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Effluent of a Polyculture System (Tilapias and Shrimps): Assessment by Mass Balance of Nitrogen and Phosphorus

Sérgio Leandro Araújo-Silva[1], Munique de Almeida Bispo Moraes[1], Clovis Ferreira do Carmo[1], João Alexandre Saviolo Osti[2], André Martins Vaz-dos-Santos[3], Cacilda Thais Janson Mercante[1]

[1]Center of Water Resources, Fisheries Institute, São Paulo, Brazil
[2]Aquaculture Center, Paulista State University, São Paulo, Brazil
[3]Federal University of Paraná, Curitiba, Brazil
Email: cthais@pesca.sp.gov.br

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Abstract

From the estimation of the mass balance model, which can also be classified as "black box" model, it is possible to infer the impact of management on the system considered. This study aimed to evaluate water pollution generated by wastewater from a polyculture system of tilapia and shrimp and discuss the management employee and their relation to the quality of the effluent released. It used a pond measuring 1500 m^2, average depth 1.6 meters, where 12 cages of 1 m^3 populated with tilapia juveniles were installed 33 days after the shrimps' population. The tilapia juveniles were distributed in densities from 200 to 400 fish per cubic meter, reaching the density of 2.4 fish per square meter within the total pond area. Shrimp post-larvae were released outside the cages within the pond area in a density of 3.3 organisms per square meter. Total density considering fish and shrimps was of 5.7 organisms per square meter in the pond area. Water samples were taken weekly in affluent and effluent of the pond (January-August/2009). The mass balance model was calculated from the difference between the estimated load for the output and input of the pond. The average flow rate was 4.46 L/s. The average loads nitrogen was 0.072 Kg/day (affluent) and 0.179 Kg/day (effluent) and phosphorus 0.0136 Kg/day (affluent) and 0.031 Kg/day (effluent). The mass balance resulted in mean values of 0.11 ± 0.06 Kg/day for total nitrogen and 0.017 ± 0.010 Kg/day for total phosphorus indicating that the system exported nutrients. The use of Best Management Practices (BMP) likes better feed and water management as a way to minimize nutrient export.

Keywords

Environmental Conservation, BMP, Aquaculture, Water Flow

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1. Introduction

The production of aquatic organisms is growing as a farming activity although it is still considered as part of the fishing segment by many people. Aquaculture comprises mainly the farming of fish, shrimps, frog and mollusk, oysters and mussels, and other aquatic cultures like algae in a lower rate [1].

Aquaculture is based on three pillars: profitable production, social development and environment preservation. These pillars are intrinsically and interdependently related as to hold a lasting activity [2]. This activity causes environmental impact especially by the effluents they generate [3].

In general feeding is the main responsible for the increase of nitrogen (N) and phosphorus (P) concentrations in the systems. The average rate for retention of nutrients per fish and shrimp is 29% for N, and 16% for P, meaning that a great number of these nutrients are released into the receptor stream. This event is even worse in ponds where water is continuously renewed because of the loads of N and P released by the effluents [4]. The water renewal, mostly to remove exceeding plankton and nutrient from the pond, may deteriorate the water quality of the stream [5].

The standard values for the concentration of nutrients is based on current legislation [6], which sets the patterns to be followed for the aquatic body and related effluents; and the nutrient loads are established taking into consideration the system water flow.

The mass balance, which is a quantitative description of all input and output matter accumulated into a closed system [7], makes it possible to characterize the impact of management over the stream. Considering that the mass balance of the culture pond is nothing but the net load generated by this system, it was assumed that the compounds found at the pond dynamics are the result of the management adopted for the productive system. Based on this assumption, this study aimed to evaluate water pollution generated by wastewater from a polyculture system of tilapia and shrimp and discuss the management employee and their relation to the quality of the effluent released.

