Shrimp Pond Effluent Quality during Harvesting and Pollutant Loading Estimation using Simpson's Rule

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Abstract

Shrimp aquaculture is a lucrative industry worldwide and more so in the tropics where two or three crops could be produced per year. Malaysia has extensive coastal zones for shrimp aquaculture and this industry will expand further with the creation of Aquaculture Industrial Zone. However, little is known about the extent of impact of this industry in terms of the quality and quantity of pollutants generated. Therefore, the objective of this study was to determine shrimp pond effluent quality and subsequently estimate the pollutants loading. Water samples were taken at the outflow gate every 10 cm drop in the level of the pond water during harvesting and analyzed. Results show that dissolved oxygen was below 4 mg/L when not aerated. Total suspended solids was high (33-173 mg/L) and five-day biochemical oxygen demand (BOD_5) ranged from 5.9 to 18.7 mg/L. Chemical oxygen demand (COD) was much higher than BOD_5 values. Total soluble phosphorus (TP) were less than 0.07 mg/L and total nitrogen (TN) was 1.2 to 3.7 mg/L. Chlorophyll a (Chl-a) was high, ranging from 61 to 112 µg/L. Using Simpson's rule, pollutant loadings were computed and the quantities (kg/ha/cycle) from the highest to the lowest were COD>TSS>BOD_5>TN>TP>Chl-a. This study shows that shrimp pond effluent needs to be treated to protect the estuarine ecosystems and ensure the sustainability of this industry.

Keywords: shrimp aquaculture, water quality, pond effluent, pollutants loading

1. Introduction

Coastal ecosystem is very valuable due to the many uses such as fisheries, aquaculture, agriculture and human settlement (Costanza *et al.* 1987; Primavera 2006). Large areas of coastal areas are developed into aquaculture ponds to meet the increasing demand of protein and an alternative to reduced landings of capture shrimp. Shrimp aquaculture is a lucrative industry worldwide and more so in the tropics where two or three crops could be produced per year. As shrimp culture requires brackish water, ponds are normally constructed at mangrove areas. However, negative impacts have been reported in many shrimp producing countries such as Taiwan and Mexico (Lin 1989; Paez-Osuna *et al.* 1999). Negative impacts of shrimp aquaculture include coastal ecosystem damages, decrease in fisheries yields and environmental pollution by solids and nutrients from shrimp ponds (Paez-Osuna *et al.* 2003; Primavera 2006).

Malaysia has extensive coastlines and many coastal areas are suitable for aquaculture development due to relatively clean environment and this industry will expand further with the creation of the Aquaculture Industrial Zone. However, little is known about the extent of impact of this industry in terms of the quality and quantity of pollutants generated. For the industry to be sustainable, efforts have to be made to quantify the pollution and manage the effluent. Previous studies on the water quality of rivers indicated that nutrients were higher near shrimp farming areas (Ling *et al.* 2010b). Previous studies of shrimp pond effluent during harvesting showed that the effluent was high in soluble inorganic nitrogen, soluble reactive phosphorus, solids and chlorophyll a (Ling *et al.* 2010a).

Effluent quality during harvesting could be affected by the discharge rate and method of pond draining as more disturbances may result in higher amount of solids being discharged. In an effort to quantify the pollutants in shrimp farm effluent, water quality and quantity were studied for a pond that was drained during harvesting.

2. Materials and Methods

Samples of effluent were collected at a commercial *Penaeus monodon* shrimp farm of the Malaysian Fisheries Development Board (LKIM) at Telaga Air, Matang, in Kuching division of Sarawak, Malaysia. The earthen shrimp pond has a surface area of one hectare and stocking density of 30 post-larvae (PL)/m^2. Shrimps were fed seven times daily until the seventh day after which they were fed four times daily and the culture period was 116 days. For harvesting, pond water was discharged in two different portions, the first half during evening (1800 hr to 2300 hr) and the other half the following morning (0600 hr to 1100 hr). Therefore, water samples were collected from 1800 hr to 2300 hr and from 0600 hr to 1100 hr. A staff gauge was inserted into the pond to show the level of pond water. Sampling was conducted every 10 cm decrease in pond depth at the outlet gate. Triplicates water samples were placed in 2-L polyethylene bottles and stored in an icebox for transportation to the laboratory for analysis.

