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Influence of Nile tilapia (*Oreochromis niloticus*) fish farming in net cages on the nutrient and particulate matter sedimentation rates in Umari reservoir, Brazilian semi-arid

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ABSTRACT

This study evaluated the sedimentation rates of nutrients and particulate matter in Nile tilapia (*Oreochromis niloticus*) net cage farming in the Umari, Brazilian semi-arid reservoir. Sedimentation chambers were installed under net cages which had stocking of 125 and 100 fish m^{-3} (experimental sites). The natural sedimentation rate of the reservoir (control site) was calculated using a sedimentation chamber installed three meters deep and about 200 m upstream from the net cages. Samples from all chambers were taken after 24 h of installation, at each sampling site. The average sedimentation rates for particulate matter, ammonia, total nitrogen, total phosphorus, total organic carbon, nitrite, nitrate and total inorganic carbon in both experimental and control sites were 8.31, 6.61, and 0.083 mg cm^{-2} day^{-1}; 60.82, 46.18, and 9.45 µg cm^{-2} day^{-1}; 0.14, 0.11, and 0.04 mg cm^{-2} day^{-1}; 189.42, 186.59, and 7.72 µg cm^{-2} day^{-1}; 1.99, 1.58, and 0.57 mg cm^{-2} day^{-1}; 0.35, 0.24 and 0.04 µg cm^{-2} day^{-1}; 6.84, 7.11 and 5.04 µg cm^{-2} day^{-1}; and 0.18, 0.18 and 0.18 mg cm^{-2} day^{-1} respectively. The sedimentation rates in the experimental sites were significantly higher than those in the control site. The fish farming activity in net cages elevates the sedimentation rates of nutrients and particulate matter in this reservoir and could accelerate the eutrophication process, thereby hindering the fish farming activity itself.

1. Introduction

The aquaculture activity in Brazilian reservoirs has expanded with the use of net cages in the Southeastern and Northeastern regions. The Nile tilapia, *Oreochromis niloticus,* is the main fish species farmed in Brazil, predominantly in net cages within freshwater reservoirs (Roriz et al., 2017). Regardless that aquaculture activities conducted in public reservoirs frequently favors local and regional economies, the practice of aquaculture in dammed natural watercourses and reservoirs leads to a series of impacts that can compromise the environment (Agostinho et al., 2016; Lima et al., 2016). Hence, fish production activities in net cages can result in harmful environmental changes in water bodies (Azevedo-Santos et al., 2011; Pelicice et al., 2015).

The impacts caused on aquatic environments from the fish farming activity using net cages can lead to loss of biodiversity, through introduction of exotic species, and changes in the trophic web. This activity generates residues that become food sources for the local biota (Brandão et al., 2012; Ortega et al., 2015) and increased concentration of nutrients that can alter the natural conditions of aquatic ecosystems (Azevedo et al., 2011; Zhou et al., 2011; Venturoti et al., 2015). The wastes from fish farming are released directly into the environment as excreta and unconsumed ration, increasing the levels of organic residues in the natural environment (Gunkel et al., 2015). Such residues can cause problems due to the high sedimentation load of total dissolved solids and nutrients such as nitrogen and phosphorus. These factors are critical to the advancement and maintenance of the fish farming activity in continental waters because the excessive release of residues to the aquatic environment can cause abnormal eutrophication and conflicting uses of these ecosystems (Degefu et al., 2011; Moura et al., 2014; David et al., 2015).

Several of these impacts have been observed in intensive fish farming carried out in net cages in Brazilian reservoirs (Lima et al., 2018; Gunkel et al., 2015; Venturoti et al., 2015). These impacts may be even more damaging in semi-arid reservoirs because arid and semi-arid regions are characterized by high temperatures, water scarcity, and unpredictable and disproportionate rainfall distribution (Costa da et al.,

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2016). Reservoirs in these regions are subjected to a decrease in water volume during the dry season favoring nutrients accumulation (Câmara et al., 2009). The water supply in this region is problematic as the result of rainfall irregularity; the decreased water volume during prolonged droughts contributes to a decline in water quality as the result of high algae biomass production and high turbidity (Braga et al., 2015).

It is important to emphasize that studies that evaluate the changes caused by aquaculture activities are essential to identify alterations in the structure and functioning of reservoirs as well as to identify ways to mitigate the negative impacts that arise from the multiple uses of an ecosystem. Furthermore, these studies contribute to the establishment of management strategies for the rational use of water and environment conservation. Hence, this study evaluated the sedimentation rate of nutrients and particulate matter in Nile tilapia (*O. niloticus*) fish farming in net cages conducted in the Umari reservoir in the Brazilian semi-arid region of the Rio Grande do Norte State.

