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Water pollution by intensive brackish shrimp farming in south-east Vietnam: Causes and options for control

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ABSTRACT

This paper focuses on both the environmental impact of intensive shrimp farming in the coastal region of Vietnam and the identification of options for cleaner production. We investigated water pollution, sediment contamination and the spread of diseases related to shrimp farming in the Can Gio district of Ho Chi Minh City (Vietnam), an area representative for the impacts of intensive shrimp production in the country. Data on the production process was compiled from site observations, interviews with local farmers and experts, as well as from secondary sources. The results indicate that, while a large number of individual farms may exceed environmental standards, intensive shrimp farming is not always associated with waste streams exceeding water quality standards. This is interesting because it shows currently available technologies can reduce pollution from intensive shrimp farms. The paper concludes by identifying technologically and economically feasible options for reducing water pollution, problems associated with contaminated sediment, and the spread of diseases.

1. Introduction

Shrimp farming plays an important but controversial role in the economic development of many countries in Asia because of the high economic returns and often catastrophic environmental impact of production in coastal areas (Senarath and Visvanathan, 2001; Huitric et al., 2002; Lebel et al., 2002a; Hall, 2003; van Mulekom and Axelsson, 2006; Vandergeest, 2007; Islam, 2008). Nowhere is this trade off between growth and environmental impact seen more clearly than in Asia where approximately 75% of the global production of farmed shrimp takes place. The three largest producing nations being China (1,242,000 tons), Thailand (501,000 tons), and Vietnam (349,000 tons), followed by Indonesia (326,000 tons), and India (132,000 tons) (FAO, 2007). Thailand is by far the largest shrimp exporting country with a market share of more than 30%, followed by China, Indonesia, India, Vietnam, Bangladesh, and then Ecuador (ibid.).

Shrimp farming in Vietnam began in earnest at the end of the 1990s in response to international market demand and supported by government coastal land conversion policies (Lebel et al., 2002a,b). Today, almost 90% of the brackish shrimp farming in Vietnam takes place in the Mekong Delta (about 600 ha). Black tiger shrimp (*Penaeus monodon*) is the dominant species with 289,000 tons produced in 2008 (MARD, 2009 (a)). In recent years, the Vietnamese government has promoted the production of white leg shrimp (*Littopenaeus vannamei*) as a more environmentally friendly alternative to black tiger shrimp. It is hoped this alternative species will help the industry maintain high yields, while providing more efficient use of water, low-feed conversion rates, high survival rates, and faster growth cycles (Wyban, 2007; Mishra et al., 2008). However, black tiger shrimp is preferred in most international markets and remains the most important species in tropical shrimp farming.

Farming systems have gradually shifted from extensive traditional systems to improved extensive, semi-intensive and intensive production that are classified according to the pond size, water use, capital, labor, feed and chemicals used, and stocking densities (Table 1). Although traditional and improved farming systems continue to exist in parallel, production does appear to have intensified. During the past ten years shrimp production increased faster than the area of shrimp ponds (Fig. 1). Since 2008, the area of shrimp farming has decreased while production has increased. Although statistics are not yet available, the area of shrimp farming in 2009 was expected to decline 9% to 580,000 ha, while production was expected to grow 10% to 380,000 tons (MARD, 2009).

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Table 1
Comparison of the general characteristics of brackish shrimp farming systems in Vietnam.

Farming system	Size	Culture method	Stocking	Density (shrimp/m^2)	Feed	Water exchange
Extensive/traditional shrimp farming	4–5 ha	Dyke enclosed with Polyculture	Natural recruitment	1–3	Natural	Tidal
Improved extensive shrimp farming	4–5 ha	Dyke enclosed with Polyculture	Artificial	1–5	Supplemental	Tidal
Semi-intensive shrimp farming	Small (1–5 ha)	Pond with Monoculture	Artificial	5–8 (up to 10–20)	Artificial	
Intensive shrimp farming	Small (<1ha)	Pond with Monoculture	Artificial	>20	Artificial	15% every 10 days

Source: EJF (2003).

Compared to other countries intensive shrimp production systems in Vietnam have a relatively low stocking density. In Can Gio, the area focused on in this study, the stocking density in aerated ponds ranges from 20 to 40 post larvae (PL)/m^2. In comparison, stocking density of comparative systems in Thailand, Taiwan, China or Mexico range between 50 and 100 PL/m^2 (Dierberg and Kiattisimkul, 1996; Páez-Osuna and Ruiz-Fernández, 2005; Flaherty et al., 2009). Nevertheless, Can Gio represents the highest concentration of intensive shrimp production in Vietnam. In addition, Can Gio is an area of significant ecological value with a large area of rehabilitated mangrove recognized as an International Biosphere reserve zone by UNESCO (2002). Combined, the concentration of intensive shrimp aquaculture and the ecological value of coastal mangrove make an important reference site to determine the potential impacts of intensive production as this farming system develops further in other parts of the country.

Like in many other Southeast Asian countries (e.g. Valiela et al., 2001; Alongi, 2002; Huitric et al., 2002) mangrove deforestation in Vietnam has become a serious issue, with at least 220,000 ha of mangrove forest removed over the last 50 years (Tuan et al., 2003). Disease outbreaks and acidification of soils, has led to crop failure rates as high as 70–80% in some areas of Vietnam, and subsequently the abandonment of ponds and further expansion of shrimp cultivation to new coastal areas (Lebel et al., 2002b; EJF, 2003). Whereas agriculture, salt pan development and the war-time use of chemicals were previously the most important threats to mangroves, for the last decade the greatest threat has been shrimp aquaculture (EJF, 2003).

To reduce the risk of crop failure, Vietnamese farmers use a relatively large amount of feed, pesticides and antibiotics in shrimp farming. Several concerns have been raised about the use of toxic compounds, including their persistence in aquatic environments, the possibility of residues in non-cultured seafood, the toxicity to non-target (off farm) species, the possible effects on sediment biogeochemistry and, finally, the possible effects on the health of farm workers (EJF, 2003). As other studies have noted (e.g. Trai et al., 2007; Mang et al., 2008; Long and Toan, 2008), shrimp farming in Vietnam may also lead to serious water pollution with wastewaters containing high biological oxygen demand (BOD), and high nitrogen (N) and phosphorus (P) concentrations from feed residue, is often released directly into canals and rivers causing oxygen depletion and eutrophication. Several studies have also indicated that intensive shrimp farming in particular has the largest share in the overall environmental impact of all shrimp production systems (Dierberg and Kiattisimkul, 1996; Senarath and Visvanathan, 2001; Jackson et al., 2004; Tzachi et al., 2004).

