Assessing the negative impact of an aquaculture farm on effluent water quality in Itacuruba, Pernambuco, Brazilian semiarid region
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ABSTRACT
This study was conducted at a fish farm in Itacuruba, located in the Brazilian semiarid region. Its objective was to quantify the impacts of aquaculture on water quality by comparing effluent and inlet water, particularly in relation to CONAMA Resolution 430 (2011) limits. Regarding the effluent, electrical conductivity, total phosphorus (TP) and total nitrogen presented values above the limits, other parameters complied with the mentioned legislation. During the dry period, the effluent’s TP values were 447% higher than the inlet water and 473% above the Resolution limit. During the wet period, TP concentration in the inlet water increased 1,000% while the effluent exceeded legislation limits by 1,175%. Based on these results, treatment of effluent from fish farms in accordance with legislation prior to its release into the receiving water body is recommended, thereby minimizing eutrophication risk for the local population, guaranteeing food security, reducing impacts to public health and aquatic biota and favoring the sustainability of the enterprise. Due to limited water resources, it is especially necessary to adopt better management practices that minimize the negative impacts of aquaculture activities.

Key words | aquaculture, eutrophication, Sub-Middle São Francisco, water quality

INTRODUCTION
Federal Law 11.959/2009, which deals with the National Policy for the Sustainable Development of Aquaculture and Fisheries, defines aquaculture as an ‘activity for the cultivation of organisms whose life cycle under natural conditions occurs wholly or partly in the aquatic environment, implying ownership of the stock under cultivation, assimilated to agricultural activity […]’ (Brazil 2009).

The availability of manpower and the growing demand of the domestic market are the main reasons to promote aquaculture in the country, which is present in all Brazilian states (Embrapa 2017). This vocation and the market potential created by the aquaculture sector attracts domestic and international investors interested in fish farming as well as several other segments of the production cluster: the production of fingerlings and the fattening of tilapia (primary sector); factories of fish food and ice for processing and manufacture of aquaculture structures (secondary sector); marketing and services (tertiary sector) (Ribeiro et al. 2015), especially fish feed, medicines, vaccines, genetics and equipment (Kubitza 2015).

Brazilian aquaculture produced a total of 574,164 tons of fish in 2015, valued at R$4.4 billion, with the largest share (69.9%) from fish farming, followed by shrimp farming (20.6%) (Carvalho-Filho 2017). According to the Brazilian Institute of Geography and Statistics (IBGE), in 2015 total fish production was 483,241 tons, with annual increases in the North (6.2%), Southeast (12.7%) and South of Brazil (13.1%). In the Northeast and Central West, production decreased by 47% and 19.7%, respectively, due to low rainfall.

The production of tilapia (Oreochromis niloticus), the main aquaculture species cultivated in Brazil, increased on average by 14.2% per year between 2004 and 2014 (Kubitza 2015). Advantages that place it as one of the main...
commercially grown species include fast growth, adaptability to different environments and production systems, acceptance of a wide variety of foods and resistance to diseases and parasitic infections (Cyrino & Conte 2006).

According to the Survey of Municipal Livestock Production 2014 (IBGE 2015), tilapia production already occurs in 1,878 Brazilian municipalities. With potential for production throughout the country, tilapia is restricted by environmental legislation from the Amazon basin.

Attracted by the warm climate and the 820 km² Itaparica Reservoir (formed via construction of the Luiz Gonçaga Hydroelectric Power Plant, operated by the São Francisco Hydroelectric Company – CHESF), companies found in the city of Itacuruba the ideal conditions for aquaculture farms with a production capacity of around 100,000 tons per year (Britto 2013).

Aquaculture is an activity that is affected by climate. The challenges that fish farmers face – particularly water shortage and water excess – are difficult to solve, causing economic losses and reductions in production. In the first case, the death of tons of fish from lack of water can even cause abandonment of the activity. In the second case, excess of water washes the organic matter from slopes and decreases oxygen in the water, and can also be a threat to production.

The municipality of Itacuruba is located in the Brazilian semiarid region, where the rainfall regime is extremely irregular. Despite this, Itacuruba is bathed by the São Francisco river, which provides water of good quality. The river crosses regions with the most diverse natural conditions: the Upper and Lower extremities of the basin present on average rainfall ranging from 1,400 mm to 350 mm per year respectively, while their Middle and Sub-Middle cross areas with a very dry climate like Itacuruba, presenting on average 451 mm per year. The São Francisco River is one of the main rivers in Brazil – its 640,000 km² basin stretches from Minas Gerais, in the wet Southwest of Brazil, to the dry zone in the Northeast with a total length of 3,160 km. Completed in 1988, Itaparica Dam was built for hydroelectric power generation (1,479 MW), and serves multiple uses such as water storage, irrigation, fishery, aquaculture and navigation (Gunkel et al. 2015).