2. Material and methods

The evaluated tilapia fish farming system was managed by the aquaculture cooperative of the Umari reservoir located in the Apodi/Mossoró River basin in the semi-arid region of the Rio Grande do Norte State – Brazil (5°42′13″S and 37°15′18″W). This cooperative was founded in 2011 and included 13 entrepreneur members who jointly produce tilapia in net cages. Each member operates 37 production units, totaling 481 net cages of six m^3. This fish farming cooperative annually produces approximately 281 tons of Nile tilapia; the final product is represented in the sale of whole fish (98%) and eviscerated fish (2%), ranging from 350 g to 10 kg of individual weight (average) depending on the buyer. The reservoir area is 2922.67 ha with a maximum capacity of 292,813.650 m^3 of water; at about 40% of the volume the mean depth of the reservoir was 818 m, with a maximum depth of 2701 m and water residence time of 13,295 days (Moura et al., 2015). According to the Köppen climate classification, the local climate is of the BSw'h' type, characterized by very hot and semi-arid climate with a rainy season in late autumn (Fig. 1). Rainfall during the study period in the Umari reservoir was 187 mm.

Eight six m^3 net cages (2 × 2 × 1.5 m) were monitored during the fattening period of Nile tilapia (*O. niloticus*) cultivation; four cages with a density of 125 fish m^{-3} (high stocking density treatment) and four with a density of 100 fish m^{-3} (low stocking density treatment), thus with 750 and 600 fish cage^{-1}, respectively. The fish farming region was at an average depth of seven meters. Nile tilapia juveniles of about 118 g (± 5 g) of average individual weight were used to populate each cage. The commercial feed offered contained 32% crude protein and 0.6% phosphorus, with 4–6 mm. The ration was offered twice a day in the amount related to the stocked biomass, with adjustments made in a weekly interval, according to changes in fish biomass. The initial feeding rate was 4.5% of the stocked biomass. This amount decreased weekly, reaching 3.1% of the stocked biomass at the end of the experiment. To estimate the biomass in each cage and the individual average fish weight a sample of 10% fish population were weighed weekly and the mean weight calculated. The biomass values were calculated, multiplying the individual average weight by the estimated total number of fish in each cage (fish deaths monitored daily).

The particulate matter generated during the experiment was measured in samples collected in sedimentation chambers installed under all studied net cages. Each sedimentation chamber consisted of six open top and closed bottom cylinders. Sedimentation chamber collectors were installed at 1.5 m depth under four net cages (three meters deep in total) with the high stocking density and under another four cages with the low stocking density (experimental sites). Samples were collected monthly, from November of 2015 to January of 2016, by rescuing collectors that had been submerged for 24 h. The natural sedimentation rate (control site, without cages) of the reservoir was calculated using three sedimentation chambers installed three meters deep (same depth was used in the control site) and about 200 m upstream from the experimental sites.

Before each sampling time, chambers were filled with distilled water to prevent interference from material previously sampled. The concentrations of ammonia, nitrate, and nitrite (Mackereth et al., 1978); total nitrogen (Koroleff, 1976); total phosphorus (Golterman et al., 1978); total organic carbon; and total inorganic carbon (oxidation on catalytic combustion using a VARIO-TOC Carbon Analyzer, high-temperature combustion method) were measured in the sedimented material from the net cages (experimental sites) or from water collum (control site). Water parameters were measured from integrated samples of the water column using a van Dorn bottle in each site; the parameters were pH, dissolved oxygen (mg/L) and temperature (°C) using a multiparameter (HORIBA Water Quality Checker).

The calculations of sedimentation rates were performed using the gravimetric method (Wetzel and Likens, 2000). A known volume of samples was filtered using filters previously dried and weighed (M1). Filters containing particulate matter were dried in an oven at 60 °C for 24 h, cooled, and weighed (M2). Subsequently, these filters were incinerated in a muffle at 480 °C for 60 min, cooled, and weighed (M3). The mass differences between M1 and M2; M1 and M3; and M2 and M3 provided the mass (in grams) of total suspended materials, inorganic and organic. The sedimentation rate corresponded to the concentration of material in the filtered sample corrected by the mean volume of sedimentation chambers. Therefore, the concentration of suspended matter was estimated by the equation $C = ((M2 - M1)/Vf) \times 1000 \times 1000$, and expressed in mg L^{-1}. The sedimentation rate was determined by the following formula: $TS = (Vc \times C)/(Ac \times T)$, wherein: Vc = volume of sedimentation chambers (2.36 L); Vf = filtered volume (mL); C = concentration of material in suspension inside the chambers (mg L^{-1}); Ac = area of the surface opening in the sedimentation chamber (78.54 cm^2); and T = time in days. The sedimentation rate was expressed in mg cm–^{2} day^{-1}.