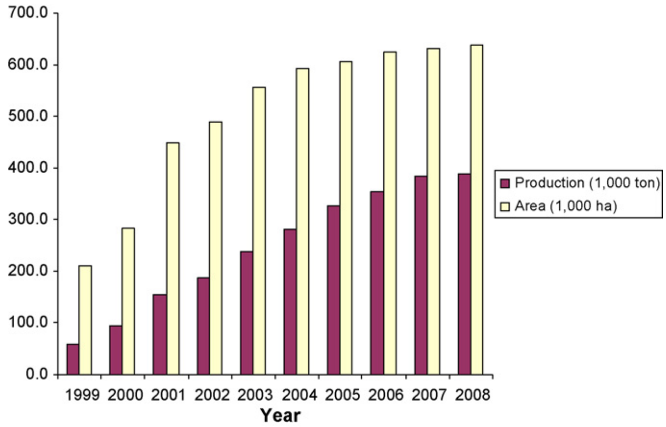

Fig. 1. Area and production of shrimp farming in Vietnam in 1999–2008.

This paper adds to several recent studies on the environmental impact of intensive shrimp production in coastal areas of Southeast Asia by providing the first system analysis of black tiger shrimp production in Vietnam. The specific aims of the paper are to analyze the causes of water pollution, contaminated sediment and spread of disease from intensive black tiger shrimp farming in Vietnam and to identify possible options to reduce these environmental impacts. For this purpose we focus our attention on the Can Gio region, a man and the biosphere reserve with high coastal environmental value and also a site representative of the impacts from the intensification of shrimp production.

Our study consists of two parts. First, we perform a systems analysis of intensive shrimp farming in Can Gio. This is an area close to Ho Chi Minh City in Vietnam with large scale of intensive black tiger shrimp production. Second, we extend the systems analysis by identifying options to reduce the environmental impact by shrimp farming. We focus on options that are both already applied in other sectors in Vietnam, or which have the potential to be applied given experience from other countries with shrimp farming and compatibility with state legislation.

2. Method

2.1. Can Gio area

Can Gio is an area located in a coastal district southeast of Ho Chi Minh City in Vietnam with latitude: 10°22′14″–10°40′,09″ and longitude: 106°46′12″–107°00′59″. It covers 75,740 ha and is dominated by mangroves, including both salt water and brackish water species. Can Gio has been subject to extensive mangrove rehabilitation after extensive deforestation during the conflict in the 1960s and 1970s, and subsequently through the expansion of Shrimp farming. The forests were replanted in stages starting in 1991 and most recently in 2000–2002 (Tuan et al., 2003). As such, Can Gio provides the opportunity to work on environmental protection on a continuum of habitats, ranging from the sea to the boundary of Ho Chi Minh City, the largest industrial city in Vietnam.

Because of their ecological importance, the Can Gio mangrove forests have been recognized as an International Biosphere reserve zone by UNESCO (The core area of this Biosphere reserve zone is 4721 ha). The buffer zone around it covers an area of 70,000 ha and a further transition area between residential and agricultural land covers another 30,000 ha. Shrimp farming is only allowed in the transition area. Nevertheless, there are serious concerns over the sustainability of shrimp production even in these areas. Trai et al. (2007) studied water pollution by shrimp farming in Can Gio and concluded that intensive and semi-intensive shrimp farms are larger sources of pollution than less intensive shrimp farming. They also concluded that intensified shrimp farming in Can Gio is not environmentally sustainable.

There are in total 66 thousand people living in Can Gio (HCMC, 2006), engaged in a range of livelihood activities including agriculture, fisheries, aquaculture and salt production. Families in the communes of An Thoi Dong, Ly Nhon, Long Hoa Binh Khanh and Thanh An are predominantly involved in shrimp production. These families have been given access to above mentioned transition areas through land allocation programmes in the 1990s. Today approximately 2830 households conduct shrimp farming. The shrimp farming area is almost 5000 ha, of which about 343 ha is used for intensive shrimp farms and 524 ha are used for semi-intensive shrimp farms. The remaining 4264 ha are used for extensive and improved extensive shrimp farms. The average production of intensive shrimp farming in Can Gio is about 5.3 tons/ha (Can Gio Economic Division, 2007).

Within the Can Gio area 40% of the shrimp farmers are located in the area of Tam Thon Hiep commune (Can Gio Economic Division, 2007). These farmers conduct intensive and semi-intensive shrimp culture. They occupy only 3% of the total shrimp farming area but contribute 8% of the total shrimp production of Can Gio. As such, this is one of the areas with the highest intensive and semi-intensive shrimp farming densities in Vietnam. Given the interest in intensive production in the country we believe Can Gio, and Tam Thon Hiep commune in particular, provide a representative case to investigate the impacts of intensive black tiger shrimp farming on the environment; and one which wider lessons can be learnt for the improved environmental production of shrimp farming in Vietnam.

2.2. Systems analysis

To determine the environmental impact of shrimp production we employed a partial environmental systems analysis following Quade and Miser (1997), Pluimers (2001), Jawjit (2006) and Neto et al. (2008). The analysis begins by defining the problem by identifying system boundaries, inputs, outputs, system elements, and their (inter)relationships (Findeisen and Quade, 1997). In this step we identify the most important causes of environmental pressures associated with shrimp farming. We then assess the environmental impact within the system under investigation by measuring key environmental indicators. This is done in part through substance flow analysis and simple material mass balances (van der Voet et al., 1997). Based on this analysis we then identify options to reduce the impact of these environmental problems in accordance with the defined system boundaries and the objectives of the production system being assessed.

Data were generated through a combination of field visits, experiments and secondary information. Twenty-two farms were visited to collect information about farming practices and environmental problems, and samples of wastewater and sludge from shrimp ponds. A total of 33 water samples were collected from farms in Can Gio at the point of water discharge during the shrimp production season. Samples were taken based on the production cycle, with 11 samples from ponds of less than one month old, 12 samples from ponds two to three months old, and 10 samples from ponds three to four months old. We also collected sediments from three of the oldest ponds.

Water quality parameters were analyzed in the water samples according to the APHA (1995). The parameters included: temperature, pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen demand (COD), Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP), Ammonia (N-NH_3), Dissolved Oxygen (DO) and Coliforms. Three samples of sludge were also collected and analyzed as dry matter, measuring TN and TP. The results of these analyses have been reported to the Ministry of Fisheries (CENTEMA, 2004). Here we focus on an interpretation and synthesis of the results and their relevance to the environmental performance of intensive shrimp farming.

3. The shrimp farming system

3.1. Phases and processes in shrimp cultivation

Our analysis focuses on shrimp production in ponds with particular attention to the preparation, cultivation and harvesting phases in the production cycle. The preparation phase includes deforestation, pond construction, pond treatment and inlet water treatment. The cultivation phase includes breeding stock, feeding and pond water exchange. The harvest phase includes harvesting and pond emptying. A number of farming processes in these phases have potentially significant impact on the environment. We focus in particular on pond treatment, inlet water treatment, feeding, water exchange, and final water discharge and sediment dredging. The system studied here is described in Fig. 2. As indicated above, Can Gio was accepted in 2000 as a World Biosphere Reserve. This implies that the area of shrimp production cannot increase. As a result, shrimp ponds are not abandoned.

