Acta Fish. Aquat. Res. (2017) 5 (3): 90-101
DOI 10.46732/actafish.2017.5.3.90-101

ORIGINAL ARTICLE

Acta of Fisheries and Aquatic Resources

Short term variations of nutrients in experimental culture of tilapia (*Oreochromis niloticus*) and potential load of N and P from culture areas in a tropical estuary (Bahia, Brazil)

Variações de curto prazo de nutrientes em cultivo experimental de tilápias (*Oreochromis niloticus*) e das cargas potenciais de N e P das áreas de cultivo em um estuário tropical (Bahia, Brasil).

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Received: may 12, 2017 / accepted: september 11, 2017 / published: december 14, 2017.

Abstract The present study was carried out in a tilapia culture system from a tropical estuarine system of the Tinharé-Boipeba Islands Archipelago (ESTBIA) on the northeast Brazilian coast (Bahia State – Brazil) and quantified the potential nutrient load from this activity into the waters. Organic and inorganic species of carbon, nitrogen and phosphorus (POC, DOC, TN, TP, PON, POP, NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-}) were monitored in experimental tanks during four days, as well as the seston, water temperature, pH, Eh, and Dissolved Oxygen. The data-set were obtained from tanks with fish fed and not fed through experiment period in order to assess the loads of N and P from fish and fish feed contributions. Three series of tanks were prepared: Control Series – CT; Non-Feeding Fish Series – NFF; and Feeding Fish Series – FF. The comparison of the three treatments showed that the FF Series was marked by the highest variations of physical-chemical parameters due the influence of fish feed residues in tanks. Based on the parameters analyzed, the estimated annual nutrient loads for the culture area would be 55 tons of TN and 9 tons of TP. The fish feed would be responsible for 64% of nitrogen and 90% of the total phosphorus loads by culture of tilapia.

Keywords: nutrients, aquaculture, tilapia

Resumo O presente estudo foi realizado em um sistema de cultivo de tilápias no sistema estuarino tropical das Ilhas do Arquipélago de Tinharé-Boipeba (ESTBIA) na costa do nordeste brasileira (Bahia - Brasil) e quantificou as cargas potenciais de nutrientes provenientes desta atividade para o ambiente aquático. As formas orgânicas e inorgânicas de carbono, nitrogênio e fósforo (COP, COD, NT, PT, NOP, POP, NH_4^+, NO_2^-, NO_3^-, e PO_4^{3-}) foram monitoradas em tanques experimentais, durante quatro dias, assim como a seston, a temperatura da água, pH, Eh e o oxigênio dissolvido. O conjunto de dados foi obtido a partir de tanques com peixes alimentados e se alimentação durante o período do experimento, a fim de avaliar as cargas de N e P provenientes dos peixes e das rações utilizadas na alimentação. Foram preparadas três séries de tanques: Série Controle - CT; Série de Peixes não alimentados - NFF e Série de Peixes Alimentados - FF. A comparação dos três tratamentos mostrou que a série FF foi marcada pelas maiores variações dos parâmetros físico-químicos, devido a influência dos resíduos das rações dos peixes nos tanques. Com base nos parâmetros analisados, as cargas de nutrientes anuais estimadas para a área da cultura seriam de 55 toneladas de NT e 9 toneladas para o PT. A ração dos peixes seria responsável por 64% de nitrogênio e 90% de fósforo das cargas totais provenientes da cultura da tilápia.

Palavras-chave: nutrientes, aquacultura, tilápia

Trabalho financiado por Banco Interamericano de Desenvolvimento - BID e Instituto de Desenvolvimento Sustentável do Baixo Sul da Bahia - IDES.

ISSN: 2357-8068
Indexadores: Sumários (www.sumarios.org) - Diretórios: Diadorim (Diadorim.ibict.br) - Latindex (www.latindex.org)

Introduction

The increase of aquaculture activities during the last decades has created negative impacts to aquatic environments (Qian, Wu & Ni, 2001). Aquaculture residues contain a variety of components such as organic particulate matter, heavy metals, food debris, excreta, and antibiotics (Crawford, Macleoud & Mitchell, 2003; Biao, Zhunhong & Xiarong, 2004; Lacerda, Vaisman, Maia, Ramos e Silva & Soares-Cunha, 2006; Brambilla et al., 2007). These adverse effects led scientists to understand and develop methods to monitor and regulate environmental impacts of aquaculture activities (Fernandes et al., 2001; Read, Fernandes & Miller, 2001; Gyllenhammar & Hakanson, 2005). As a result, many countries established policies and regulatory frameworks for the management and control of these impacts (Wu & Yang, 2010).

One of the most significant problems concerning aquaculture is the eutrophication of coastal waters since the organic matter wastes contain high levels of nitrogen and phosphorous. N and P compounds are derived primarily from fish excreta and feeding (Amikolaie, 2005), and the organic matter mineralization processes result in inorganic forms (e.g. NO_2^-, NO_3^- and NH_4^+) that may stimulate algal proliferation. This can strongly influence planktonic food webs leading to increase of organic matter in sediments. Therefore, the organic matter tends to accumulate in the culture areas changing the quality of the sediment and its associated fauna (McGhie, Crawford, Mitchell & O'Brien, 2000; Qian, Wu & Ni, 2001; Sutherland, Petersen, Levings & Martin, 2007). The environmental impacts of aquaculture can affect the activity itself since pollution can be associated growth reduction and increase the vulnerability of individuals to diseases (Wilkie, 1997; Mantzavrakos, Kornaros, Lyberatos & Kaspiris, 2007; Brambilla et al.,2007).