The identification of significant differences in the sedimentation rates of particulate matter, ammonia, nitrate, nitrite, total nitrogen, total phosphorus, total inorganic carbon, and total organic carbon between the experimental sites and the control site was conducted through the Kruskal–Wallis test with a p-value correction according to the Bonferroni test for non-parametric data, both at 5% probability. The statistical assumptions of normality and homoscedasticity were evaluated with the Shapiro-Wilk and Bartlett tests, respectively, at 5% probability, and both conditions were rejected ($p < 0.05$). Spearman's correlation tests ($p < 0.05$) between fish biomass and sedimentation rates of particulate matter, total nitrogen, and total phosphorus during the 63 experimental days were applied. All statistical analyses were performed using the R Software v3.0.1 (R Core Team, 2013).

3. Results

The survival rate of Nile tilapia at the end of the experimental period was 90%, and the apparent feed conversion was 1.5 in both stocking densities. The average biomass per net cage was 150.5 kg (the individual average weight was 316.9 g) and 136.4 kg (the individual average weight was 358.8 g) after 63 days of fattening in the high and low stocking densities, respectively (Tables 1 and 2). The biomass increased throughout the experimental period (63 days) and consequently, the amount of offered ration increased in both cage densities (Table 3). Average values of water temperature ranging from 28.5 to 29.5 °C, 6.9–8.5 pH, and 4.4 to 5.7 mg L^{-1} of dissolved oxygen (Table 4).

The sedimentation load of particulate matter and nutrients did not present significant differences between the experimental sites. However, significant differences were observed in some of these analyzed variables between the experimental and control sites. The control site showed a relatively stable sedimentation load throughout the experiment, with an average of 1.30 mg cm^{-2} day^{-1} in the first 35 days,