Typical shrimp farms have one production cycle per year, which lasts for four months. Before each production cycle, farmers empty their ponds and dredge the sludge (both after harvest and before the new cycle). Depending on the natural conditions of each area the ponds may require further treatment before the new cycle. In the case of acid sulfate soil, common to many parts of the Mekong Delta, this may include flushing the ponds three to four times followed by treatment with lime (CaO) to increase the pH.

The ponds are then aerated continuously for three to four days, to kill vectors of infectious diseases such as snails and crabs. The ponds are sterilized with chlorine, Saponine (of herbal origin), or $KMnO_4$, and then fertilized to promote algal production with urea phosphate (or super phosphate), and/or a mix of chicken dung and lime in a ratio of 1:3. The quality of the water before stocking shrimp larvae is supposed to meet the criteria listed in Table 2 according to the guideline for black tiger shrimp farming from the government (MoFI, 2001), and should be maintained throughout the cultivation season.

After preparation the ponds are stocked and fed with pelleted industrial feed. The Feed Conversion Ratio (FCR) measures the efficiency of converting the total quantity of feed in one grow-out period with the total biomass of shrimp harvested. Different feeds have different conversions, but current feeds on the market have an FCR between 1.4 and 2 (Funge-Smith and Briggs, 1998; SEAFDEC, 2008). At these FCRs it is estimated that approximately 80% of the feed nitrogen enters the pond nutrient cycling, through both inefficient conversion and excrement (Australian Prawn Farmers Association, 2004).

Depending on the age of the shrimp and the scale of the pond, there are several ways to ensure efficient feed use. First, the calculation of feed quantity needs to be made in accordance with shrimp size. The quantity of feed for 100.000 PL_{15} (Post Larvae 15 days of age) can be calculated as: PL_{15}–PL_{20}: 1–2 kg of food/100.000 PL/day (MOFI, 2006). After five days from PL_{21} and onwards, the feed can be increased by 0.1–0.4 kg/day, depending on the capacity of the Post Larvae. After one month, when the

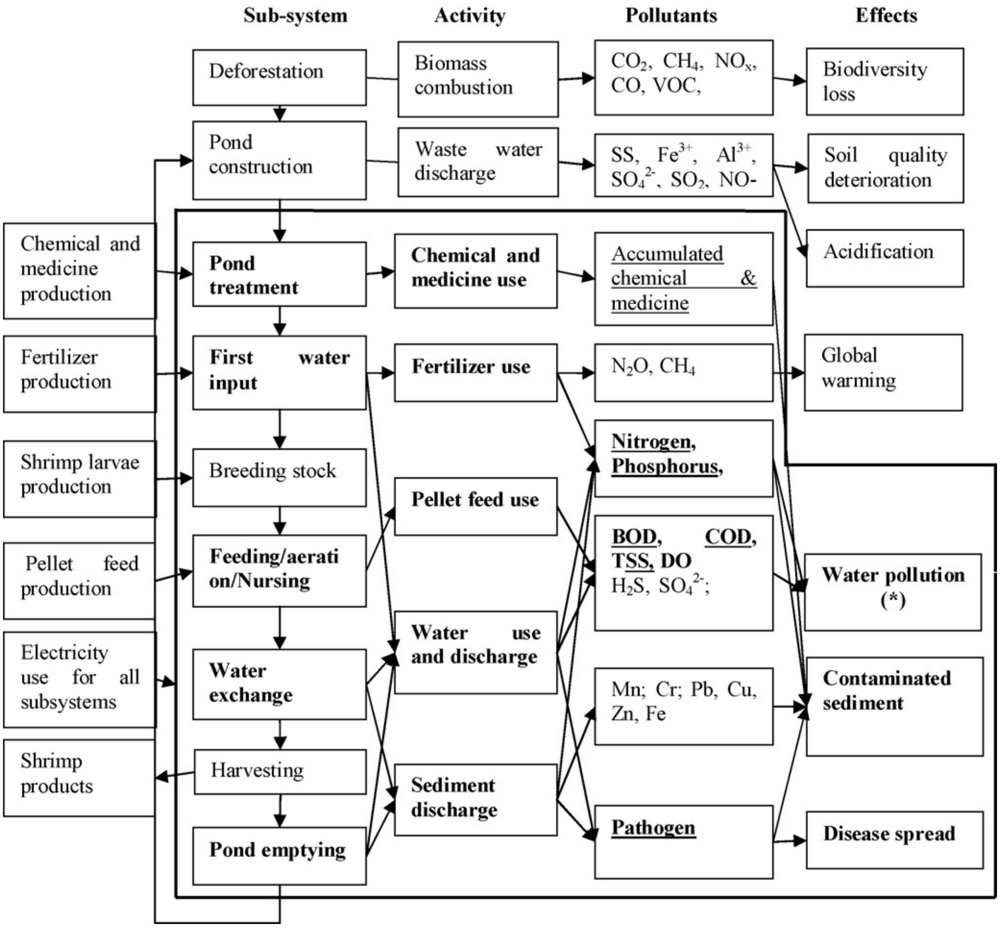

Fig. 2. Schematic overview of Shrimp production in Can gio area and its environmental impact. The bold line indicates the system boundary; bold system elements and the underlined substances are included in the analysis. Characteristics of a typical intensive black tiger shrimp pond in Can Gio: Area = 5000 m^2 (50 m × 100 m); Water depth = 1.5 m; after one month of cultivation, 15 (10–25)% of the water is exchanged every 10 days; Density: 20–40 shrimps/m^2; Average production: 5.3 tons/ha/y. (*) Including eutophication and toxicity problems.

shrimp are approximately 1.5–2.0 g, the amount of feed in intensive farms can double from 2% to 4% of the estimated total shrimp weight in accordance with Standard 28 TCN 171: 2001 from the Vietnamese Ministry of Fishery (MOFI, 2006).

Controlling water quality involves careful control of water exchange. The water level in the pond increases over time. In the beginning of the cycle, the water in the pond is set at a depth of 0.8–1 m. After one month, the water level in the pond is increased to 1.2–1.5 m, and after the third month the water level is increased and maintained at a depth of 1.5–2.0 m.

Depending on the season and the quality of the water in the shrimp pond, the water needs to be exchanged about every 10 days. During the dry season, the temperature and salinity of the water increases, requiring between 10 and 15% water exchanges. When the shrimp pond is polluted or diseases show up, also 10–15% of the water is exchanged.

Table 2
Recommended water quality for black tiger shrimp farming.

Parameters	Unit	Optimal range	Remark
pH (water)	–	7.5–8.5	Daily fluctuation ≤0.3
Temperature	°C	28–33	No sudden change
Salinity	‰	15–25	Possible range: 10–30‰
Transparency	m	0.4–0.5	–
Hardness $CaCO_3$	mg/l	>80	–
H_2S	mg/l	<0.02	–
NH_3	mg/l	<0.10	–
pH (soil)	–	>5.0	–

Source: MOFI (2006).

The duration of a typical crop of intensive shrimp farming is usually 100–120 days, after which the harvested shrimp reach a size of 40–50 shrimp/kg. After harvesting, a large amount of wastewater is discharged to the surrounding environment and clean water is pumped into the pond to flush the pond sediment. This water is then often pumped back into canals or used for putting in the mangrove forest area. The cycle is then started again with pond treatment.