The present study was carried out in a tilapia culture system from a tropical estuarine system of the Tinharé-Boipeba Islands Archipelago (ESTBIA), on the northeast Brazilian coast (Bahia State – Brazil). It aims to establish the potential nutrient load from this activity to the surrounding waters. Some studies have been proposed to assess fish farming effects using experimental manipulations in tanks (Mazzola & Sarà, 2001; Qian, Wu & Ni, 2001; Franco-Nava, Blancheton & Le-Gall, 2004; Lojen et al., 2005; Vizzini, Savona, Caruso, Savona & Mazola, 2005; Avnimelech & Kochba, 2009). However, few quantified potential nutrient loads from this activity and none of them evaluated the loads of fish and fish food separately. In this study, organic and inorganic species of carbon, nitrogen and phosphorus were monitored in experimental tanks through four days. Data were obtained from tanks with fish fed and not fed in order to assess the loads from fish and fish food contributions individually.

Material and Methods

The Design of the Experiment

This experiment was conducted from October 19th to 22nd, 2007 in experimental tanks and aimed to evaluate the influence of tilapia culture in the chemical composition of waters (carbon, nitrogen and phosphorus). The tanks contained estuarine water and/or juveniles of tilapia.

Water samples were collected daily in the tanks during the four days of experiment. Three series of tanks, containing ~1000 L of estuarine water each one, were prepared (Figure 1). The first set (Tanks 1, 2 and 3) was called Control Series (CT), and contained only estuarine water. The second set (Tanks 4, 5 and 6), called Non-Feeding Fish Series (NFF), contained 11 individuals fish (each one weighing 300g approximately) and the fish were not fed since three days before the beginning of the experiment (October 16th). Similarly to NFF, the third set (Tanks 7, 8 and 9; named Feeding Fish Series - FF) contained 11 individuals fish, but they were fed from the first to the last day of the experiment. In this series, the fish were fed with 35g of fish food a day at each tank.

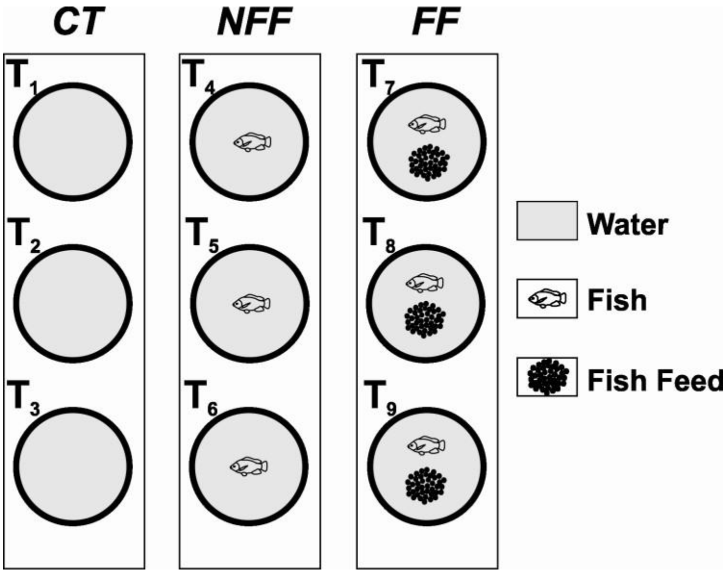

Figure 1. Design of the tilapia tanks experiment (CT – Control Series; NFF = Non Feeding Fish Series, FF = Feeding Fish Series).

SAMPLING PROCEDURES AND ANALYTICAL TECHNIQUES

The water samples were filtered through a precombusted GF/F Whattman (Millipore – 0.7µm, 47mm Ø) membrane to separate the dissolved from the particulate matter (seston), and stored in ice for transportation to the laboratory. Seston were measured according to the gravimetric technique described by Strickland & Parsons (1972). Particulate and Dissolved Organic Carbon (POC and DOC) were determined with a Total Organic Carbon Analyzer - TOC-VCPH, SHIMADZU. Total nitrogen and total phosphorus (TN and TP), Particulate Organic Nitrogen (PON), Particulate Organic Phosphorus (POP), the dissolved inorganic nitrogen (DIN) – ammonium (NH_4^+) + nitrite (NO_2^-) + nitrate (NO_3^-), and orthophosphates (PO_4^{3-}) were analyzed following standard colorimetric techniques according to Grasshoff, Ehrhardt & Kremling (1983). Precision of these analysis, as indicated by relative standard deviations of replicates, was less than 3 % for TN, PON, NO_2^- and NO_3^-, 5 % for NH_4^+, 5 % for TP, POP and PO_4^{3-} and 2 % for TOC and DOC. Detection limits were about 0.01□M, 0.05 □M, 0.1 □M for N and P species, and 100 and 50mgL^{-1} for TOC and DOC. Water temperature, pH, Eh and Dissolved Oxygen (DO) were measured *in situ* daily in each tank using portable probes.

STATISTICAL ANALYSIS

The response variables presented a distribution with strong asymmetrical tendency that indicates an absence of homoscedasticity and normality (Figure 2). From the eighteen variables analyzed, only three of them presented normality and homoscedasticity of variances (NO_3^-, NO_2^- and salinity). A parametric approach using the classical Variance Analysis model would not be recommended. Therefore, the Variance Analysis by permutation, as proposed by Anderson (2001a,b) and validated by Anderson & Braack (2003), was adopted. The analysis was undertaken using three analysis of partial redundancy using CANOCO software (Braak & Šmilauer, 2002). The two factors, Treatment (*CT*, *NFF* and *FF*) and Time (Day 2, Day 3 and Day 4), and their interactions were expressed in the form of Helmert contrasts matrix (Venables & Ripley, 2002), also called ‘‘orthogonal dummy variables’’ (see details for elaboration of this matrix in apendice of Anderson & Legendre (1999).