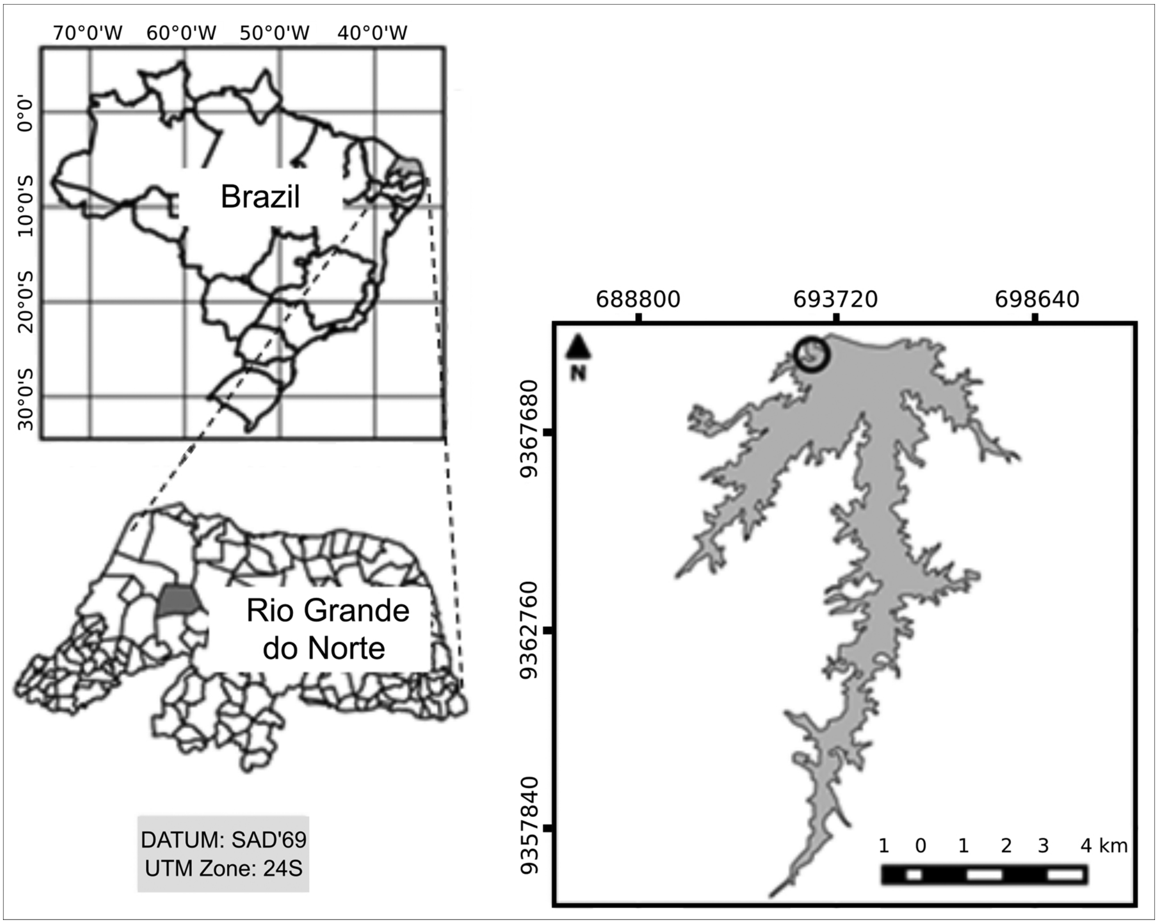

Fig. 1. The Umari reservoir location in Upanema, Rio Grande do Norte, Brazil (5° 38′31″S and 37° 15′28″W) with emphasis on the location of tilapia production in net cages.

Table 1
Average values and standard deviation of survival, initial weight, final weight, apparent feed conversion, and biomass per net cage in different stocking densities.

Parameters	Stocking densities High density	Low density
Survival (%)	90 ± 5	90 ± 5
Initial weight (g)	118.5 ± 5	118.5 ± 5
Final weight (g)	316.9 ± 18.7	358.8 ± 25.7
Apparent feed conversion	1.5 ± 0.1	1.5 ± 0.2
Net cage biomass (kg)	150.5 ± 4.2	136.4 ± 3.7

Table 2
Average values and standard deviation of biomass gain in Nile tilapia fish farming at different stocking densities.

Days	Average weight by net cage (g)	
Stocking density	High density	Low density
1	118.5 ± 5.0	118.5 ± 5.0
35	219.5 ± 12.7	242.1 ± 15.7
63	316.9 ± 18.7	358.8 ± 25.7

Table 3
Average values and standard deviation of biomass and the amount of ration offered daily in Nile tilapia fish farming in net cages.

Days	Biomass net cage^{-1} (kg)		Ration amount offered Net cage^{-1} day^{-1} (kg)	
Stocking density	High density	Low density	High density	Low density
1	59.2 ± 0.1	47.4 ± 0.08	2.2	2.1
35	104.3 ± 2.3	92.0 ± 2.2	3.7	3.3
63	150.5 ± 4.2	136.4 ± 3.7	4.7	4.2

decreasing to a 0.92 mg cm^{-2} day^{-1} average rate at the end of the experiment. The rate of sedimentation load of particulate matter increased throughout the experiment, reaching an average of 9.72 (high density) and 8.74 mg cm^{-2} day^{-1} (low density) by the end of the experiment (Fig. 2A).

The ammonia sedimentation showed an increasing trend during the experiment; the highest values reached on day 63 were 123.43 and 100.88 µg cm^{-2} day^{-1} in the experimental sites with high and low densities, respectively. This ammonia sedimentation rate was already higher than that in the control site after 35 days of the experiment (18.02 µg cm^{-2} day^{-1} for control site) (Fig. 2B). The nitrite sedimentation rate showed similar values between the site with cages at low density and the control site; however, the site with the high density showed significantly higher values compared to the control. At the end of the experiment (63 days), significantly higher average values were observed in both experimental sites (0.72 µg cm^{-2} day^{-1} in high-density cages and 0.51 µg cm^{-2} day^{-1} in the low-density cages) compared to the values observed in the control site (0.06 µg cm^{-2} day^{-1}, Fig. 2C). At the beginning of the experiment, the nitrate sedimentation showed higher values in both experimental sites compared to the control site. At the end of the experiment, the nitrate sedimentation rates were 5.62 (high density), 6.21 (low density), and 6.18 µg cm^{-2} day^{-1} (control),

Table 4
Average values and standard deviation of limnological variables in the studied experimental and control sites.

