Bon (Sub-districts) and 859 Mu Ban (Villages). The major area for shrimp aquaculture is Amphoe Muang, Bang Khla, Bang Pakong, Ban Pho, and Klong Khuan (Chachaengsao's Provincial Fisheries Office 2005). In 2004, it occupied 8,981 hectares of the shrimp culture area with 8,224 shrimp farmers and their production was 31,047 tons. From 1997 up to 2004, the shrimp culture areas and shrimp farmers rapidly expanded to 66% and 132%, respectively. (Chachaengsao's Provincial Fisheries Office 2005). In this study, a total of 24 shrimp farms were selected randomly in the concentrated shrimp culture area, based on the remote sensing GIS database with map 1:50,000.

Sampling protocol

This study had two main components: 1.) shrimp farm survey to collect information on shrimp farms concerning the farm operational profile, management of the water supply system, management of effluent and solid wastes, including knowledge and awareness of environmental implications of shrimp pond waste disposal, and 2.) to assess harvest draining associated nutrient loading from the shrimp farm to the external waters. The manuscript from the survey data is under preparation and will be published separately. This paper deals with the second component of effluent and sediment analysis data collected for determining the quantity and quality of effluent water and solid wastes disposed to the external waters. Table 1 shows pond descriptions and general information about shrimp farms covered in this study. In 23 farms out of the 24 farms selected for the study, black tiger shrimp (*Penaeus monodon*) was the prime culture species and one farm dealt with white shrimp (*Litopeneaus vanamei*). One pond from each farm was randomly selected for collecting effluent and sediment samples during harvest. Effluent samples were collected when pond water levels were 100-50 (surface), 50-30 (middle) and 30-0 cm (bottom), respectively, and were analyzed to assess effluent quality and mass discharge during harvest draining. Sediment samples were collected after complete draining of the pond. Sediment samples were collected by taking 15 cores from each pond and mixed in a composite sample for analysis. Sediment samples were collected from the top 10-cm layer of bottom soil with a 5.4 cm diameter PVC pipe of 30 cm length with fine holes on the side; PVC pipe was forced at least 15-20 cm into the bottom soil to collect the sediment sample. Sediment samples from 15 random points along the pond length (in S-shaped pattern) were collected from each pond. Core sediment sample from the PVC pipe was removed using a plunger and the upper 10 cm length of the core was cut for bulk density, moisture, nutrients (N & P) and organic carbon analysis.

Table 1. Description of shrimp pond selected for effluent and sediment sampling from 24 commercial shrimp farms in Chachaengsao province of Thailand

Pond Number	Farm location (Tambole, Amphoe)	Culture Area (m^2)	Culture period (days)	Shrimp yield (kg/ha)
1	Chimpee, Bangnampaew	4,800	92	2,292
2	Klong17, Banhnampaew	3,200	117	4,063
3	Klong17, Banhnampaew	900	118	7,222
4	Donkoaka, Bangnampaew	4,000	80	2,375
5	Donkoaka, Bangnampaew	1,600	110	2,500
6	Donkoaka, Bangnampaew	4,000	90	2, 500
7	Klong19, Bangnampaew	3,200	105	2,188
8	Klong19, Bangnampaew	3,200	120	1,563
9	Klong17, Banghnampaew	4,800	125	2,500
10	Klong21, Bangnampaew	4,000	89	1,500
11	Paknam, Bangkla	3,200	120	3,750
12	Huasai, Banhkla	3,200	90	2,188
13	Paknam, Bangkla	3,200	132	3,438
14	Bangkajed, Bangkla	3,520	126	2,131
15	Paknam, Bangkla	1,920	135	5,052
16	Paknam, Bangkla	800	120	3,375
17	Bansaeng, Prachinburi	3,200	90	3,063
18	Maungmai, Rajchasan	6,400	120	3,125
19	Klongkuen, Klonhkuen	4,000	110	1,375
20	Tathonglang, Bangkla	5,600	110	3,571
21	Takai, Muang	4,000	90	1,750
22	Bangpai, Muang	3,200	120	4,375
23	Tasa-an, Bangpakong	8,000	78	1,875
24	Bangkajed, Bangkla	8,000	126	2,625