2. Materials and Methods

The experiment was conducted at APTA (Agência Paulista de Tecnologia dos Agronegócios), Aquaculture Sector at Vale do Paraiba, in the Pindamonhangaba City, São Paulo (SP), from January 16th until August 4th, 2009, dates that comprise the shrimps population and harvest, respectively. It was used a pond measuring 1500 m^2, average depth 1.6 meters, where 12 cages of 1 m^3 populated with tilapia juveniles (*Oreochromis niloticus* Linnaeus, 1758) were installed 33 days after the shrimps population. The tilapia juveniles were distributed in densities from 200 to 400 fish per cubic meter, reaching the density of 2.4 fish per square meter within the total pond area. Shrimp post-larvae (*Macrobrachium rosenbergii* De Man, 1879) were released outside the cages within the pond area in a density of 3.3 organisms per square meter. Total density considering fish and shrimps was of 5.7 organisms per square meter in the pond area.

Before filling the pond, liming was applied for disinfection using quicklime in a ratio of 100 g/m^2. After washing and 3 days before being populated with shrimps, the pond was fertilized with 4 g/m^2 of regular super phosphate and 4 g/m^2 of ammonia phosphate.

M. rosenbergii post-larvae were fed during the first 30 stocking days only, with ration containing 32% of protein. The tilapias were fed with extruded ration containing 32% of protein and the daily portion ranged from 0.75% to 4% of the fish biomass during the experiment due to the growing process. Rationing was practiced twice a day (8 a.m. and 4 p.m.) and there was no feeding if the water temperature was less than 19˚C.

A "paddle-wheel" aerator (1 HP engine) was turned on daily late in the evening and early in the morning (from 2 a.m. to 8 a.m.).

Water samples were collected from the pond affluent (inflow) and effluent (outflow) on a weekly basis, n = 20, from January 21st until June 4th, 2009, always between 9 a.m. and 10 a.m. The samples were frozen and sent to the Research and Development Center Laboratory of Fisheries Institute in São Paulo, stored in polyethylene bottles (5-liter capacity) for further analysis of Total Nitrogen (TN) and Total Phosphorus (TP) concentrations.

Analysis of TN and TP were performed according to the techniques described by Valderrama [8] for the digest process. For measurements of dissolved oxygen (mg/L) was used, *in situ*, the handset of the brand HORIBA U-22 model. The concentration of chlorophyll *a* was estimated based on the method described in Nush [9].

The pond water was renewed continuously and the effluent was released by a bottom and a top water flow. The flows were determined by the volume meter method based on the time spent by a determined water flow to fill a recipient of a known volume.

TN and TP loads were estimated by taking the result of multiplication between water flow values (L/s) and nutrient concentrations (µg/L) in both affluent and effluent, adjusting the units to Kg/day. Mass balance values were the result of the difference between the pond effluent and affluent estimated load.

Nutrients input via affluent and nutrients output via effluent were converted to logarithm base 10 for due normalization and then submitted to variance analysis (ANOVA). The obtained averages were compared to 5% level of probability applying Tukey test in order to evaluate significant differences between the sample places. BioEstat 5.0 was used for these calculations.

The results of the analyses were compared to the quality patterns for effluents, specifically for water of studied class (class II) that is intended to aquaculture and fishing activity, as established in the current Brazilian environmental legislation [6].

3. Results

Concentrations of TP at the effluent did not increase drastically along the culture. However, the values obtained for both nitrogen and phosphorus were different ($p < 0.05$) from those obtained for the affluent (**Table 1**), thus evidencing the impact of management over these variables due to the animals confinement and feeding practices.

Concentration values of TP at the effluent were higher than those recommended by CONAMA resolution 357 [6], because average values were above the limit of 50 µg/L indicated for water class II and lentic environment, proper to aquaculture and fishing activities (**Table 1**).

In August, 2009, seven months after the beginning of culture, was obtained the highest value of TP at the pond effluent. This sample also showed high value for TN concentration (705.9 µg/L) and low values for dissolved oxygen (3.2 mg/L), when compared to their respective averages at the effluent. These values may be influenced by the rain fallen one and two days before the collection (16.9 mm and 7.8 mm, respectively), possibly carrying organic matter from the surroundings to the pond. Added to the organic matter from feeding and excrement this fact promoted an intensive decomposition activity in the system, what explains the elevated nutrients values and reduced oxygen contents.