Days	Temperature (°C)			pH			Dissolved oxygen (mg L^{-1})		
	High density	Low density	Control	High density	Low density	Control	High density	Low density	Control
1	28.6 ± 0.07	28.5 ± 0.12	28.7 ± 0.10	7.7 ± 0.29	7.7 ± 0.38	8.5 ± 0.31	4.9 ± 0.17	5.7 ± 0.68	5.7 ± 0.61
35	28.8 ± 0.41	29.1 ± 0.23	29.0 ± 0.15	6.9 ± 0.41	6.9 ± 0.34	7.3 ± 0.20	4.4 ± 0.08	4.4 ± 0.17	4.6 ± 0.61
63	29.1 ± 0.50	29.2 ± 0.14	29.5 ± 0.07	7.2 ± 0.29	7.2 ± 0.31	7.6 ± 0.25	5.0 ± 1.41	4.5 ± 1.06	5.3 ± 0.61

presenting no significant differences between sites (Fig. 2D).

The rates of total nitrogen sedimentation were significantly higher in the experimental sites compared to the control site. This sedimentation rate presented increasing values during the experiment in both experimental sites. At the end of the experiment, the total nitrogen sedimentation was 0.25 (high density) and 0.18 mg cm^{-2} day^{-1} (low density); the control site presented an average value of 0.05 mg cm^{-2} day^{-1}, behaving practically constant during the experiment (Fig. 2E). The rates of total phosphorus sedimentation were also significantly higher in the experimental sites than control site throughout the experimental period; the sedimentation load was 313.36 (high density) and 317.10 μg cm^{-2} day^{-1} (low density). The phosphorus sedimentation in the control site was relatively stable throughout the experiment with a maximum average value of 10.74 μg cm^{-2} day^{-1} after 35 days of the experiment (Fig. 2F).

The total organic carbon sedimentation rate (TOC) presented increasing values throughout the experiment in the experimental sites, reaching the maximum values at the end of 63 days of 3.06 (high density) and 2.34 mg cm^{-2} day^{-1} (low density). The TOC sedimentation rates were lower and stable in the control site throughout the experiment, with a maximum average value of 0.61 mg cm^{-2} day^{-1} in the first 35 days (Fig. 2G). The total inorganic carbon sedimentation rate (TIC) showed an increasing tendency throughout the experiment, peaking after 63 days, however, with the same average loads of 0.21 mg cm^{-2} day^{-1} in both densities, and 0.20 mg cm^{-2} day^{-1} in control. No significant differences were observed between the experimental sites and the control site (Fig. 2H).

There was a positive strong correlation between the tilapia biomass gain and particulate matter sedimentation rates ($r = 0.79$), total nitrogen ($r = 0.93$), and total phosphorus ($r = 0.92$). The other variables presented weak correlations with the biomass gain. (Fig. 3).

4. Discussion

Cage fish farming activity has affected the sedimentation rates of nutrients and particulate matter at both experimental sites. Pillay (2004) stated that up to 30% of the ration offered in a fish farming system ends in the aquatic environment in the form of unconsumed feed or excreta. Thus, the amount of fecal material and unconsumed feed is the main reason of the increased sedimentation in sites near cage fish farming activities in reservoirs. Moura et al. (2014) found that the values of the sedimentation of particulate matter are 6.13 mg cm^{-2} day^{-1} below net cages and 0.33 mg cm^{-2} day^{-1} in regions away from the fish farming region. His results corroborate the current results, showing average sedimentation rates of particulate matter of 7.7, 6.6, and 0.8 mg cm^{-2} day^{-1} for high density, low density and control sites, respectively.

There was a similar gradual increase in the sedimentation load of ammonia and nitrite during the experimental period in both experimental sites. The sedimentation loads of ammonia were higher than those of nitrate, possibly indicating a slow nitrification process. The opposite pattern was observed by Moura et al. (2014), reporting ammonia levels lower than nitrate at sites of tilapia farming in net cages in a tropical reservoir close to the reservoir studied in the present work. In the current study, the control site had lower ammonia levels and higher nitrate levels than the experimental sites, indicating that the nitrogen cycle in the fish farming region is different from the natural reservoir cycle. Therefore, the bacterial community is probably supporting the reduction of N-ammonia (decreasing levels) in N-nitrate (raising levels) with more intensity in the control site than the fish farming region.