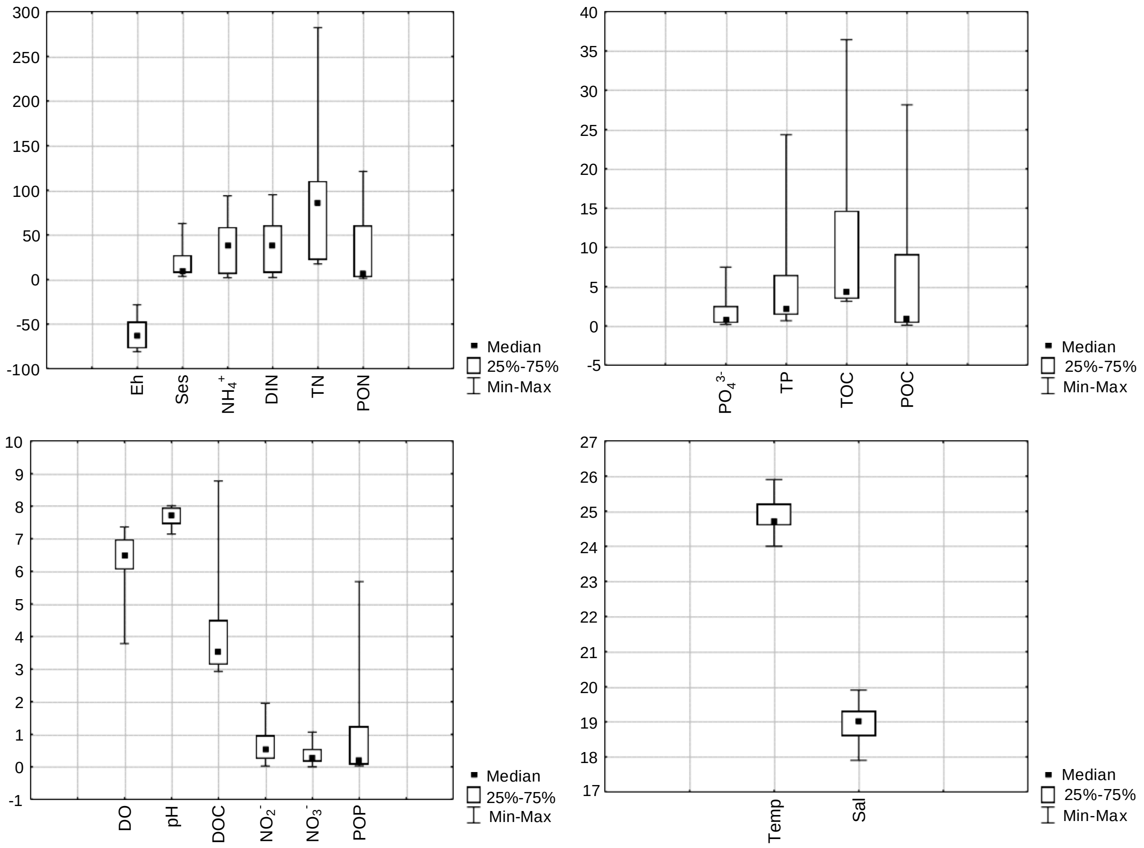

Figure 2. Minimum and Maxima values of the physical-chemical parameters (omitting outliers) with 25% and 75% percentile box and black square = median.

In order to estimate the effect and significance of factor 1 (Treatment), the eighteen response variables were factored separately, first by the effects of factor 2 (Time) and then by the vectors representing the interaction between the factors (first analysis of partial redundancy). To estimate the effect of factor 2 (Time), the response variables were factored by the effects of factor 1 (Treatments) and their interactions (second analysis of partial redundancy). For the estimation of the effect of the interaction, the response variables were factored by the effects of the matrixes representing both factors (third analysis of partial redundancy). The data were transformed by the fourth root and Ranging transformation, and 9999 permutations were used (taking the reduced model) for each analysis of redundancy into account.

Results

The temperature and salinity did not show significant variations through time and among the three treatments (Table 1, Figures 3a and 3b). The most important variations in DO were observed for *FF*, in which concentrations ranged from 7.1 mg L^{-1} in the first day to 5.4 mg L^{-1} in the last day of the experiment (Table 1). The temporal variation of DO was marked by stability at *CT* and *NFF* and a gradual reduction in the *FF* treatment since the first day (Figure 3c). Similarly, the pH values also showed the greatest decreases in the *FF* (from 7.9 in the first day to 7.3 in the last day). The other two Series (*CT* and *NFF*) did not showed significant changes in the pH values through time (Table 1, Figure 3d). On the other hand, the Eh exhibited an opposite pattern in relation to DO and pH in *FF* treatment, *i.e.*, the Eh values increased since the first day of experiment (Table 1, Figure 3e).

The temporal variation of seston in the *CT* was similar to that of *NFF*. The concentrations were lower and no significant changes were observed during the experiment (Figure 3F). In contrast, the *FF* temporal variation was characterized by significant increases in concentrations through time. In the last day of experiment, average concentration was about five fold higher than the one observed at the beginning of the experiment (Table 2, Figure 3f).

The C, N, P total concentrations and POM composition (particulate organic matter – POC, PON, POP) presented similar temporal variations in all series. In the *CT* and *NFF*, the concentrations tended to remain stable during the experiment, whereas they increased from the beginning to the end of the experiment in the *FF*. In this Series, TOC, TN and TP concentrations, for example, were seven, twelve and seventeen fold higher in the last day when compared to those of the first one (Table 2, Figure 4). In the FF series, the average concentration of TOC increased from 3.6 to 27.5 μM. For TN and TP, its concentrations increased from 19.5 to 234.4 μM, and from 1.0 to 17.7 μM, respectively. Similarly, the POC, PON, and POP concentrations augmented from 0.5 to 19.4 mg L^{-1}, from 4.2 to 102.5 μM, and from 0.2 to 3.9 μM, respectively. An exception to this pattern was observed for TN in *NFF*, in which the average concentrations also tended to increase through time (from 19.5 to 81.7 μM).

All dissolved species showed a similar pattern in the *FF* series, increasing its concentrations from the beginning to the end of the experiment. This was mainly observed for DOC and PO_4^{3-}, in which the measured final concentrations (8.1 mg l^{-1} and 5.6 μM, respectively) were three and ten times higher than the initial ones (3.1 mg l^{-1} and 0.5 μM). The other two series (*CT* and *NFF*) showed low variations through time for these parameters, with final values of 3.0 and 3.5 mg l^{-1} for DOC, and 1.0 μM and 1.6 μM for PO_4^{3-} (Table 3, Figure 5a).