In situ parameters such as temperature and dissolved oxygen (DO) were measured using Hydrolab Data Sonde Surveyor 4a with Water Quality Multiprobe (SN39301). pH and salinity were measured using a pH meter (Cyberscan 20) and a refractometer (Atago S-10) respectively. Water samples were analyzed for total suspended solids (TSS), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP). TSS and BOD_5 analyses followed that of standard methods (APHA 1998). For the other parameters, water samples were filtered through a 0.45 μm pore size membrane filter before analysis using Hach procedures where concentrations were determined colorimetrically using the Hach spectrophotometer DR2010 (Hach 2000). COD was determined using the reactor digestion method. TN concentrations were analyzed using persulfate digestion method (Hach 2000). TP analysis followed the acid persulfate digestion method and concentrations were determined using spectrophotometer (DR 2010). Simpson's rule of numerical approximation (Hass *et al.* 2007) was used to compute the loading of each pollutant and it can be expressed as equation [1].

$$L = 10 * \sum[(d_i - d_j) * (C_i + 4\, C_{½(i+j)} + C_j)/6] \quad [1]$$

where:

L is the loading of a pollutant (kg/ha)
d_i is the depth of pond water (m) at the i^{th} sampling
C_i is the concentration of the pollutant at the i^{th} sampling (mg/L)
$j = i+2$ and $i = 1, 3, 5, 7$ and 11

3. Results and Discussion

Figure 1 shows temperature trend during the course of draining of the pond water. Results show that temperature ranged from 29.0 to 31.8°C. Temperature was higher in the beginning, dropping to its lowest value at about 0.7 m depth before going up again toward the end of the draining. This was because the water was heated by solar radiation in the day as the draining of the pond started in the evening until almost midnight before continuing the next morning. For salinity, it was quite uniform from 32.8 PSU in the beginning to 32.4 PSU toward the end. The high salinity was due to the location of the pond being near the coastline.

Figure 2 shows the pH and DO values of the effluent during draining of the pond. pH ranged from 8.4 to 8.8, showing alkaline condition. The pH values were higher than that of the water source from the estuary. According to Lawson (1995), mean pH of ocean surface water is about 8.3 and remains fairly constant due to the great buffering capacity of the ocean. Previous studies at another shrimp farm farther inland showed lower range of pH i.e. from 7.6 to 8.0 (Ling *et al.* 2010a). The high pH reported here could be due to application of agricultural limestone between crops as part of the pond bottom management strategies. Shrimp farms located in mangrove areas normally have high sulfide concentrations. Oxidation of sulfide produces sulfuric acid and highly acidic condition could harm shrimp (Soonnenholzner and Boyd 2000). As this study area is located in a former mangrove area, agricultural limestone is commonly added to prevent the occurrence of acidic condition in the pond. However, the range of values in the present pond still falls within the optimum range of 7.5 - 9.0 for shrimp growth (FAO 1986). DO values during draining process ranged from 2.6 to 5.7 mg/L. It decreased initially and increased before dropping to the lowest level at the end of draining period.

The large increase after 0.8 m depth was when aerators were used to increase the DO for shrimp survival when the value dropped too low. This probably explained the higher DO in this study when compared with Ling *et al.* (2010a) where it was reported that DO of water continuously drained from three shrimp ponds ranged from 3.0 to 3.2 mg/L. TSS reflects organic and inorganic particulates in the wastewater. TSS was very high initially and at the end of draining period (Figure 3). The high value of TSS in the beginning was due to disturbances during the draining process which resulted in suspension of bottom sediment. TSS was also high at the end of the draining process because the low water level caused sediment near the bottom of the pond to be drained together with the moving water. The beginning and end values of TSS were close to those observed in Ling *et al.* (2010a). However, other values excluding the first and last ones ranging from 33.7 to 72.0 mg/L were lower due to the different technique of harvesting which affects the amount of disturbance during harvesting. In the report of Ling *et al.* (2010a), in addition to opening outflow gate, a pump was used to draw out water from the middle of the pond. Pumping the water from the middle of the pond disturbed the bottom sediment where the most sludge accumulated resulting in higher TSS. TSS in the effluent at the beginning and the end exceeded the Standard B limit (100 mg/L) of the Malaysia Sewage and Industrial Effluent Discharge Standards (DOE 1979).