The sedimentation of total nitrogen presented a gradual increase throughout the experiment in both experimental sites. This increasing sedimentation rate is mainly due to the increasing biomass of tilapia stocked in the net cages and a consequent increase in the level of artificial feed offered during the cultivation. The control region showed stable N-total values during the experiment, emphasize that the total nitrogen sedimentation in the fish farming area of the Umari reservoir was influenced by fish production in cages. Degefu et al. (2011) studied the influence of net cage fish farming on the water quality of an Ethiopian reservoir. They observed an increase in nitrogen concentration and a decrease in oxygen concentration, which confirm the influence of this activity on the reservoir's biotic characteristics. It is important to emphasize that temperatures between 28 and 31 °C promote an increase in inefficiency in the use of nutrients. In these conditions, the animal's metabolism tends to accelerate; fewer compounds are metabolized and, consequently, are lost to the environment (Guo and Li, 2003). In the present study, the water temperature ranged from 28 to 29 °C, which may have favored the increment of sedimentation rates in the studied nutrients.

The increase in the rate of total phosphorus sedimentation in fish farming sites was related to the biomass gain and, consequently, to the increase in the offered food. Moura et al. (2014) observed a similar effect by noting that emissions from net cages raise the levels of P-total sedimentation in a fish farming area to higher values compared to those in regions far from these production sites. Ferraris et al. (2006) found that a large part of phosphorus present in effluents from aquaculture activities comes from the feed; phosphorus is added in excess in rations to ensure availability for the fish (Beveridge, 2004). In other temperate and tropical aquatic environments, the presence of aquaculture activities also increases the sedimentation of phosphate compounds onsite and in the surrounding areas (Yiyong et al., 2001; An and Kim, 2003; Guo and Li, 2003; Azevedo et al., 2004). In the present study, we observed an increase in the sedimentation rates of P-total. However, this increment was restricted to the fish farming site and was not observed in the sedimentation rates of nutrients and particulate matter in the control site, probably due to the distance between the two areas and the upstream position of the control site.

The results demonstrate that the main source of organic carbon in the reservoir is the waste from the net cages, represented by leftover feed and fish excreta, raising the organic matter content in the system, and consequently, contributing to high total organic carbon sedimentation rates. The fish farming activity did not influence total inorganic carbon sedimentation rates because the content of inorganic carbon is small in emissions from fish farming activities (Moura et al., 2014). The correlation results demonstrate that these high sedimentation rates were mainly due to the contribution of suspended solids, and consequently organic matter, due to the increase in fish biomass produced in the net cages and the increasing amount of feed during the experimental period. In general, high intensification systems such as net cages has a negative impact on water characteristics in tropical reservoirs, mainly because of the high stock density and high artificial feed used (David et al., 2018).