The Dissolved Inorganic Nitrogen (DIN) showed concentrations ranging between 7.3 and 8.2 μM in *CT*, 7.3 and 52.2 μM in *NFF* and 7.3 and 89.9 μM in *FF*. The averages were 6.5, 37.0 and 57.6 μM, respectively (Table 3). The *FF* and NFF series showed strong increases in DIN concentrations through the experiment. In contrast, there were no marked variations in the CT (Figure 5b). The NH_4^+ was the main constituent of DIN, and its concentrations ranged between 6.7 and 7.4 μM in *CT*, 6.7 and 50.4 μM in *NFF* and between 6.7 and 88.0 μM in *FF*. The NH_4^+ averages were 5.6, 35.4 and 56.8 μM, respectively (Table 3). This may indicate that NH_4^+ comes both from fish metabolism and the mineralization of the organic matter from fish food residues (Figure 5c).

The NO_3^- and NO_2^- concentrations were much lower than those measured for NH_4^+. The NO_3^- did not change significantly in the *CT* and NFF, and slight increases (0.5 to 0.6 μM) occurred in the last day in the *FF* treatment (Figure 5d). However, no interpretable patterns were detected through the experiment in all treatments (Figure 5d). The temporal variation of NO_2^- concentrations were similar in shape to that of NH_4^+ in NFF and NFF, increasing from the first to the last day (Figure 5e). The averages of CT, NFF and FF were 0.2, 0.9 and 2.7 μM, respectively (Table 3).

Table 1. Average, first and last day of the Temperature (Temp), Salinity (Sal), Dissolved oxygen (DO), pH and Eh values, measured during the experiment period.

Series	Temp	Sal	DO (mg L^{-1})	pH	Eh
CT	**24.6** 24.0 - 24.7	**18.6** 18.4 - 18.6	**7.0** 7.1 - 7.2	**7.9** 7.9 - 7.9	**- 77.2** - 74.1 - -77.4
NFF	**25.2** 25.1 - 25.2	**19.5** 19.3 - 19.6	**6.6** 6.8 - 6.7	**7.7** 7.7 - 7.7	**- 62.8** -66.0 - -60.1
FF	**24.3** 23.5 - 24.6	**18.7** 18.6 - 18.8	**5.9** 7.1 - 5.4	**7.5** 7.9 - 7.3	**- 49.7** -73.3 - -39.4

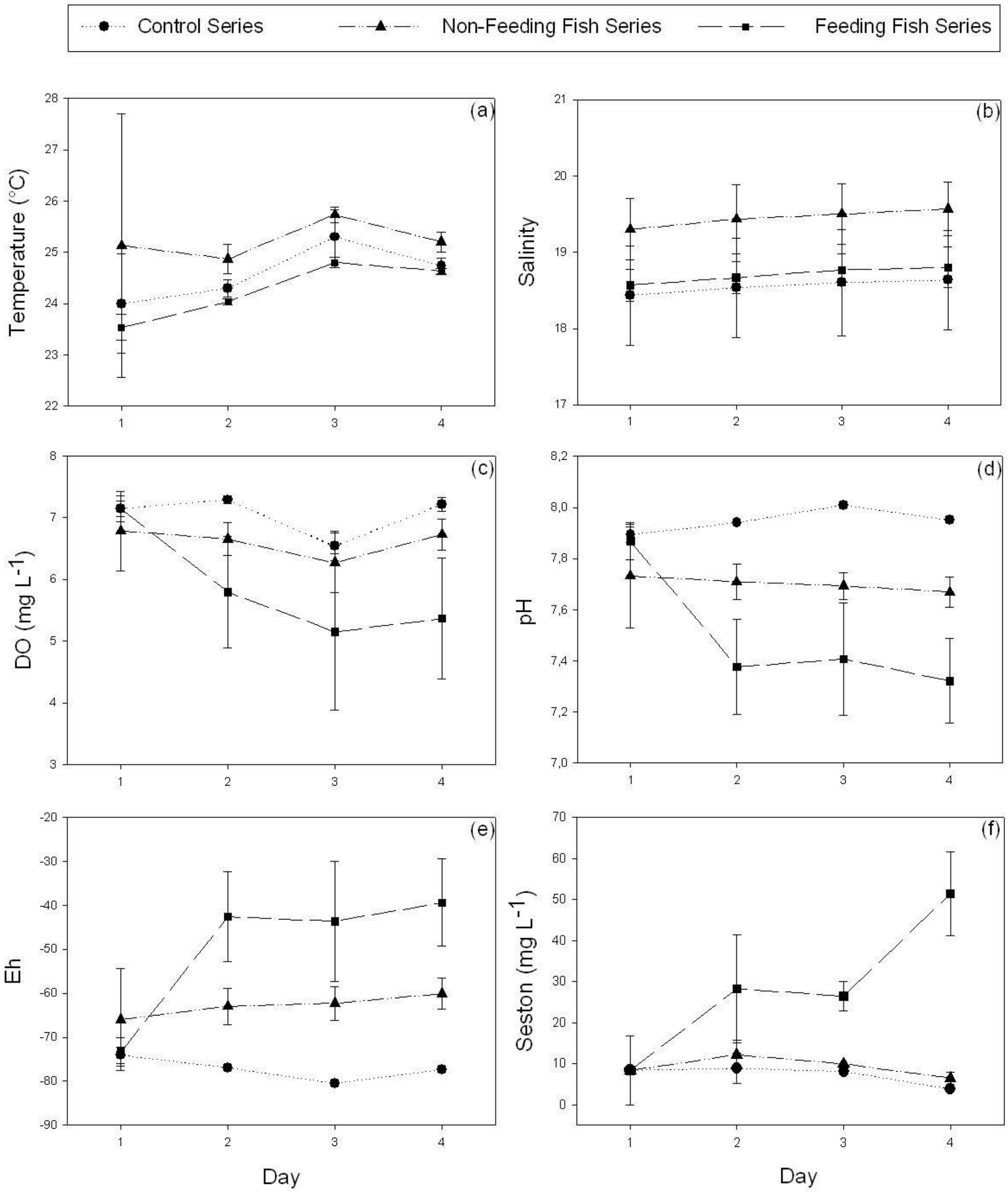

Figure 3. Physical-chemical values from Control (*CT*), Non-Feeding Fish (*NFF*) and Feeding Fish (*FF*) tanks: (a) Temperature, (b) Salinity, (c) DO, (d) pH, (e) Eh and (f) Seston, during the experiment period.