3.2. System definition and indicators

From the above description of shrimp cultivation we distinguish five important sub-systems in intensive black tiger shrimp farming: (1) Pond treatment, (2) Inlet water treatment, (3) Feeding (4) Water exchange and (5) Pond emptying (Fig. 2). The analysis and evaluation of other sub-systems such as deforestation, pond construction, breeding stock and harvesting are not included in this study. The reason for not including deforestation is that since 2000 Can Gio was accepted as a World Biosphere reserve and the Vietnamese government issued regulation and policy outlawing any deforestation activities for shrimp cultivation. Breeding stock and harvesting are also not explicitly included but, along with the production of shrimp larvae, food and other input materials are implicitly included through other sub-systems to calculate the

Table 3
Indicators for environmental pressures caused by shrimp production in Can Gio.

Environmental issues	Indicator number	Indicator	Unit
Wastewater	1.1	Total volume of water use	m^3
	1.2	Total volume of wastewater	m^3
	1.3	BOD	mg/l
	1.4	COD	mg/l
	1.5	TSS	mg/l
	1.6	Total Nitrogen	mg/l
	1.7	Total Phosphorus	mg/l
	1.8	$N\text{-}NH_3$	mg/l
	1.9	DO	mg/l
	1.10	Total Coliforms	MNP/100 ml
Sediment	2.1	Volume of sediment	m^3/y
	2.2	Total Nitrogen	mg/l
	2.3	Total Phosphorus	mg/l
Disease spread	3.1	Infected shrimp ponds	(%)

pollutants and production of waste in the shrimp cultivation process.

The five sub-systems considered include six activities, giving rise to emissions of a number of different pollutants and waste streams. These include the use or application of chemical and drugs, fertilizer, feed and discharge of water and sediment. In this study, we focus in particular on what are generally considered key environmental problems of intensive shrimp farming, including the release of polluted water resulting in eutrophication and elevated toxicity levels, contaminated sediments, and the spread of disease (Fig. 2). Other regional and global problems, such as global warming, acidification and biodiversity loss are not taken into account. Heavy metals are also not considered in this study.

The associated environmental impacts are assessed by use of environmental pressure or effect indicators (Table 3). For water pollution the following indicators are used: the volume of water use, the volume of wastewater generated, and the BOD, COD, TSS, Total Nitrogen, Total phosphorus, $N\text{-}NH_3$, DO, Total Coliform content of wastewater. Indicators for problems associated with contaminated sediment include the volume of sediment, total Nitrogen, total Phosphorus and accumulated chemicals and medicines in the sediment. Finally, the indicator for the spread of diseases is the number of infected shrimp ponds. The following identifies, and where possible quantifies these indicators (summarized in Table 3) at the pond level.

4. Environmental impact of intensive black tiger shrimp farming

4.1. Water pollution

Water pollution is largely associated with the use and discharge of water in shrimp ponds. Each time water is exchanged, wastewater is discharged to the surrounding surface waters, as indicated in Fig. 3. The wastewater carries a number of pollutants, reflected in the selected indicators. These pollutants ultimately stem from chemicals, fertilizers and feed added to the ponds.

Lime ($CaCO_3$, $CaOH)_2$ or CaO is used to neutralize the acidity of the soil in the pond in the preparation phase, and the amount used depends on the pH of the soil. Typically 200–250 kg/ha of lime is applied to the surface water during the grow-out phase to stabilize the acidity of the water. In Can Gio, the soil often has a pH below 6 or 5. According to the experiences of the farmers, 1.0–1.5 tons/ha of Lime is required. Fertilizers are used for increasing the food (algae) for shrimps in the preparation phase (also referred to as coloring). In intensive farming, pelleted industrial feed is increasingly being used instead of fertilizers. Fertilizers are typically organic such as chicken, pig or cow manure, or inorganic such as ammonium phosphate called NPK (N:P:K = 16:20:0), di-ammonium phosphates—called DAP (N:P:K = 16:46:0), applied in a NPK: DAP ratio of 1:3. The average dose is 0.7 kg per 1000 m^3 of water per crop. For this study the total amount of fertilizer is estimated at 3.5 kg/pond/crop, including NPK and DAP.

Chemical flocculants like aluminium-sulfate and kali-sulfate are used at concentration of 10–20 mg/l to reduce the turbidity of water. Zeolite is used at 100–500 kg/ha to remove NH_3 in the pond, however, the efficiency of this chemical has been subject to recent discussion (Anh et al., 2004). Axit Dinatri Ethylendiamin Tetra acetic (EDTA) is used to reduce the effects of heavy metals in the water by creating compound matters. Decontaminants used include chlorine at 25–30 ppm, $KMnO_4$ at 5–10 ppm, and formalin at 15–250 ml/l. Other antibiotic agents, despite being illegal, such as Nitrofuran, Phenicol, 4-Quinolon, Tetracycline and other pesticide agents such as Rotenone, organic phosphate, and Saponin are used to kill other fish in the pond preparing phase.

Feed rates depend on the shrimp density and body weight. We assume a stocking density of 25 shrimp/m^2 in a shrimp pond with an area of 5000 m^2 and, after four months, a survival rate of 65% with shrimp size of about 40–50 shrimp/kg. The crop would then be about 1.6–2.0 tons of shrimp per crop. We also assume an FCR of 1.3 with an average shrimp harvest of 1.8 tons. Therefore, the amount of feed used is $1.8 \times 1.3 = 2.34$ tons.

We assessed the indicators for water pollution on the basis of a water balance for shrimp ponds. Water supply includes initial and supplemental water, as well as rainfall. Water removal is through continual exchange during the grow-out phase (at a rate of 15% of total volume every 10 days), emptying ponds after harvesting, and through evaporation (see Fig. 3).

The volume of water used (Indicator 1.1) was calculated based on the average dimensions of surveyed shrimp ponds and the total initial and supplemental supply. The volume of initial water supply is 7500 m^3/pond/crop and supplemental water is estimated at 10,125 m^3/pond/crop. The total water supply for one pond over one crop is therefore estimated at 17,625 m^3.

The volume of wastewater (Indicator 1.2) is calculated using an evaporation coefficient of K_e^d for the dry season of 173 mm/month and 83 mm/month for the wet season (based on Vietnamese meteorological data). This gives a total volume of wastewater in the dry season of approximately 14,165 m^3/pond/crop and, with an estimated amount of rainfall of 150 mm/month, an estimated 18,965 m^3/pond/crop in the wet season.

The rest of the key indicators (1.3–1.10 in Table 3) are based on direct measurements taken from ponds in Can Gio with different cultivation periods. The results are compared with Vietnamese water quality and BAP[1] standards (Table 4).

The results indicate that there are no significant changes in pH during the cultivation period because pH is maintained by adding dolomite and lime. The levels of BOD_5, COD and TSS increase with the cultivation period. This result concurs with Senarath and Visvanathan (2001), and can be explained by the fact that older shrimp need more feed and produce more waste than younger shrimp.