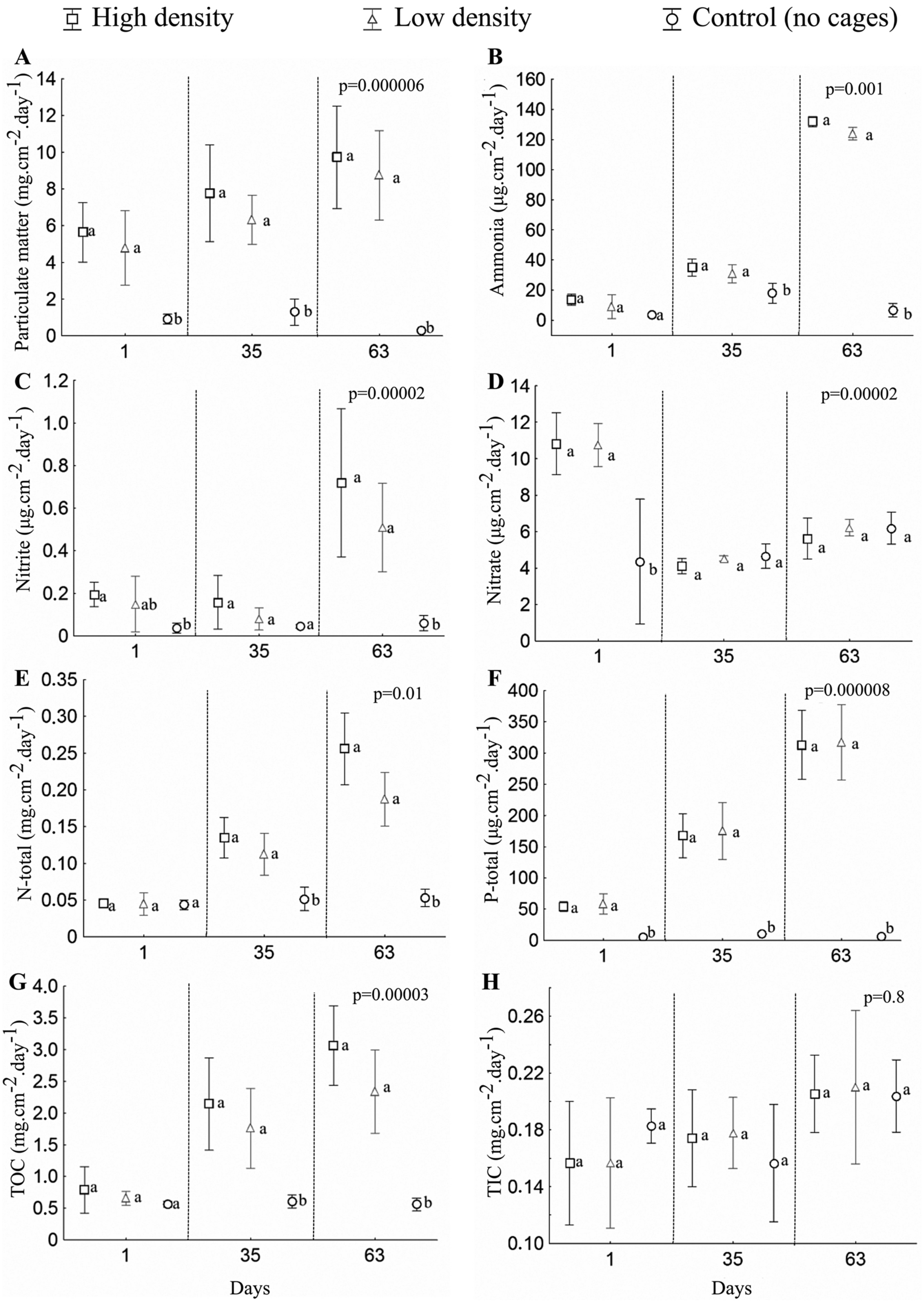

Fig. 2. Average values and standard deviations of sedimentation rates: (A) particulate matter; (B) ammonia; (C) nitrite; (D) nitrate; (E) total nitrogen; (F) total phosphorus; (G) total organic carbon (TOC); and (H) total inorganic carbon (TIC). Different letters represent significant differences between treatments according to the Kruskal–Wallis non-parametric test.