Table 2. Average, first and last day of the Seston, Total Nitrogen (TN), Total Phosphorus (TP), Particulate Organic Carbon (POC), Particulate Organic Nitrogen (PON) and Particulate Organic Phosphorus (POP) concentrations, measured during the experiment.

Series	Seston (mg L^{-1})	TN (μM)	TP (μ M)	TOC (mg L^{-1})	POC (mg L^{-1})	PON (μM)	POP (μ M)
CT	**7.3** 8.4 - 3.8	**22.0** 19.5 - 28.9	**1.2** 1.0 - 1.6	**3.5** 3.6 - 3.3	**0.4** 0.5 - 0.3	**2.8** 4.2 - 2.3	**0.1** 0.2 - 0.1
NFF	**9.2** 8.4 - 6.5	**66.7** 19.5 - 81.7	**2.0** 1.0 - 3.3	**4.2** 3.6 - 4.6	**0.8** 0.5 - 1.2	**6.8** 4.2 - 8.2	**0.2** 0.2 - 0.3
FF	**28.6** 8.4 - 51.4	**128.2** 19.5 - 234.4	**8.5** 1.0 - 17.7	**14.9** 3.6 - 27.5	**9.6** 0.5 - 19.4	**60.2** 4.2 - 102.5	**1.8** 0.2 - 3.9

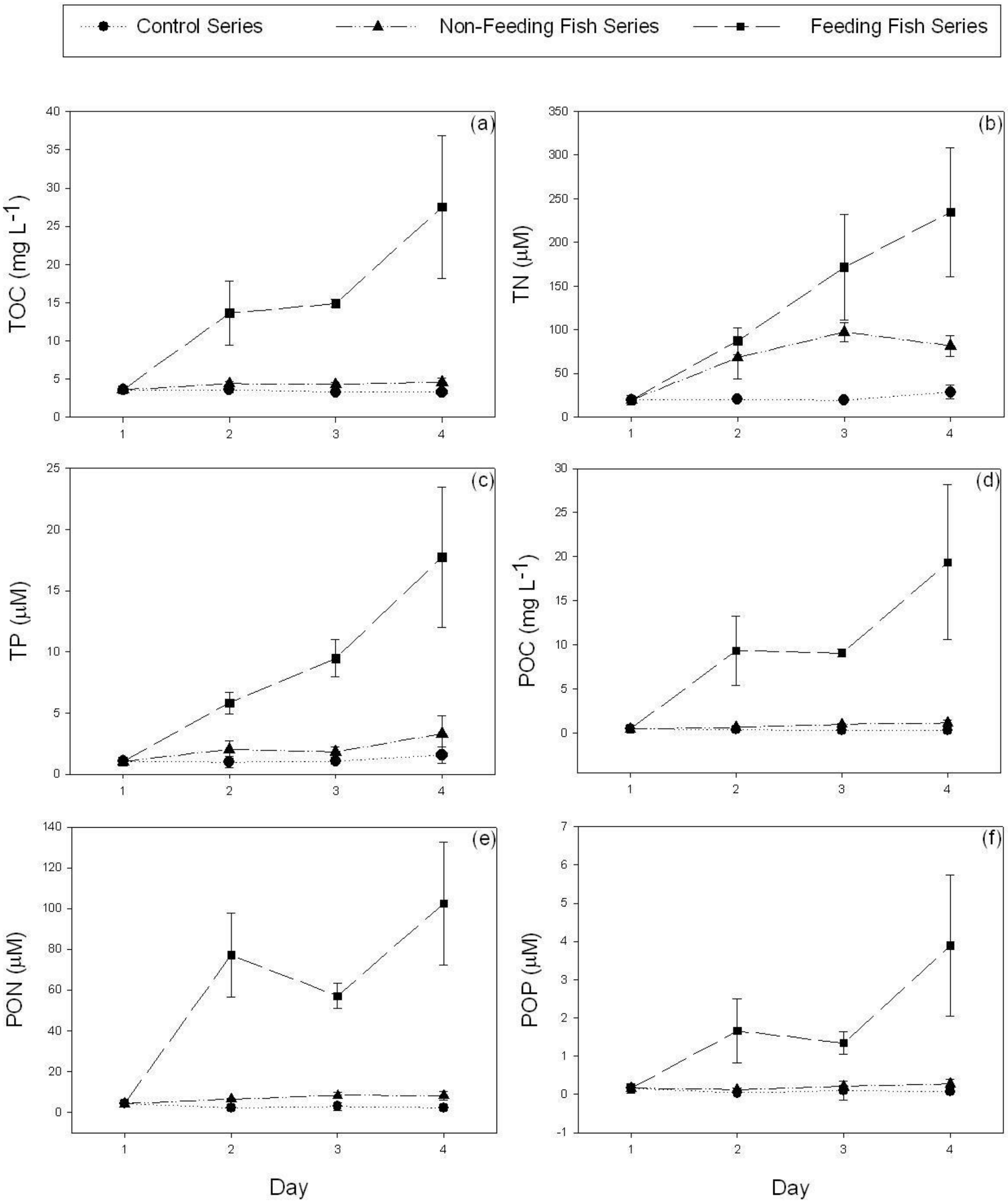

Figure 4. Nutrient concentrations from Control (*CT*), Non-Feeding Fish (*NFF*) and Feeding Fish (*FF*) tanks: (a) TOC, (b) TN, (c) TP, (d) POC, (e) PON and (f) POP, during the experiment period.