Effluent and sediment analysis

At the sampling point, pH and temperature of the effluent samples were measured in situ. Effluent samples were collected in 2-liter size plastic bottles and preserved in an icebox below 4°C and transported to the AARM laboratory, Asian Institute of Technology, Thailand for analysis. Water quality parameters analyzed were organic matter (OM), total solids (TS), total settleable matter (TSM), total volatile solids (TVS), total suspended solids (TSS), total ammonia nitrogen (TAN), total nitrogen (TN) and total phosphorus (TP) following standard methods (Parsons et al. 1984; APHA 1989). Sediment samples were analyzed for pH, bulk density, organic matter, total nitrogen and total phosphorus. Sediment samples were placed in an aluminum tray and dried in an oven at 60 °C for 48 hours. Dry samples were pulverized and passed through a sieve of mess size of 0.25 mm (USA Standard Series No. 60) to control particle size. Pulverized samples were placed in a zipper bag and stored in a dry place prior to nutrient and organic matter analysis. Total nitrogen in sediment was analyzed using the method described by Raive and Avnimelech (1979) followed by determination of total ammonia (Solozno 1969); total phosphorous content was analyzed by persulphate digestion method followed by ascorbic acid method (APHA 1989). Organic carbon was measured following the Walkley-Black dichromate oxidation technique (Nelson and Sommers 1982) and then converted to percentage organic matter by multiplying with a constant factor.

Statistical analysis

Water quality and sediment data were analyzed by one-way analysis of variance and significant differences between mean values for effluent form different pond depths were compared with LSD (Steel and Torrie, 1980) using SPSS (version 10.0) statistic software package (SPSS, Chicago). Differences were considered significant at $P<0.05$. All means were given with ±1 standard error (S.E.).

Results and Discussion

Mean water quality parameters at different depths during harvest draining of shrimp ponds are presented in Table 2. Water temperature and pH of surface effluent was significantly lower than those for bottom effluent. The TAN in effluent ranged from 0.0 to 1.1 mg l^{-1} and were not significantly different among the three depths. The TN and TP concentrations ranged from 2.3 to 9.7 mg l^{-1} and 0.2 to 1.3 mg l^{-1}, respectively; and the values were significantly higher at the bottom effluent than at the surface effluent. The results showed that TN and TP in effluent water at harvest draining increased with decreasing depth of pond effluent water. The OM and TS in effluent water ranged from 0.7 to 1.0 g l^{-1} and 3.3 to 3.8 g l^{-1}, respectively, and were not significantly different among the three depths. Concentrations of TSM, TVS and TSS in the bottom effluent were significantly higher than both the surface and middle effluents. The results showed that nutrient and organic matter in the effluent at harvest are not uniformly distributed as significantly higher content of nitrogen, phosphorous and organic matter was found in the bottom effluent. Evidently, retaining only the bottom effluent on farm for treatment can significantly reduce waste discharge to the external environment. The practice of differential pond draining, retaining the last 30 cm of the shrimp pond effluent during harvest, while reducing nutrient discharge to the external environment may also facilitate on farm recycling/treatment of wastes due to the small volume of concentrated effluents.