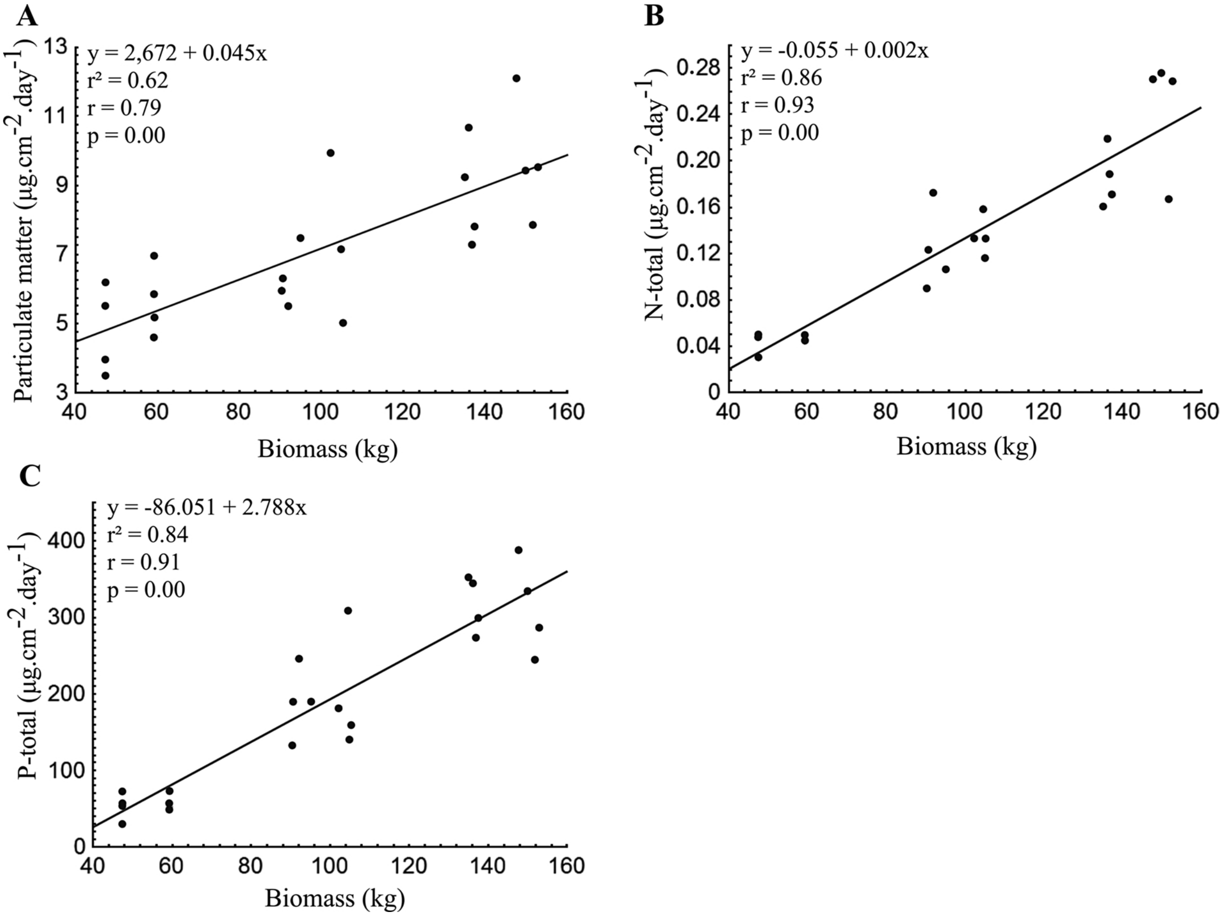

Fig. 3. Regression between the tilapia biomass and particulate material sedimentation rates (A); total nitrogen (N-total) (B); and total phosphorus (P-total) (C).

It is important to emphasize that the main problem with the use of net cage fish farming is that these systems are open production models that do not allow effluent treatment. David et al. (2015) evaluated the impacts on the aquatic environment of Nile tilapia fish farming in net cages in a Southeastern Brazilian reservoir. He observed that the impacts were mainly caused by the release of nutrients that affect the quality of water and generate conflicts in the multiple uses of that water body, including the negative effects on the fish farming activity itself. This activity can also affect the bioaccumulation of phosphorus in the sediment, which hinders the development of fish farming in continental waters. The excessive release of this nutrient to the aquatic environment can lead to eutrophication problems and, consequently, to a range of conflicts related to the use of affected ecosystems. Furthermore, the sedimented material resulting from fish farming practices is responsible for a reduction in oxygen levels in the water and can compromise the sustainability of this aquaculture activity (Degefu et al., 2011; Moura et al., 2016).

The control of the amount of residues eliminated in the environment by fish farming in cages could possibly be achieved through a management planning that could stimulate the consumption of natural food, as periphyton (Garcia et al., 2016), and thus decreasing the amount of artificial feed used, without compromising the production. Tilapia grown in net cages with a mixed feeding of artificial feed and natural food (mainly periphyton and phytoplankton) has shown adequate development and indicate that the use of artificial feed can be reduced, in the presence of natural food sources, without decreasing the production level of the system (Garcia et al., 2017). The use of natural food has been shown not only to be suitable but even contributing to the growth of tilapia reared in cages (Sakr et al., 2015), even increasing the profit and production of other fish in different systems (Jha et al., 2018), thus making the activity more economically and environmentally sustainable. In addition, further studies on nutrient utilization, genetic improvement of alevins and functional ingredients that may decrease the dependence on high protein feeds are necessary (Costa-Pierce et al., 2010). Meanwhile, the constant monitoring of water and sedimentation rates in aquaculture areas practiced in reservoirs is important.

5. Conclusions

It can be concluded that the cultivation of tilapia in net cages increased the sedimentation rates of nutrients and particulate matter, as demonstrated by a significant difference in the analyzed variables between the experimental and control sites. The farming activity generates a contribution of particulate material, nitrogen, carbon, and phosphorus, altering the natural conditions of sedimentation rates of nutrients and particulate matter in the reservoir. Nevertheless, we observed that these changes are still punctual in the Umari reservoir, that is, restricted to the area of fish farming in net cages. The natural rates of sedimentation of particulate matter and nutrients only 200 m away from the fish farming site were reduced and stable throughout the experiment regardless of increases in the Nile tilapia biomass and offered artificial feed in the farming site.

CRediT authorship contribution statement

Júlio César da Silva Cacho: Writing - original draft, Data curation, Methodology, Visualization, Investigation, Formal analysis. **Rodrigo Sávio Teixeira de Moura:** Conceptualization, Methodology, Writing - review & editing. **Gustavo Gonzaga Henry-Silva:** Conceptualization, Data curation, Methodology, Supervision, Writing - review & editing, Investigation, Funding acquisition, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aqrep.2020.100358.

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