Table 3. Average, first and last day of the Dissolved Organic Carbon (DOC), Dissolved Inorganic Nitrogen (DIN), Ammonium (NH_4^+), Nitrate (NO_3^-), Nitrite (NO_2^-) and Orthophosphate (PO_4^{3-}) concentrations, measured during the experiment.

Series	DOC (mg L-1)	DIN (μM)	NH_4^+ (μM)	NO_3^- (μ M)	NO_2^- (μM)	PO_4^{3-} (μM)
CT	**3.1** 3.1 - 3.0	**6.5** 7.3 - 8.2	**5.6** 6.7 - 7.4	**0.4** 0.5 - 0.5	**0.2** 0.1 - 0.3	**0.6** 0.5 - 1.0
NFF	**3.5** 3.1 - 3.5	**37.0** 7.3 - 52.2	**35.4** 6.7 - 50.4	**0.5** 0.5 - 0.4	**0.8** 0.1 - 1.8	**0.9** 0.5 - 1.6
FF	**5.4** 3.1 - 8.1	**57.6** 7.3 - 89.9	**56.8** 6.7 - 88.0	**0.3** 0.5 - 0.6	**0.6** 0.1 - 1.3	**2.7** 0.5 - 5.6

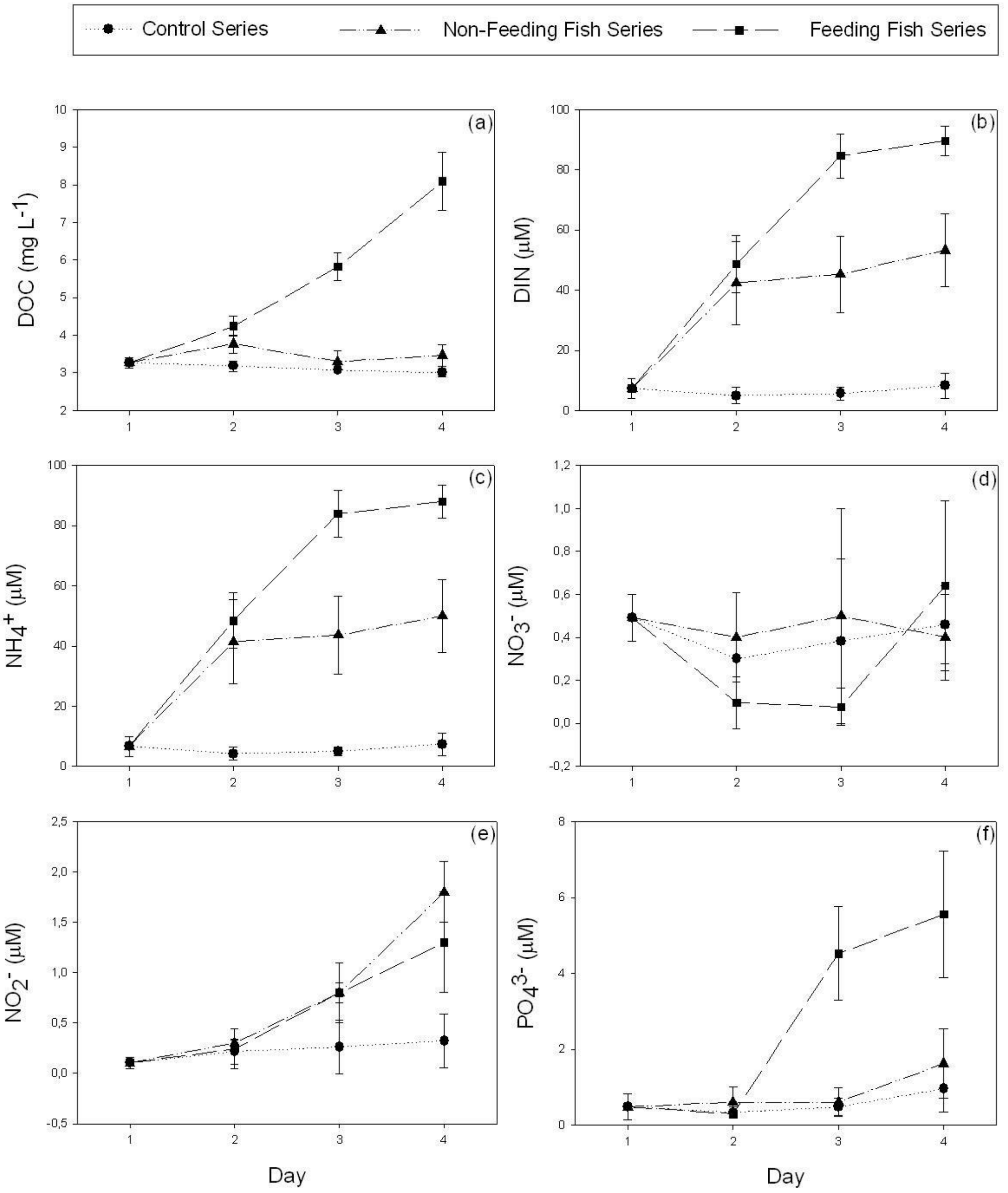

Figure 5. Dissolved nutrient concentrations from Control (*CT*), Non-Feeding Fish (*NFF*) and Feeding Fish (*FF*) tanks: (a) DOC, (b) DIN, (c) NH_4^+, (d) NO_3^-, (e) NO_2^- and (f) PO_4^{3-}, during the experiment period.

Table 4. Statistical analyses showing the significance of the treatment effect, the time effect, and the effect of the interaction of the factors (*p*-values).