After two months, the average water quality parameters in the ponds exceed the BAP and Vietnamese standards for BOD, COD, TSS and Coliforms. For other indicators this is not the case. However, because of the variation among ponds (Table 4) we may conclude that there are many individual ponds that exceeded the standards. For instance, COD and TSS concentrations show large variation among ponds and periods. This also implies that some indicators do not exceed the standards. However, given the large volume of

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[1] BAP: Global Aquaculture Alliances Best Aquaculture Practices Standards.

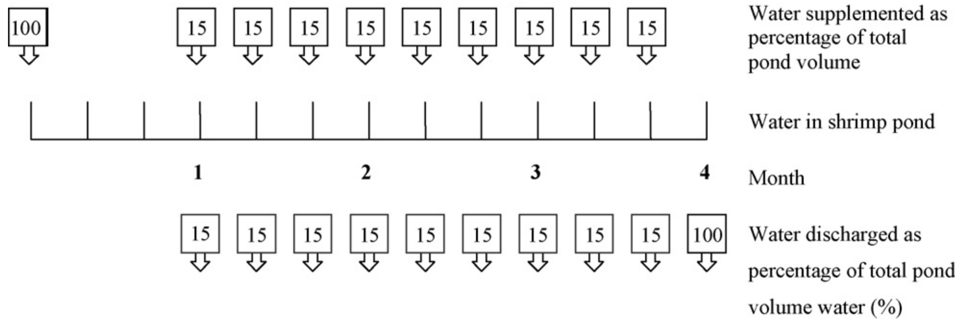

Fig. 3. Overview of water supply and discharge in ponds over time.

wastewater collected in canals high pollutant loading in the surrounding environment greatly exceed water quality standards. Similarly, total coliforms in the wastewater samples were high compared to standards.

4.2. Contaminated sediment

Sediment in shrimp ponds is generated from many sources: (1) suspended solids from inflow, lime, fertilizers, chemicals, and antibiotics, (2) uneaten feed, dead phytoplankton, and prawn moults, (3) solid waste from shrimp production process, and (4) inorganic matter eroded from the pond walls. The contribution of different sources of sediment in shrimp ponds is outlined in Table 2.

Solid waste from shrimp production includes bottles, cans, paper, plastic bags of chemicals, food and additives, and plastic bottom layers. According to the farmers, total solid waste generated after one crop is about 30–50 kg per pond. Because there is no solid waste collection system in Can Gio we added total solid waste to the total volume of sediment.

There is a relationship between accumulated sediment, pond water, feeding rate, and stocking density throughout all stages of shrimp farming cycles. An upward trend in shrimp stocking or shrimp biomass level results in an increased input of organic matter into the pond in terms of feed, as well as a downward trend in feed efficiency (increasing the FCR). Consequently, more waste is produced when organic matter accumulates in sediment and degrades, beginning a nutrient cycle in which ammonia, nitrite, nitrate, are formed.

The volume of sediment (Indicator 2.1) that accumulates within the shrimp farming pond during each rearing cycle and that is removed from the pond after harvesting have been estimated at 185–199 t dry wt/ha or 139–150 m^3/ha (Funge-Smith and Briggs, 1994) or 200–836 t dry wt/ha or 151–629 m^3/ha (Tunvilai et al., 1993). In our study, we estimate the calculated sediment to be approximately 150–200 m^3/ha. This sediment is not suitable for agriculture and horticulture fertilizer because of its low organic content, large volume and high salt content (Dierberg and Kiattisimkul, 1996).

Our measurements indicate that total nitrogen content in sediments is about 0.7–1.7 mg/g, and total phosphorus content about 0.003–0.2 mg/g. This is considerably less than concentrations found in sediments of shrimp pond systems outside of Vietnam. For example, in New Caledonia the TN content was 1.1–2.66 mg/g of dry sediment in semi-intensive shrimp ponds (Lemonnier and Faninoz, 2006). In Sri Lanka, TN contents were 0.7–2.8 mg/g and TP contents 0.36–0.74 mg/g (Senarath and Visvanathan, 2001).

Finally, the use of chemical, fertilizers, drugs as antibiotic into the shrimp ponds can accumulate into the sediment (Indicator 2.4). This raises an important issue in shrimp hatcheries. Antibiotic concentration in shrimp ponds may do harm to the environment, and contribute to the increase in drug-resistant diseases (Tuan et al., 2003). Chemical characteristic of shrimp pond effluents have been evaluated in different shrimp culture systems (Briggs et al., 1994; Rivera-Monroy et al., 1999; Lyle-Fritch et al., 2006). However, the use of chemical substances in shrimp aquaculture remains low in comparison with agriculture and other economic activities (Paez-Osuna, 2001). The most common substances used in shrimp ponds are fertilizers and liming materials; other substances are used less frequently. However, sediment only causes problems when it is discharged to surface waters, and this is not always the case if there is good management and awareness by farmers.

Table 4
Characteristics of wastewater from intensive black tiger shrimp ponds in Can Gio.

Parameter	Unit	Wastewater from shrimp ponds by month during grow-out period			Standard
		<1month	2–3 month	3–4 month	
Temperature	°C	30.5 (30–32.4)	30.8 (29.4–32.9)	30.5 (30–32.4)	n.a.
pH		7.6 (7.2–8.4)	7.6 (7.3–8.2	8 (7.2–9.1)	6.0–9$^{(1)}$
BOD$_5$	mg/l	21 (8–48)	39 (15–84)	41 (22–59)	≤50$^{(1)}$
COD	mg/l	68 (6–106)	100 (72–120)	132 (79–246)	≤100$^{(2)}$
TSS	mg/l	69 (26–95)	81 (53–158)	254 (22–1031)	≤100$^{(1)}$
N$_{total}$	mg/l	2.2 (0.08–3.2)	3.2 (0.1–7.6)	5.7 (1–14.8)	n.a.
P$_{total}$	mg/l	0.25 (0.1–0.5)	0.4 (0.1–1.0)	0.7 (0.1–1.7)	n.a.
N-NH$_3$	mg/l	0.5 (0.1–0.6)	0.8 (0.1–1.6)	0.7 (0.56–0.84)	≤5$^{(2)}$
DO	mg/l	6.6 (3.5–8.2)	6 (3.9–8.6)	6.6 (5.5–7.5)	≥4$^{(2)}$
Coliforms	MPN/100 ml	4475 (2100–11,000)	2.4.10^3–24.10^3)	11.10^5–15.10^5	≤5000$^{(2)}$

n.a. = Not Available.
$^{(1)}$BAP standard (Global Aquaculture Alliances Best Aquaculture Practices Standards) and Vietnamese water quality standard for industrial effluents discharged into coastal water using for protection of aquatic life (TCVN 6986-2001).
$^{(2)}$TCVN 6986-2001.