Table 2. Effluent water quality parameters during harvest draining of shrimp pond in commercial shrimp farms in Chanchaengsao province of Thailand

Water quality parameters	**Pond water level during harvest draining** 100-50 cm	50-30 cm	30-0 cm
Temperature (°C)	28.0±1.0[a] (24.6 - 31.3)	28.9±1.2[ab] (24.4 - 33.2)	29.6±1.1[b] (24.7 - 33.3)
pH	7.0±0.2[a] (6.6 - 7.8)	7.1±0.3[ab] (6.4 - 8.6)	7.3±0.3[b] (6.4 - 8.6)
Total ammonia nitrogen (mg l^{-1})	1.0±0.5 (0.0 - 3.3)	1.1±0.5 (0.1 - 3.4)	1.1±0.5 (0.1 - 3.4
Total nitrogen (mg l^{-1})	3.3±0.4[a] (2.3 - 5.0)	3.8±0.6[a] (2.3 - 6.8)	5.6±1.0[b] (3.6 - 9.7)
Total Phosphorus (mg l^{-1})	0.4±0.1[a] (0.2 - 0.8)	0.5±0.1[ab] (0.2 - 1.0)	0.6±0.1[b] (0.3 - 1.3)
Organic matter (g l^{-1})	0.7±0.3 (0.1 - 2.0)	0.9±0.4 (0.2 - 3.0)	1.0±0.4 (0.2 - 3.0)
Total solids (g l^{-1})	3.3±1.6 (0.6 - 12.1)	3.6±1.6 (0.8 -12.3)	3.8±1.4 (1.2 - 11.3)
Total settleable matter (mg l^{-1})	0.5±0.4[a] (0.1 - 4.0)	0.7±0.3[a] (0.1 - 2.3)	1.7±0.7[b] (0.4 - 5.0)
Total volatile solids (mg l^{-1})	78.3±28.8[a] (22.0 - 219.8)	99.1±49.0[a] (12.5 - 435.7)	161.0±62.9[b] (46.4 - 465.5)
Total suspended solids (mg l^{-1})	217.4±90.9[a] (52.5-678.0)	315.0±125.9[a] (68.0-879.2)	598.3±143.5[b] (315.3-1467.3)

Values are mean ± S. E. (n = 24). Mean values with different superscript letters in the same row were significantly different among water depths ($P< 0.05$). Values in parenthesis show the range for each parameter measured.

Table 3 shows nutrients (N & P) and wastes discharged through effluent during harvest draining from shrimp ponds. Mean effluent loading to the external environment were 43 kg N, 5 kg P, 9 ton OM, 40 ton TS and 3.6 ton TSS per hectare shrimp culture area. The results showed that effluents from the bottom contained about half of TSM and TSS, 37% of OM, 40% of TS, 44% of TVS, 39% of TN and 35% of TP discharged during harvest draining. The choice of effluent treatment method for shrimp farm depends on the objectives determined by economical and environmental consideration and regulation. It is usually impractical and uneconomical for most aquaculture operations to treat the whole of the effluents before being discharged to the external environment. The study suggested that discharge of potential pollutants from shrimp ponds to the public waters can be significantly reduced by retaining the last 30 cm of pond effluent during harvest. The result of the study is in agreement with the earlier reports that solids removal is comparatively easier and less expensive than other water treatment operations that may impact nutrients (Clark et al. 1985; Chen et al. 1993). However, most of the organic matter and nutrients in aquaculture pond effluents are associated with phytoplankton and other solids that do not readily settle (Tucker and Hargreaves 2003). In fact, these characteristics make it difficult to formulate affordable post-discharge treatment technologies for shrimp farm effluents. Therefore, reducing effluent volume at harvest draining seems to be a practical approach for reducing mass discharge of substances from shrimp ponds. It should be noted that during harvest draining there were periods when solids from the pond bottom were discharged along with pond water; accordingly, the effluents had temporarily higher concentration of solids, nutrients, and organic mater than the bulk pond water. In this study no attempt was made to estimate the solid discharged though occasional scouring of solids from the bottom during harvest draining, which may constitute a minor portion of the total discharge. According to Tucker and Hargreaves (2003), the elevated solid levels in the initial flush contained 1 - 4 % of the solids discharged during pond draining.