Test of significance
Treatment effect
Lambda = 0.083
F -ratio = 4.634
p -value = 0.0001
Time effect
Lambda = 0.689
F -ratio = 38.680
p -value = 0.0001
Treatment and Time interaction effect
Lambda = 0.068
F -ratio = 1.897
p -value = 0.01

According to the statistical analysis applied, the results revealed significant differences (p = 0.0001) among the three treatments (*CT*, *NFF* and *FF*) and the three times (Days 2, 3 and 4). An interaction between the two factors (p = 0.01) was also recognized (Table 4). These differences can be showed in the PCA (Principal Components Analysis) plot (Figure 6), in which a clear separation of the treatments is observed (Figure 6). In this analysis, the first and the second axis together explained 78% of the variance. The FF samples, with the highest Seston, TN, TP, TOC, POC, PON, POP, DIN and NH_4^+ concentrations and the lowest pH and DO values, were plotted on the right side of the abscissa axis. The *CT*, with the opposite pattern (in general, with the highest pH and DO values and the lowest nutrients concentrations), was negatively correlated with *FF* samples. The *CT* samples were plotted at the left side of the same axis, and this pattern was resultant of the influence of fish feed residues in the tanks. The *NFF*, with intermediate nutrient concentrations, were plotted in the second axis and was associated with NO_3^-, temperature and salinity.

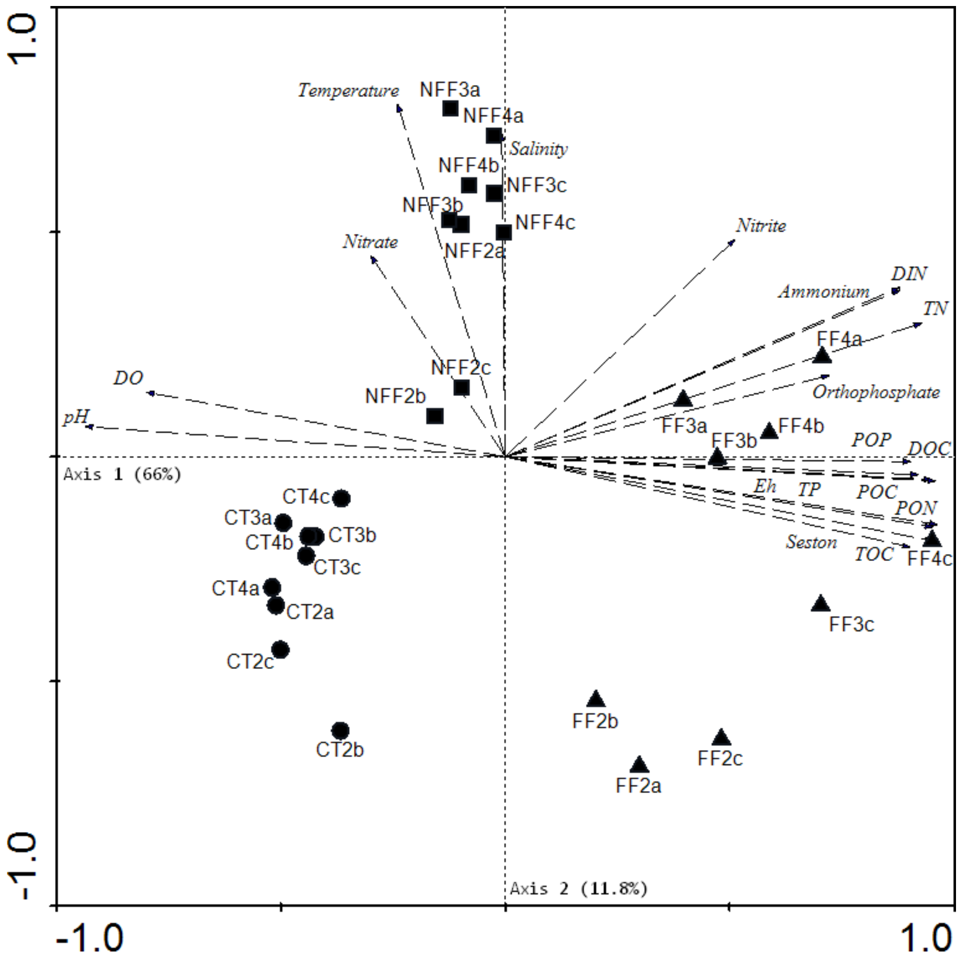

Figure 6. Graphical representation of the factorial plan of the first and second axes of the Principal Components Analysis (PCA) of the data from experiment tanks; black circles (Control Series), black squares (Non-Feeding Fish Series) and black triangles (Feeding Fish Series).

Discussion

Physical-Chemical Characteristics

The results obtained from the three series (*CT*, *NFF* and *FF*) showed that presence of fish, being fed or not, can influence significantly the water quality of the tanks. The *FF* series was marked by the strongest variations of physical-chemical parameters through the experiment. The fish feed introduction led to significant continuous decreases in the pH and DO concentrations, which is related to the intensification of bacterial activity in tanks. Negative significant correlations ($p < 0.05$) between Eh, and both pH and DO corroborate this assumption. Previous studies evidenced water quality deterioration due to aquaculture (Qian, Wu & Ni, 2001).

The fish excreta accumulation in tanks and bacterial mineralization of organic matter from fish feed was associated with increases of DIN and orthophosphate concentrations through time. It is important to emphasize that temporal variations of DIN concentrations in NFF and FF tanks were mainly controlled by NH_4^+ increase since it appears as the main species. Similarly, the Eh, DO and pH temporal patterns in these treatments indicate that they became more and more reduced through the days. This explains the prevalence of the reduced form of mineralized inorganic nitrogen (NH_4^+) in these tanks. High concentrations of NH_4^+ related to fish metabolism and organic matter mineralization were reported in other experiments with tanks (Avnimelech & Kochba, 2009). In some cases, the NH_4^+ may represent 90% of N excreted by fish (Islam, 2005). The NH_4^+ concentrations were very higher in *FF* and *NFF* tanks (98% and 93% of DIN) demonstrating that the fish feces also contribute to the NH_4^+ enrichment in the environment.