COD ranged from 110 - 144 mg/L (Figure 3) and on average it was 11 times that of BOD_5 values (Figure 4). COD values were much higher than BOD_5 likely because organic matter was continuously oxidized in the pond by microorganisms over the culture cycle and those that were more resistant to biological oxidation were captured by chemical oxidation because more compounds can be chemically oxidized than biologically oxidized (Metcalf and Eddy 1991). COD values might have also included inorganic materials oxidized (Chapman 1996). COD in this study was closer to the lower values of the range reported in a growout pond (108.0 - 1238.0 mg/L) (Matis *et al.* 2002). The difference could be due to the lower stocking density in the present study. All the COD values of the effluent exceeded the Standard B limit (100 mg/L) of the Malaysia Sewage and Industrial Effluent Discharge Standards (DOE 1979). Chl-*a* was higher in the first 20 cm of the drained pond water then the subsequent 40 cm depth of water (Figure 3). The second half of the water discharged had higher mean concentrations than the first half and therefore higher loading. The range of Chl-*a* (61.4 - 111.7 µg/L) was lower than that reported in Ling *et al.* (2010a) at 169.2 - 388.4 µg/L. This is likely due to the limiting nutrient such as phosphorus which might have been lower in this pond compared to Ling et al. (2010a). However, this range falls in the range reported by Matis *et al.* (2002) at 10.15 - 358.98 µg/L. The high Chl-*a* concentrations indicate the bloom of phytoplankton in the nutrient rich water of the pond. If untreated, effluent has to be diluted 28 to 51 times to comply with the nutrient criterion of 2.2 µg/L protective of aquatic life (Smith and Tran 2010).

The trend of BOD_5 values in Figure 4 showed a sudden increase after 0.6 m water depth. This is likely due to the bottom water with higher organic matter being discharged during the second half of pond draining where the gate was opened to let the water drain from the bottom instead of the top for the first half of pond water. The range of BOD_5 values (5.9 - 18.7 mg/L) was similar to two of the ponds reported by Ling et al. (2010a). BOD_5 reflects the organic matter in the pond effluent and the main sources were uneaten feed and waste excreted by the shrimps. BOD_5 in the effluent did not exceed the Standard A limit (20 mg/L) of the Malaysia Sewage and Industrial Effluent Discharge Standards (DOE 1979). In this study, TN did not show much fluctuation during the pond draining (Figure 4). The values ranged from 1.2 to 3.7 mg/L. The main source of nitrogen in the effluent was the feed and waste which accounted for 76 - 92%. It has been reported that 69 - 77% of the total input of nitrogen were not assimilated by the shrimp (Thakur and Lin 2003). In estuary and coastal ecosystems, nitrogen was found to be most often the dominant limiting nutrient (Paerl *et al.* 2004). In order to comply with the nutrient criteria for the protection of aquatic life in large rivers (Smith and Tran 2010), this nitrogen had to be diluted 1.7 to 5.3 times.

TP ranged from 0.027 - 0.065 mg/L during the draining of the pond as shown in Figure 5. Of these concentrations, 92.3% exceeded the nutrient criteria for the protection of aquatic life in large rivers of 0.03 mg/L (Smith and Tran 2010). TP was not very high possibly due to the uptake by the blooming phytoplankton as indicated by the high Chl-*a* (Figure 3). This is lower than the range of 0.073 - 0.585 mg/L in growout pond as reported by Matis *et al.* (2002). One possible explanation is that the stocking density in this study was 30 PL/m^2 but that of Matis *et al.* (2002) was higher (37 PL/m^2). Since the major source of phosphorus input was shrimp feed (Thakur and Lin 2003), with lower stocking density in the present study there was probably less feed wasted and also less waste generated. Dissolved TP in the present study was not high likely due to the high absorptive capacity of sediment for phosphorus as reported by Lai and Lam (2009). Thakur and Lin (2003) reported that 39 - 67% of the total phosphorus input were in the sediment.

Based on the results of concentrations, using a numerical method, loadings of pollutants from this shrimp pond was estimated and shown in Table 1. It shows that in untreated effluent COD was the highest, followed by TSS, BOD_5, TN, P and Chl-*a* in that order. Discharging such water into the surrounding surface water could result in fish suffocation due to suspended solids, lack of oxygen due to sudden surge of low oxygenated water and algal blooms due to nutrients such as nitrogen and phosphorus. Therefore, it is recommended that the pond water must be treated before discharge. One of the treatments could be retention in sedimentation ponds (Nyanti *et al.* 2010; 2011) and subsequent controlled circulation to enclosed mangrove area that is large enough to treat the effluent as reported in Shimoda *et al.* (2005).