The average water flow of the pond was 4.46 L/s and the average residence time was 5 days what classified it as an intermediate environment (residence time between 2 and 40 days, and direct tributaries of lentic water), according to CONAMA resolution 357 [6]. At this experiment, the spillway was open when water transparency was reduced due to the proliferation of phytoplankton. This explained the reduced average concentration of chlorophyll *a* at the effluent (24 µg/L) when compared to the pattern recommended by CONAMA resolution 357 [6] (<30 µg/L).

Regarding TN, the daily average load in affluent was 0.07 ± 0.04 Kg/day and the outflow load via effluent was 0.18 ± 0.10 Kg/day. TN load values showed an expressive time variance, oscillating from 0.0057 Kg/day to 0.18 Kg/day in affluent, and from 0.027 Kg/day to 0.42 Kg/day in effluent. Concerning TP the daily average load was 0.014 ± 0.0097 Kg/day in affluent and 0.03 ± 0.02 Kg/day in effluent. Amplitude ranged from 0.003 Kg/day to 0.05 Kg/day in affluent and from 0.006 Kg/day to 0.15 Kg/day in effluent. **Table 2** shows the average values for the affluent and effluent loads and the mass balance of nutrients (Kg/day) achieved not only in this study but in studies of different authors.

The mass balance of nitrogen shows an increment up to 0.13 Kg/day transported by the effluent of the production system and demonstrated a transition of the system between importer (larger loads in the affluent than

Table 1. Average concentrations of Total Nitrogen (TN) and Total Phosphorus (TP) with standard deviations, amplitude (between parentheses) and ANOVA statistical analysis comparing the pond affluent with the effluent. Means followed by the same letters in the line do not differ by Tukey test (0.05). Reference values for comparison of the results according Brazilian environmental legislation [6].

Nutrients	Affluent	Effluent	Reference values
TN (µg/L)	184.81 ± 96.38^{a} (54.27 - 363.88)	472.97 ± 245.77^{b} (167.76 - 1232)	1270
TP (µg/L)	33.88 ± 23.72^{a} (9.90 - 98.39)	90.59 ± 75.42^{b} (21.75 - 374.55)	50.00

Table 2. Average load values and mass balance for Total Nitrogen (TN) and Total Phosphorus (TP) in different production systems. NL = Nitrogen Load; PL = Phoosphorus Load; NMB = Nitrogen Mass Balance; PMB = Phosphorus Mass Balance; SD = Stocking Density; FB = Final Biomass.

Place		NL (Kg/day)	PL (Kg/day)	NMB (Kg/day)	PMB (Kg/day)	SD (m^2)	FB (ton/ha)	Authors
Polyculture pond	Affluent	0.072	0.014	0.107	0.017	2.4	10.9	This study
	Effluent	0.179	0.031					
Tilapias pond	Affluent	0.053	0.010	0.259	0.039	2.3	15.5	[10]
	Effluent	0.312	0.049					
Shrimps pond	Affluent	0.018	0.007	0.029	0.002	-	1.5	Pereira[1]
	Effluent	0.047	0.009					
Frogs pond	Affluent	0.002	0.001	0.014	0.014	-	-	[11]
	Effluent	0.016	0.014					

the effluent) and exporter. A similar result was obtained for phosphorus that presented an increment of the mass balance ranging from 0.003 to 0.026 Kg/day. Mass balance of nitrogen and phosphorus indicated that the productive system worked as a nutrient exporter. The system exported during the production cycle approximately 13 Kg of nitrogen and 3 Kg of phosphorus.

4. Discussion

In 2008, world aquaculture production of fish and crustacean resulted in environmental load of 1.7 million metric tons of nitrogen (N) and 0.46 million tons of phosphorus (P) [12]. In this context eutrophication is undoubtedly one of the barriers to the sustainable development of aquaculture. The nutrients enrichment, mainly N and P, at pisciculture ponds is very common due to the input of compounds from feeding and fertilization; and that inappropriate management of the nutrient sources associated with a number of other biotic and abiotic factors (like biomass, luminosity, temperature) may cause environmental and financial losses [13].