4.3. Spread of diseases

Shrimp diseases are often caused by polluted water in the pond itself. High BOD and COD concentrations are a favorable condition for pathogenic microorganisms. Most of the wastewater and contaminated sediment from shrimp ponds is discharged into receiving waters. This, however, is the source of water for other shrimp ponds. Without proper treatment, the pathogens from infected ponds are likely to spread to other ponds. Currently, hardly any shrimp farm carries out water or sediment treatment in Can Gio since the costs of between VND 4–5 million (about USD 300) for a 5000 m^2 pond, are relatively high compared to the costs of losing a crop. The disease spread is partly a result of shrimp cultivation in the second season (from July to November) when the farmer wants to get higher prices in the market. Breeding stock in inappropriate conditions also enhances the risk for disease epidemics. When the diseases can be detected, they are difficult to control because of poor regulation, and the 'open' nature of land and water resources.

The majority of current shrimp disease problems can be categorized into two major groups: bacterial and viral. The causes of bacterial diseases are mostly Vibrio spp. Vibriosis outbreaks constitute a serious problem in intensive shrimp ponds (Menasveta, 2002). Viral shrimp diseases include the Monodon Baculo virus (MBV), Yellow-Head virus (YHV), and White Spot Syndrome virus (WSSV). Viral diseases provoke the largest losses in shrimp farming (Rosenberry, 1998), with many countries having faced significant reduction in production because of different diseases, although they include varying degrees of intensification, different climates, and distinct cultured species (Páez-Osuna et al., 2003).

Since 2005, Vietnamese shrimp cultivation has been hindered by disease in many regions. Less than 70% of shrimp farmers stop farming in order to avoid further infection. As a result, many shrimp farmers suffered a loss of income and some abandoned production altogether. To illustrate the impact of disease, in the 2006 shrimp season, approximately 22,500 households practiced shrimp cultivation, stocking approximately 2 billion larvae in 23,000 ha of ponds. Of this approximately 1 billion larvae, aged between 30 and 50 days, belonging to around 14,000 households were infected and died (Hoang, 2006).

4.4. Overall pollution

Table 5 summarises the overall pollution of intensive black tiger shrimp farming in Can Gio (Table 5). These calculations ignore evaporation and rainfall, and assume that the average amount of wastewater produced equals the amount of water used in shrimp farming. We calculate the pollutants' load based on the frequency and amount of water exchange. We estimate that during the first month of farming about 1125 m^3 of wastewater is produced per farm (0.5 ha); during the second and third month about 6750 m^3, and during the fourth month about 9750 m^3. Based on this, we calculated the average pollutant load of farming per ton of shrimp produced and per hectare.

The water pollution per ton of shrimp product and per hectare of shrimp farming from farming process are 259 and 1373 kg BOD, 769 and 4077 kg COD, 1170 and 6201 kg TSS, 30 and 159 kg of total nitrogen and 3.7 and 20 kg of total phosphorus, 4.8 and 26 kg of Ammonia-Nitrogen (N-NH_3), respectively. The loads per hectare are considerable. For instance, N and P loads exceeding 150 and 20 kg per hectare in shrimp ponds are comparable with N and P loads in agriculture fertilizers, and pose a real threat to oligotrophic aquatic systems. Our estimates for total pollution are calculated from wastewater discharge only. Where sediment is discharged direct to the river or canal, the estimated pollution load to water surface would be higher.

Comparable studies do exist on shrimp farming in Vietnam (e.g. Mang et al., 2008), but most have not been published. Table 6 therefore compares our TSS, TN, TP and Ammonia Nitrogen loads with those from intensive black tiger shrimp in Thailand (Dierberg and Kiattisimkul, 1996). The result first of all indicates that the Vietnamese ponds, although intensive, have lower stocking densities than the ponds in Thailand and, in line with this, lower concentrations of TSS, TN, TP and N-NH3. Compared with other studies on black tiger shrimp with almost the same production of 2–5 tons/ha/crop, our results show a lower net nitrogen discharge of 159 kg/ha/crop than in Thailand, where estimates range between 190 and 509 kg/ha/crop (Jackson et al., 2003; Robertson and Phillips, 1995).

5. Options to reduce the environmental impact

The second objective of this paper is to identify options to reduce the environmental impacts of water pollution, contaminated sediment and the disease spread. However, effectiveness is not the only criterion for selecting the following options. We have also taken into consideration both technological and economic feasibility of the technologies. This is especially important because of the variability of income from shrimp farming in Vietnam and the reluctance of farmers to invest in high cost technologies (Lebel et al., 2002a; Hue and Scott, 2008). The identification and evaluation of these technologies is based on secondary sources, as well as newly collected information from field research and the system analysis presented above. The following reports on two approaches for ameliorating the impacts of water pollution, contaminated sediment and disease spread: (1) waste prevention and minimization at source and (2) treatment and reuse of effluent streams.

5.1. Waste prevention and minimization at source

Waste prevention and minimization at the point source of pollution holds some promise as an abatement strategy for shrimp production in Vietnam. These approaches adopted in other sectors

Table 5
Pollution caused by black tiger intensive shrimp farming in Can Gio district.

No.	Indicator	Pollutant load (1)		Per ton of shrimp (2)		Per ha of farming	
		Value	Unit	Value	Unit	Value	Unit
1.1	Water use	35,250	m^3/ha/crop	6651	m^3/ton		m^3/ha
1.2	Wastewater	28,330–37,930	m^3/ha/crop	5345–7157	m^3/ton		m^3/ha
1.3	BOD content	0.04	kg/m^3	259	kg/ton	1373	kg/ha
1.4	COD content	0.12	kg/m^3	769	kg/ton	4077	kg/ha
1.5	TSS content	0.18	kg/m^3	1170	kg/ton	6202	kg/ha
1.6	Total N content	4.5	g/m^3	30	kg/ton	159	kg/ha
1.7	Total P content	0.6	g/m^3	3.7	kg/ton	20	kg/ha
1.8	N-NH3 content	0.7	g/m^3	4.8	kg/ton	26	kg/ha

Notes: (1): calculated from Table 3 and the volumes of wastewater in different periods of shrimp farming; (2) average 5.3 ton of shrimp/ha.

Table 6
Comparison of intensive shrimp farming in Vietnam (Can Gio) and Thailand.

Stocking density	Unit	Thailand[1]		Can Gio[2] (Vietnam)
	Shrimp/m^2	50–60	80–100	20–40
TSS	kg/ha/crop	6650	9658	6201
Total Nitrogen	kg/ha/crop	178	223	159
Total Phosphorus	kg/ha/crop	15.7	24.9	19.6
N-NH$_3$	kg/ha/crop	18.4	71	26

[1] Source: Dierberg and Kiattisimkul (1996); [2] This study.

include more efficient use and management of waste streams, often labeled 'good housekeeping' (Ramjeawon, 2000; Henningsson et al., 2001; Hyde et al., 2001), as well as more strategic changes to input control, including changing raw material inputs (Chaan-Ming, 1995; Vigneswaran et al., 1999), or adopting new technologies (European Commission, 1997). The information presented in Sections 4.1, 4.2 and 4.3 reveal there are considerable gains in pollution mitigation through appropriate options for prevention and minimization of environmental problems from shrimp farming. The different measures, outlined below and summarized in Table 7, include techniques for the reduction of water, feed, chemical and medicine use, as well as improved farm management.