4. Conclusions

This study shows that pond effluent was high in TSS, COD, BOD_5, TN and Chl-*a* and it was also rich in dissolved TP. The concentration of dissolved oxygen was below 4 mg/L most of the time. Except for the first and last samplings, TSS in between samplings were very much lower due to little disturbance during draining. Therefore, it is recommended that effluent be drained gradually with minimal disturbance to reduce solids from pond bottom being resuspended. Effluent needs to be treated before being released to protect the surface water from eutrophication and fish kills and to ensure the sustainability of the industry.

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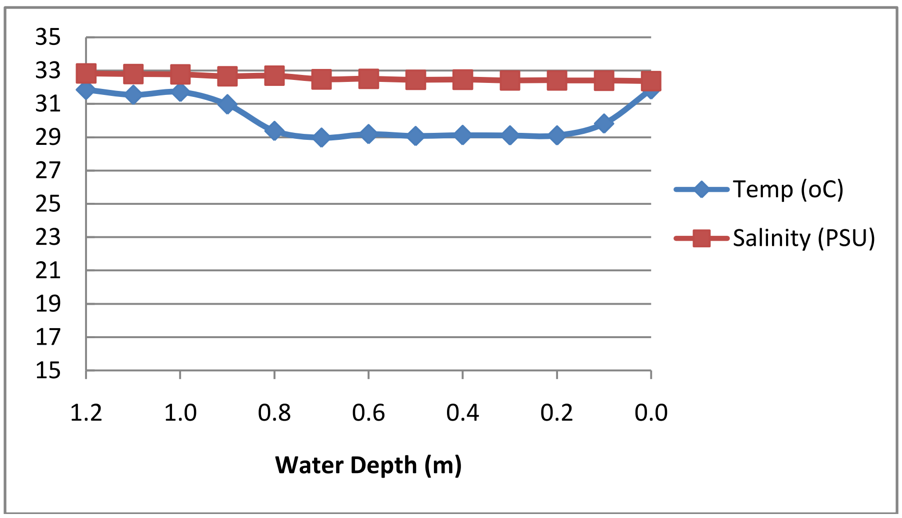

Figure 1: Temperature and salinity of drained water during shrimp harvesting

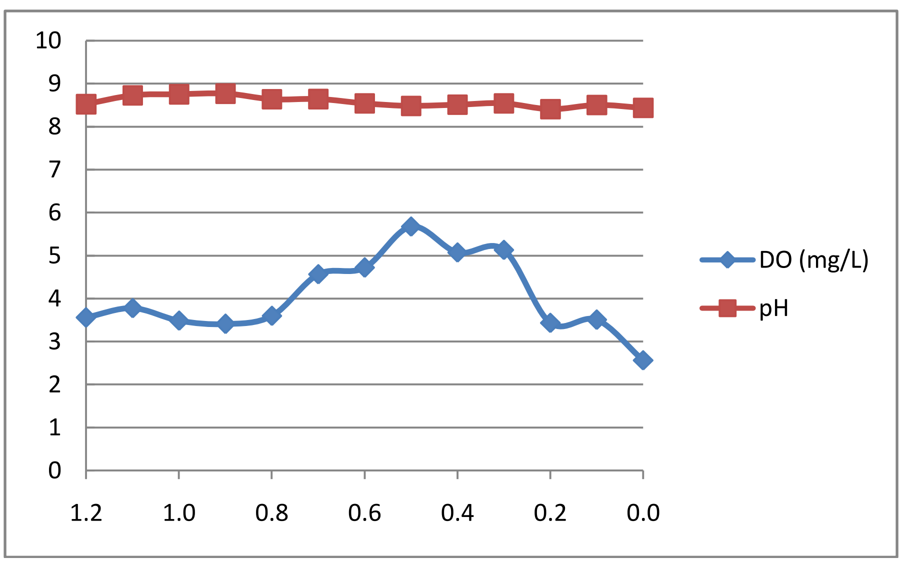

Figure 2: pH and dissolved oxygen (DO) of drained water during shrimp harvesting.