Table 3. Nutrient (N & P) and waste discharged through effluent during harvest draining in commercial shrimp farms in Chanchaengsao province of Thailand

Parameters	Pond water level during harvest draining			Total
	100-50 cm	50-30 cm	30-0 cm	(100%)
TN (kg ha^{-1})	19.1±3.8^{a} (43.3)	7.6±1.3^{b} (17.7)	16.7±2.9^{a} (38.9)	43.3±6.9
TP (kg ha^{-1})	2.4±0.7^{a} (45.6)	1.0±0.2^{b} (19.4)	1.7±0.4^{c} (35.0)	5.1±1.1
TSM (kg ha^{-1})	2.9±2.1^{a} (27.7)	1.3±0.6^{b} (15.6)	5.2±2.0^{c} (56.7)	9.4±3.5
OM (t ha^{-1})	4.4±2.1^{a} (43.8)	1.7±0.8^{b} (19.4)	3.1±1.2^{a} (36.8)	9.2±3.8
TS (t ha^{-1})	21.8±14.4^{a} (48.0)	7.1±3.2^{b} (18.9)	11.4±4.2^{c} (33.1)	40.3±21.5
TVS (t ha^{-1})	0.5±0.2^{a} (38.8)	0.2±0.1^{b} (17.2)	0.5±0.2^{a} (44.1)	1.2±0.5
TSS (t ha^{-1})	1.2±0.4^{a} (32.2)	0.6±0.2^{b} (16.9)	1.8±0.4^{c} (50.9)	3.6±0.8

Values are mean ± S. E. (n = 24). Mean values with different superscript letters in the same row were significantly different among water depths (P< 0.05). Values in parenthesis show percentage of the total discharge in the effluent at different water depths.

Table 4. Shrimp pond sediment quality at harvest in commercial shrimp farms in Chanchaengsao province of Thailand

Parameters	Mean	Range
Moisture (%)	47.9±5.3	28.9 - 67.1
Bulk density(g cm^{-3})	0.66±0.10	0.32 - 1.24
pH	6.8±0.3	5.5 - 7.4
Organic Matter (%)	7.76±0.90	5.39 - 12.10
Nitrogen (mg g^{-1})	1.19±0.32	0.61 - 2.40
Phosphorus (mg g^{-1})	0.14±0.03	0.07 - 0.34

Values are mean ± S.E. (n = 24)

Mean OM content in the pond sediment was 7.8% and ranged from 5.4 to 12.1% in the 24 shrimp farms surveyed during the study (Table 4). Mean nitrogen and phosphorous content in the sediment were 1.19 mg N g^{-1} dry sediment and 0.14 mg P g^{-1} dry sediment. The results showed that on the average only the top 10 cm sediment of one-hectare commercial shrimp pond at harvest contained about 383 kg N, 46 kg P and 2,675 kg OM, (Table 5). Nonetheless, nutrients contained in the pond sediment varied largely among the farms studied as OM ranged from 1,143 to 6,438 kg ha^{-1}, TN ranged from 206 to 732 kg ha^{-1} and TP ranged from 23 to 102 kg ha^{-1}. Such variation in nutrient build-up in the pond over the culture period might have been the result of the difference in farm management practices of the farms. It has been reported earlier that aquaculture wastewater outputs and load vary widely depending on management practice and aquatic environment employed (Boyd and Queiroz 2001). Bergheim and Asgard (1996) observed that though feed is the ultimate source of nutrients released into the water, the amount and the form that the nutrients take depends not only on feed proportions, but also on the type of culture system used. Similarly, Cripps and Kelly (1996) also observed that discharge water and sludge composition of aquaculture systems are highly variable. Therefore, it can be suggested that strategy for on farm effluent treatment must take account of the nutrient loading rate from the shrimp farm under normal operation.