5.1.1. *Ozone aeration technology*

Water use reduction by ozone aeration technology is a widely proposed technology for use in shrimp farming to improve the water quality in the pond, which means the frequency of water exchange can be reduced. Currently, ozone aeration technology is generally studied and used in USA, Thailand, Korea and India for shrimp farming and other forms of aquaculture (Schuur, 2003; Jongsuphaphong and Sirianuntapiboon, 2008). With this technology, ozone is aerated into ponds via ozone generation equipment. In Thailand, Jongsuphaphong (2008) have demonstrated success with the oxygen supply apparatus in shrimp farms with a water flow rate of 10 l/min. The results show that when the apparatus was used with ozonation there was more of an effect than aeration with oxygen supply alone. Moreover, ozone generation showed the additional advantage of reducing organic matter in the water, such as BOD and COD, while increasing DO at the same time. By doing this, the disease outbreak is also reduced because of less water discharge and degradation of water quality in the receiving streams.

Ozone aeration technology is not currently applied in Vietnam. Some experiments have been carried out in Nam Dinh province with freshwater shrimp (*Macrobrachium rosenbergii*). The results show higher yields of 10 ton/ha compared to 4 ton/ha in normal aeration system, as well as less water use and a low mortality rate (Liêm, 2008). Ozone aeration has been promoted by provincial governments for Tiger shrimp. However, due to the added cost and required technical knowledge farmers have not adopted this technology. If it can be demonstrated to farmers that ozone aeration increases production at minimal extra cost, as seen in Nam Dinh, it may prove a very suitable. Costs can also be reduced given many farmers have already invested in oxygen-based aeration equipment and by selectively applying aeration in the last months of the grow-out cycle when the concentration of wastewater pollutants are at their highest. If ozone aeration is limited to this last grow out phase, thereby reducing the overall cost of water treatment, it may prove suitable for Vietnamese intensive production.

5.1.2. *Feed strategies*

Reduction of feed is another option to reduce pollution given that feed residue is the most important factor in the generation of sludge. Currently in Vietnam pellet feeds are predominantly used is semi-intensive and intensive shrimp farms. Domestic companies produce over 100 types of feed and many more are imported from Germany, Thailand, Korea, China. Although attempts are made by the National Fisheries Quality Assurance and Veterinary Directorate (NAVIQAVED) the large number of feeds available on the market means the government is unable to test and control feed quality across the industry. Because of the uncertainty over the composition and quality of feed farmers often fail to determine the most efficient feeding regime for their ponds.

The FCR used in this paper demonstrates a high efficiency, however according to interviewed farmers FCR in intensive farmers in Vietnam can be as high as 2.2. In Thailand FCR is even as high as 4 (NACA, 2004). The individual FCR of farms varies greatly between brands and the experience with feeding techniques used by farmers. If farmers can gain access to more accurate information over the composition of feed it is likely they could better determine the most efficient feeding regime. However, many farmers interviewed in Can Gio and other provinces in this study were unable to accurately calculate their FCR. Further research is therefore needed to determine the benefits of quality testing and control would support farmers to improve their feeding efficiency.

5.1.3. *Drug and chemical use*

A reduction in the use of drug and chemical use is also an option to reduce pollutant load in wastewater and sediment, as well as the accumulation of these components in the shrimp itself. Shrimp remains one of the most risky aquaculture products in terms of food quality (Dey et al., 2006). In Vietnam technical guidelines are available to farmers listing over 17 banned and 34 limited use substances (Decision 07/2005/QD-BTS). Yet it is only since the private sector drug and processing companies have began offering greater control over the input of drugs for intensive farms in

Table 7
Waste prevention and minimization at source.

Options	Description	Pollutants/problems reduced	Sub-system to be applied	Problems reduced			Remarks
				WP	CS	DS	
Water use reduction	Ozone aeration	BOD, COD, Pathogen, water use, wastewater	Aeration/water	+++	+++	+++	Need a technical transfer to farmer
Feed use reduction	More efficient feed use: Careful in checking optimum use of feed	BOD, COD, Pathogen,	Feeding	++	++	++	Lack of information on experiences with different type of feeds. Need information exchange
Chemical, medicine use reduction	Better guidelines and monitoring for correct use of chemical and medicine on appropriate doses and frequency are needed	Accumulated chemical and medicine	Pond treatment/ nursing	+	+	+	

[1] WP: Water Pollution; S: Contaminated Sediment; DS: Disease Spread; + indicates a moderate improvement, ++ a considerable improvement, +++ a large improvement.

Table 8
Treatment and reuse of effluent streams.

Options	Description	Sub-system to be applied	Problems reduced[1]			Remarks
			WP	CS	DS	
Treatment and reuse of sediment	Make compost, or soil conditioner from sediment	Sludge discharge	+	+++	+	More research is needed on the practical and species of plant
Treatment and reuse of wastewater	Use Mangrove forest wetland or Constructed wetland	Wastewater discharge	+++		+	Research on feasible plant in the constructed wetland in the soil and saline condition of Vietnam
Wastewater and sediment discharge	Optimal design and plan for the shrimp farming area to ensure that wastewater do not return directly to the surface water or overflow to other system	+	+	+++		

[1] WP: Water Pollution; S: Contaminated Sediment; DS: Disease Spread; + indicates a moderate improvement, ++ a considerable improvement, +++ a large improvement.

Vietnam that the incidence of contaminated shrimp products has reduced in consumer markets.

More stringent food safety testing has led to a reduction in product contamination, yet farmers remain highly sensitive to the risk of crop failure and continue to use both pro and antibiotics. Farmers know techniques to reduce the level of chemicals and drugs in shrimp, for example by stopping inputs in the weeks before harvest. Although reducing the food safety risk, these chemicals and drugs are flushed with water exchange and accumulate in water and sediment, and subsequently, the development of antibiotic resistance in bacteria in the environment (Tuan et al., 2005). As such, the environmental risk of drug and chemical use remains high.

5.2. *Treatment and reuse of effluent*

In addition to more efficient use and management of inputs farmers also have a range of water treatment and reuse options available. Generally, these offsite reuse and recycling options create economic benefits as less energy is consumed for producing new products from recycled materials, thereby sparing the environment from further degradation as less virgin material is used (EPA, 1996). If there are no possibilities of waste minimization nor recycling and reuse, waste treatment of waste streams is the approach of last resort (Table 8).