The increase of particulate matter and also POC, PON and POP concentrations only in the *FF* treatment was associated with fish feed leftovers. Each day, more residues were deposited inside these tanks, explaining the continuous augmentations in seston through time. Other authors reported that more than half of total nitrogen and total phosphorus contents in fish feed are released into the environment (Hall, Holby, Kollberg & Samuelsson, 1992; Merceron et al., 2002). For nitrogen, approximately 70-90% of the loss to the environment occurs in dissolved form, which is related to fish excreta and organic matter remineralization (Piedrahita, 2003). Our results showed that 53% of nitrogen released in the *FF* series was in the dissolved form. On the other hand, only a smaller amount of phosphorus is lost in dissolved form. Enell (1995) estimated that 30-80% of losses of phosphorous to the environment occurs in particulate form and accumulates in sediments. Our experiment showed that only 21% of phosphorus released in the waters of the *FF* tanks was in the particulate form. Other studies of salmon and trout cultivation showed that 50% of nitrogen and 28% of phosphorus from fish feed are also released in dissolved forms. Thus, improvements in quality and composition of fish feed could reduce substantially the amount of nutrients discharged into the environment, and consequently lead to decreases in environmental impacts generated by the activity. In synthesis, fish feed has a great potential to pollute aquaculture environments.

N and P Loads and Potential of Eutrophication of the Tilapia Culture

As seen above, fish feed is strongly related to increases in N and P loads in the tanks, and consequently may affect surrounding waters of the estuarine systems. Taking into account this polluting potential, and based on data obtained in the experiment, nutrient loads from the tilapia culture in ESTBIA were estimated. The calculations allowed to distinguish the direct contributions of fish (*NFF*) from fish feed (*FF*) to the aquatic environment. Considering the average nutrient concentrations in the *NFF* tanks (694 $\mu g\ L^{-1}$ for TN and of 35 $\mu g\ L^{-1}$ for TP and 438 $\mu g\ L^{-1}$ for NH_4^+), each fish would contribute daily with an amount of 0.06 g of TN, 0.003 g of TP and 0.04 g of NH_4^+ (Table 5). According to data provided by local fish farmers, the annual mean production of tilapia in the ESTBIA estuarine area in 2011 was about 260 tons. In that case, the nutrients loads would be 20 tons $year^{-1}$ of TN, 1 ton $year^{-1}$ of TP, and 13 ton $year^{-1}$ of NH_4^+ (Table 5). In a similar way, if we take the average concentrations of fish feed contribution based on FF tanks (1226 $\mu g\ L^{-1}$ of TN, 282 $\mu g\ L^{-1}$ of TP and 380 $\mu g\ L^{-1}$ of NH_4^+), the each daily fish feeding would be 0.11 g d^{-1} of TN, 0.03 g d^{-1} of TP and 0.03 g d^{-1} of NH_4^+. For the mentioned annual fish production (260 tons), fish feed would be responsible for annual loads of 35 tons of TN, 8 tons of TP and 11 tons of NH_4^+ (Table 5).

Based on these calculations, the total annual nutrient loads for the "Baixo Sul Baiano" estuarine area would be 55 tons of TN and 9 tons of TP (Table 5). In this case, the fish feed would be responsible for 64% of nitrogen load, and for approximately 90% of total phosphorus input by the tilapia culture. According to Islam (2005), for a production of 1000 tons of fish in cage aquaculture, the estimated total annual loads released into the environment would be 133 tons of N and 25 tons of P. Karakassis, Hatziyanni, Tsapakis & Plaiti (1999) reported loads of N and P of 120 and 20 tons in the Mediterranean for every thousand tons of fish produced. Similarly, loads of N and P to 1000 tons of fish produced were estimated in 97.9 tons of N and 18.6 tons of phosphorus and 19 to 22 tons of P for an experiment in tanks (Holby & Hall, 1991; Merceron et al., 2002). Our results tended to be higher since if we extrapolate from an annual production of 1000 tons, the loads of N and P to the environment would be 212 and 35 tons respectively. It must be emphasized that these loads related to input of nutrients from fish feed could vary substantially depending on its type. As observed for other areas, our results suggest that environmental sustainability of the tilapia culture in the ESTBIA depends on nutritional aspects. Therefore, the diets that are better assimilated by the fish could lead to lower losses of nutrients to the environment.

Table 5. N and P loads from tilapia culture estimated for the ESTBIA estuarine area.

		TN	*TP*	*NH_4^+*
Fish Contribution (NFF)	Mean concentration in Tanks (μg L^{-1})	694	35	438
	g / day / fish	0.06	0.003	0.04
	ton / year in the Estuary	20	1	13
Fish food Contribution (FF)	Mean concentration in Tanks (μg L^{-1})	1226	282	380
	g / day / fish	0.11	0.03	0.03
	ton / year in the Estuary	35	8	11
Total Load for the Estuary	(ton/year)	55	9	24

Conclusions

The monitoring of physic-chemical parameters measured in experiment tanks revealed that the presence of fish, fed or not, can alter substantially the water quality of the environment. However, the worst effects were recorded in the presence of feed in tanks.

The estimate of potential N and P loads into the environment from the tilapia culture to waters of ESTBIA, with a production of 260 tons of tilapia per year, would be about 55 tons for nitrogen and 9 tons for phosphorus. About 64% of the nitrogen and 90% of the total phosphorus lost to the environment comes from the fish feed. These values tend to be higher than others reported in the literature, especially for nitrogen.

The data of this study indicate that the pollution potential of this activity is mainly related to feeding processes. In this way, management strategies that minimize food losses would be environmental and economically interesting.

Acknowledgements

Helpful assistance from Dr. Marcelo Correa Bernardes, is much appreciated. We also thank Dr. Cassiano Monteiro Neto for his comments, which led to significant improvements in this paper.

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