Table 5. Nitrogen, Phosphorus and organic matter retained in pond sediment (10 cm depth) after harvest draining in commercial shrimp farms in Chanchaengsao province of Thailand

Parameters	kg ha^{-1}	Range
Nitrogen	383.3±87.7	206.0 - 732.9
Phosphorus	46.3 ± 10.6	22.6-102.3
Organic Matter	2674.8±716.4	1142.7-6438.3

Values are mean ± S.E. (n = 24)

Table 6. Distribution of nitrogen and phosphorus outputs from shrimp culture pond at harvest in commercial shrimp farms in Chanchaengsao province of Thailand

Variables	Nitrogen		Phosphorus	
	kg ha^{-1}	Percentage	kg ha^{-1}	Percentage
Shrimp harvest	81.2 ± 21.2	16.5 ± 4.1	7.4 ± 1.9	13.0 ± 3.0
Effluent drained	44.0 ± 6.8	9.3 ± 2.1	5.2 ± 1.0	9.3 ± 1.8
Sediment	387.6 ± 88.9	74.2 ± 5.2	46.8 ± 10.7	77.7 ± 4.0
Total	512.7 ± 90.1	100	59.4 ± 11.4	100

Values are mean ± S.E. (n = 24)

Distribution of TN and TP within different pools in shrimp pond is presented in Table 6. Pond sediment contained about 74% N and 78% P of the total nitrogen and phosphorous outputs, respectively; whereas, effluent at harvest draining contained only about 9% nitrogen as well as similar proportion of phosphorous of the total outputs. Shrimp harvest accounted for 16% N and 13% P of the total outputs. The study revealed that in closed shrimp culture systems about three-fourths of the total nutrients (N and P) are contained in sediment and effluent water at harvest constituted relatively smaller proportions (<10%) of the total nutrient outputs. Nutrient retained in shrimp observed in the present study is comparable to the values reported previously for intensive shrimp culture systems (Briggs and Funge-smith 1994; Thakur and Lin 2003). However, water borne loss of nutrient (TN and TP) observed in the present study is lower than the values reported earlier for water exchange shrimp culture systems (Muthuvan 1991; Stapornvanit 1993). Briggs and Funge-Smith (1994) mentioned that water borne loss of nutrient is less important than loss through the sediments, in low water exchange systems, due to rapid accumulation of sediments in shrimp ponds. Notably, farms selected in the present study were operating with zero daily water exchange and had only added water to the pond to compensate water loss through seepage and evaporation. Evidently, surveyed shrimp farms operation as closed system, no routine water exchange, had resulted into increased nutrient accumulation rates and hence, higher proportions of nutrients were retained in the pond sediment than the values reported earlier for water exchange systems. Enell and Ackefors (1991) observed that about 50% of TN and TP settled at the bottom can be translocated back into the water column. The result of the study highlights the importance of pond bottom in nutrient management of closed shrimp culture pond. Adapting proper effluent draining scheme during harvest, shrimp farms can capitalize on the economic benefits by retaining bottom muds on farm to stimulate natural productivity in the subsequent culture cycle, as the bottom mud can readily make nutrients available to the water column.

Conclusion

The shrimp aquaculture sector is facing serious challenges to overcome environmental concerns and improve economic efficiency by developing and implementing management strategies to reduce nutrient wastes. The use of sedimentation ponds is being publicized in many shrimp farming countries. It is practically difficult to retain the whole effluent from harvest draining for on farm treatment, particularly for the small-scale shrimp farmers who dominate the shrimp farming in Thailand. The study showed that sequential discharge during harvest and retaining the bottom effluent (about 30%) can significantly reduce waste outputs from shrimp farms and thus, minimize the environmental impacts of shrimp farming. Additionally, nutrient rich effluent retained on the farm may improve economic efficiency of the farm by boosting pond productivity in the subsequent production cycle. The results of the study highlighted the importance of pond sediment management to minimize waste loading from shrimp ponds as the top 10 cm sediment constitutes about three-fourths of the total nutrient outputs at harvest. It was also observed that despite serious efforts being made by the Department of Fisheries, Thailand in promoting sustainable shrimp farming, effluent discharge from shrimp farms at harvest remains largely unregulated. The present study provided first hand information on effluent and waste generated by commercial shrimp farms during harvest draining, which is important and may contribute to the development of strategies for shrimp farm waste management.

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