5.2.1. *Sediment treatment and reuse*

The treatment and reuse of the sediment through composting remains limited in shrimp farming in Vietnam. Such approaches have been proposed by Xia et al. (2004) in China and Páez-Osuna et al. (2003) in the Gulf of California. Currently, bioremediation or bacterial augmentation has received increasing attention because it appears an environmental friendly approach to minimize environmental degradation. Bioremediation products are known as probiotics. Some studies indicated that the application of probiotics to pond sediments could accelerate decomposition of undesirable organics and other waste products (Wang and Han, 2007; Nimrat et al., 2008). In Vietnam, the use of probiotics is not officially recommended. However, to ensure their proper use it is necessary to develop publically accessible guidelines to farmers on suitable probiotics, thereby increasing their efficiency and reducing pollution. In Vietnam, the Centre of Applied Science and Technology in Binh Dinh province has researched the possibility of using shrimp pond sediment for composting (Mai, 2006). Their study found that the sediment contained less nutrients than other compost and has a high salinity content as also noted by Boyd et al. (1994). In the trial they mixed in coconut husk and other additives to increase the nutrient content and reduce the salinity. The compost residues from the Binh Dinh trial have been tested in onion cultivation and have shown promising results, doubling the production compared to normal cultivation. The study is continuing with different composition for different products.

The N and P content of sediment found in Can Gio (see Section 4.2) is relatively similar to other parts of the country (Long and Toan, 2008)—including Binh Dinh. Sediment reuse therefore appears to be a viable option for intensive shrimp farming. However, further research is needed to determine if there is enough economic incentive for farmers to engage in sediment composting. In addition, more information is needed on the practical and long-term aspects of treatment and reuse of sludge including the possibilities for on farm production and trade.

5.2.2. *Constructed wetlands*

Because the low concentration of pollutants found in Can Gio intensive farming systems one of the most suitable, low-cost wastewater treatment technologies may be the use of wetland sedimentation. Constructed wetlands represent a natural treatment system based on biological symbiosis between macrophytes and microorganisms (bacteria, fungi, algae), and their interactions with the soil (Schulz, 2003). Schulz (2003) show that subsurface horizontal-flow constructed wetlands, consisting of a coarse sand bed with emergent macrophytes, can be used for the treatment of aquaculture effluent flow-through systems by applying hydraulic retention times of 1.5, 2.5 and 7.5 h. Treatment efficiencies of TSS and COD were in the range of 96–97% and 64–74%, respectively and appeared independent of hydraulic load. Removal rates of total nitrogen and total phosphorus were 21–42% and 49–69% respectively, showing lower efficiencies at decreasing residence times. The filtering characteristics of the sand bed at high TSS loading rates (9–73 g TSS/m^2/d) were expected, but were not observed during the six months of testing.

Such methods have been identified in various forms in the Best Management Practices and Good Aquaculture Practices (GAqP) of the Vietnamese Government (NACA, 2008), and also in international standards, including GlobalG.A.P., the Aquaculture Certification Council Best Aquaculture Practice standards and the ongoing WWF Shrimp Aquaculture Dialogue standards (ACC, 2007; WWF, 2008; GlobalGAP, 2009). Compared to conventional treatment methods, wetlands tend to be simple and inexpensive (where a sufficient supply of filter bed material is available). The disadvantage of this technology is the need of a large area of land at low loading rates. Indeed, farmers have had difficulty building these wetlands, or even more simple sedimentation ponds, because of a lack of available land (Gowing et al., 2006). If hydraulic retention times are in the order of 6–8 h, as applied by Schulz (2003), the land requirement would be relatively modest.

In some cases natural or rehabilitated Mangrove forest can be considered as bio-filters for the pond effluents in place of constructing wetland areas (Fitzgerald, 2002; Primavera, 2006; Vaiphasa et al., 2007). However, within these systems farm density is important so as to not exceed the capacity of the environment to assimilate waste as ponds are flushed during low tide, and therefore are less suitable for intensive farming systems. The main indirect impacts from shrimp farming on mangroves could be changes in the hydrological pattern, as well as hyper-salinity and eutrophication (Páez-Osuna et al., 2003). In order for optimal functioning of mangroves to remove nutrients it has been estimated that 2–3 ha of forest is needed for one hectare of semi-intensive shrimp ponds (Robertson and Phillips, 1995).

Can Gio provides a very suitable site for bio-filtration given the large area of rehabilited mangrove forest. However, it is not possible to discharge to Mangrove areas for bio-filtration, because of the Man and the Biosphere designation the Vietnamese government is unlikely to approve the application of such techniques. Shrimp production areas in other provinces, such as Kien Giang and Ca Mau, may be more suitable given their large area mangrove and tendency towards more intensive shrimp production. The potential for provinces with a high degree of deforestation to develop bio-filtration technology will depend on the extent to which mangrove reforestation, as seen in Can Gio, can be implemented.

6. Conclusions

This paper has assessed the environmental impact of intensive black tiger shrimp farming and discussed relevant cleaner production techniques for Vietnam. We show that in an assessment of the environmental impact of shrimp farming, the following five activities need to be considered: pond treatment, inlet water treatment, feeding, water exchange and pond emptying. Within these activities, six practices can be identified as important sources of pollutants: chemical and medicine use, fertilizer use, water resource use, pellet feed use, wastewater discharge and sediment discharge. The most important environmental problems caused by shrimp farming are associated with water pollution, contaminated sediments and the spread of diseases. Based on this we identified fourteen different indicators that can be used to assess the environmental pressure (Table 3).

The pollutant loading from wastewater to produce one ton of shrimp are 259 kg BOD, 769 kg COD, 1170 kg TSS, 30 kg N, 3.7 kg P and 4.8 kg N-NH_3. The results indicate that the levels of BOD_5, COD and TSS increased within the culture period as well as the age of ponds. The concentration of pollutants in wastewater varies greatly among shrimp ponds. Given the variation in our results there are probably many individual ponds where the water quality standards are exceeded by a large degree. On the other hand, not all intensive shrimp farming is causing environmental problems. Intensive and semi-intensive shrimp farming in Can Gio account for about 17% of the total shrimp farming area. The remainder include improved extensive farming (55%) and extensive farming under rice shrimp farming (28%) (Can Gio Economic Division, 2007), that are not considered a major source of pollution.

Two groups of technical options are identified for reducing the environmental pressure of water pollution, contaminated sediment and disease spread from individual shrimp farming pond in Vietnam. Based on the scale and potential of intensive shrimp farming in Vietnam the most viable options for waste reduction include more efficient feed use and ozone aeration. For the reduction of feed it is important that adequate and sufficient information is available to farmers and that the government can efficiently regulate the quality and composition of feeds. Aeration is noted as a particularly suitable technology given the low level of expense needed to implement it in existing intensive systems.

Options for waste treatment through sediment reuse and the construction of artificial wetlands are both viable options in Vietnam. Sediment reuse in agriculture may prove successful if the economics of its production can be justified to farmers. Wetland construction, although practiced on some farms, remains difficult to implement due to the lack of land available to farmers. Coordinated communal lands, or the rehabilitation of mangrove areas for this purpose, as partly seen in Can Gio, may prove a more viable low(er) cost option. Future research should assess the feasibility of these options, as well as the network of material flows creating waste/by product exchanges and the role of actors involved in their implementation to analyze the political/institutional feasibility of existing and potential options to reduce the environmental problems in aquaculture.

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