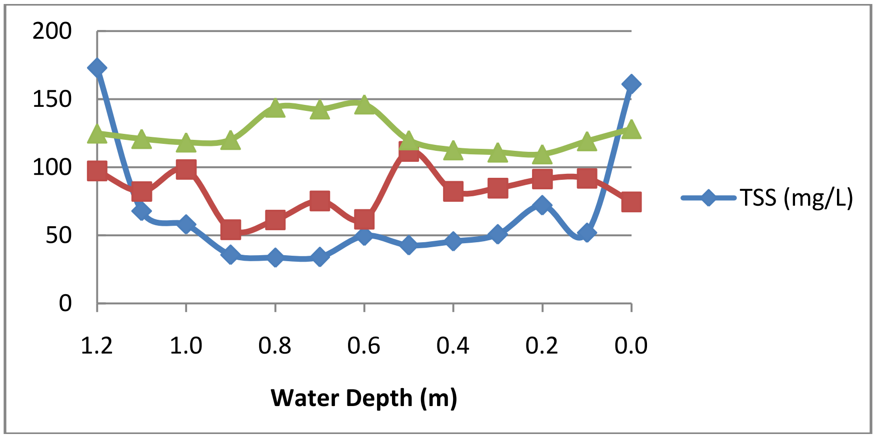

Figure 3: Total suspended solids (TSS), Chlorophyll-a (Chl-a) and chemical oxygen demand (COD) of drained water during shrimp harvesting.

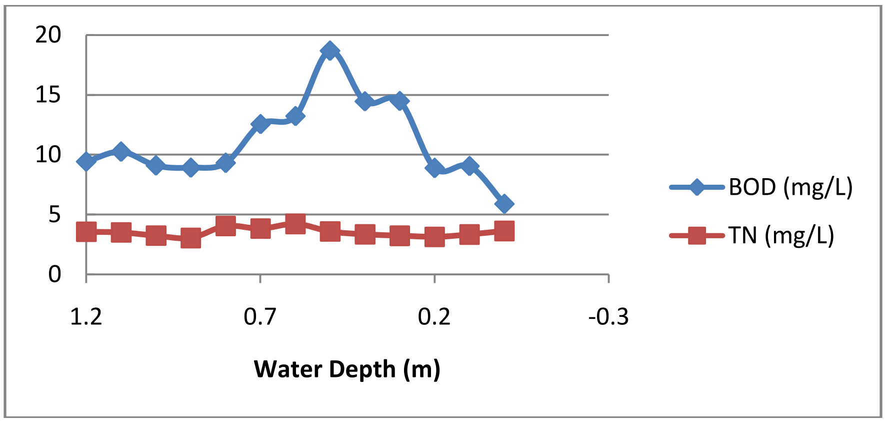

Figure 4: Biochemical oxygen demand (BOD_5) and total dissolved nitrogen (TN) of drained water during shrimp harvesting.

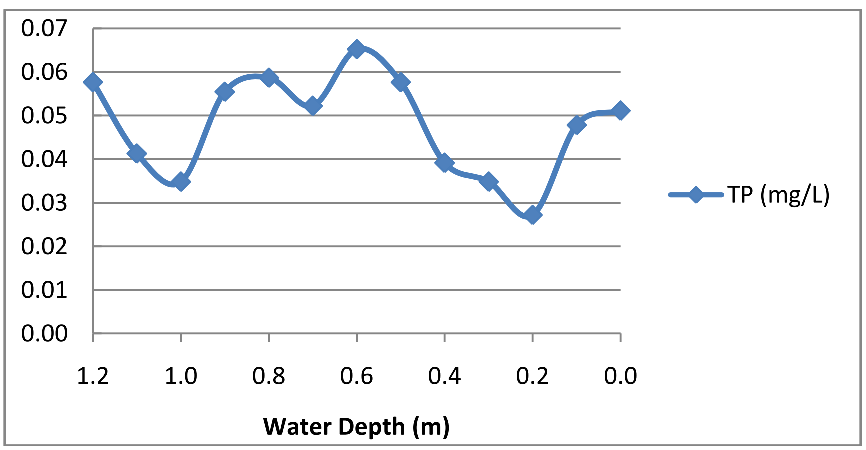

Figure 5: Total dissolved phosphorus (TP) of drained water during shrimp harvesting.

Table 1: Loadings of pollutants during harvesting

Pollutant	Loading (kg/ha)
TSS	3,533.3
BOD_5	735.6
COD	7.824.4
Chl-a	0.52
TP	3.0
TN	167.8