Phosphorus is one of the main chemical elements that compose the rations; such evidence does infer that the food currently produced alters water quality, resulting in eutrophication of water [14]-[16]. Reference [17] proposed that the control of effluent production is required to maintain the sustainable growth of aquaculture strategy. This author pointed out that the food is the major source of nutrients for aquaculture effluent, and recommends that the management of effluent from aquaculture should consider formulating diets and/or food strategies.

When the quality of the pond water is poor it is common to occur an intensive increase of the water flow, thus reducing the residence time and consequently quickly releasing organic matter, inorganic salt, nutrients, plankton, among other components of the pond that might be damaging the production at that moment, therefore the flow control prevented the growth of phytoplankton [18]. The constant inflow and outflow in a short residence time and the uncontrolled management of rationing and supply water are some of the factors that directly influence the dynamics of nutrients. Additionally, they state that during the high production season rationing is more intense and climate events, like temperature and rain, strongly impact the dynamics of these systems [19].

A short residence time is not enough for the transformation of nitrogen by bacteria or assimilation by algae at the culture systems and a great deal of these nutrients is eliminated into the effluents [20]. At this study it was observed an increment of TN concentration in the pond effluent along the culture cycle, thus confirming the author's statement.

As to increase the capacity of retention of nutrients in the pond, and consequently decrease the loads released to the environment, water renewal has to be reduced to the most [14] [21], so that the intense water flow controls the dynamics of phosphorus in the environment as per its absorption by the sediment [22].

The simultaneous production of more than one aquatic organism into polyculture systems makes the food conversion better in comparison with the results observed in the monoculture [23]. This fact was detected in the present study, as demonstrated by Marques *et al.* [24], once the average of Feed Conversion Ratio (FCR) for ti-

[1]Unpublished.

lapias was 1.64:1 and 1.53:1 for fish and shrimps. So, the use of polyculture systems may minimize the release of nitrogen and phosphate compounds into the water column, thus improving water quality when compared to monoculture systems.

Among the culture systems mentioned in **Table 2**, the shrimp was the one that less exported nutrients via effluent but its produced biomass (1.5 ton/ha) was 7.2 times lower than in the polyculture. The tilapia culture pond studied by Pereira [10] was the same used for this study, but the tilapias were free, the ration supplied contained 28% of gross protein, the average flow was 2.7 L/s and the water residence time was 8 days. Despite of the longer residence time, the system behaved as an exporter, showing values 2.24 and 2.42 times higher than the ones found in the present study for TP and TN, respectively. The biomass produced at the tilapia monoculture pond was 15.5 ton/ha, 41% higher than at the present study (10.9 ton/ha). However, it should be taken into account that the period of tilapia culture in the monoculture system was from October 2006 until March 2007, and the average water temperature was 28.13˚C against 25.19˚C in the polyculture. Additionally, the initial tilapia average weight in the monoculture was 191 g and 48.4 g in the polyculture. These factors contributed to the lower biomass produced in the polyculture.

The hypothesis based on this study assumed that the introduction of shrimps into a fish productive system tends to contribute for the reduction of exportation of nutrients by the pond effluent. Part of the chemical compounds of non-eaten ration and fish excrements would be converted into biomass by the shrimps, thus reducing the impact caused by the productive process to the environment and consequently increasing the business economic feasibility.

Reference [25] observed that in a polyculture system with tilapias (1 tilapia per square meter) and shrimps (0, 2, 4 and 6 shrimps per square meter), the different stocking densities of shrimps did not either affect tilapia production or required significant changes in management. In this concern it is suggested to change density from 3.3 shrimps per square meter (present study) to 6 shrimps per square meter, maintaining the same feeding rate. This way the impact of mitigation over the mass balance would be effectively higher, influencing the environmental sustainability of the productive system and increasing the financial result of the culture.

5. Conclusion

The evaluation of the results leads to the conclusion that the management applied to the polyculture contributed to the alteration of the effluent chemical characteristics. Due to the short water residence time, the control of the pond water flow may have hindered the mechanisms of retention of the nutrients by sediments and absorption by phytoplankton. Thus, the use of the Best Management Practices (BMP) likes better feed and water management as a way to minimize nutrient export.

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