According to the natural resources of the region, the municipality’s agricultural potential has been very limited. For this reason, fish farming is one of the industries that has been gaining strength in the region and can be an important alternative source of income from non-agricultural activities (Condepe & Fidem 2008). Some inland water environments, such as reservoirs, also present potential for net cage farming, due to the availability of a large number of reservoirs, low water velocity in backwater areas where the tanks are installed, water turnover (residence time) and depth (at least one meter above the bottom) (Dias et al. 2012). Fish aquaculture is regarded as a means to improve the economic situation of people affected by the Itaparica Dam construction; however, the implementation of aquaculture techniques such as net cages in the lake or tanks and ponds along the banks leads to severe nutrient input into the reservoir (Gunkel et al. 2015).

Tilapia production has increased very rapidly due to the small volume/high density (SVHD) net cage technology used in reservoirs. These SVHD cages allow a fish yield of 80–250 kg m⁻³ crop⁻¹, with two crops per year (Kubitza 2011) or up to 330 kg m⁻³ crop⁻¹ with three crops per year (Halwart et al. 2007). Alternatively, growth can also occur in ponds, tanks, or raceways, albeit with higher capital costs. The fish yield in naturally managed ponds amounts to 8–10 t ha⁻¹, with a production cycle of 1 year, but with high flow-through rates and artificial aeration it can be increased to 60–80 t ha⁻¹ crop⁻¹ (Kubitza 2011).

Cage culture of fish has advantages and disadvantages that should be considered carefully before cage production becomes the chosen method. The advantages include relatively low initial investment in an existing water body; simplified monitoring and harvesting; and less manpower. Among the disadvantages are the total dependence on the supply of fish feed of superior quality; predation by aquatic animals and birds; incidence of diseases can be high and they spread rapidly; deterioration of water quality; accumulation of unused feed and excreta leading to water pollution as well as eutrophication; and conflicts with the community (EMATER 2007).

Managing a fish farm sustainably can help reduce its disadvantages and increase its advantages. For conventional open-pen operators, for example, that can mean reducing the populations of fish in each pen to cut down on waste and reduce the need for medications. On land, fish farmers can opt for recirculating aquaculture systems that filter and reuse the same water constantly, isolating the farmed fish from local waterways and minimizing the risk that they will escape and become invasive. An especially appealing option is aquaponics, a method of growing vegetable crops such as herbs, lettuce and tomatoes hydroponically with the same water that supports the fish. Waste from the fish fertilizes the plants, which in turn help filter the water and keep the fish healthy (Decker 2018).

Due to the growth in demand for protein from fish for human nutrition, there is the need to intensify breeding
systems to meet the demand. Intensive systems continually expose the fish to changes in water quality along with intensive handling practices – for example, excessive handling, transport and densification (Chagas et al. 2009). In this rapidly growing and maturing industry, adaptive management will be important to ensuring economic, social, and environmental sustainability (Waite et al. 2014). The objective of this study is to characterize the chemical and physical quality of inflow and effluent water from an intensive fish farm located in Brazil’s semiarid region. The objective of this work is to quantify the impact of aquaculture on the region’s water quality, comparing the quality of the effluent to the incoming water quality (inlet) as a control, and also in regard to the limits determined by CONAMA Resolution 430 (Brazil 2011). The hypothesis is that fish farming changes the water quality.

MATERIALS AND METHODS

The study occurred from April 2015 through March 2016 (12 months), including 9 months of the dry period (April–December 2015) and 3 months of the wet period (January–March 2016). It was conducted at a fish farm in Itacuruba (08°50’22.50” S and 038°41’47.38” W), located in the State of Pernambuco, Sub-Middle São Francisco River Basin, in the Brazilian semiarid region (Online Resource 1, available with the online version of this paper). The fish farm operates under an intensive production regime and has six excavated tanks for cultivation of O. niloticus juveniles and three excavated tanks for fingerlings with volumes of 1,800 m³ and 1,200 m³ per tank, respectively.

Seventy-five kg ton⁻¹ of fish feed were used in the juvenile phase and 25 kg ton⁻¹ in the fingerling phase. Feeding was carried out four times per day at feeding rates of 2% to 4% of total biomass with feed for omnivorous fish with average weight between 200 g and 500 g cultivated in nurseries with high stocking density.

Samples of inflow water and effluent were collected for physical and chemical characterization. The untreated inlet water is pumped from Itaparica Reservoir up to the fish tanks. The effluent goes to a constructed wetland (4,500 m³) containing the aquatic macrophytes Eichhornia crassipes and Egeria densa. After passing through the wetland, effluent water flows back into the reservoir.

According to the data from the 2010 IBGE Census (IBGE 2010), Itacuruba has an area of 430 km² (about 0.44% of the State of Pernambuco). The municipality has an average annual temperature of 26 °C and, according to the classification of Köppen (McKnight & Darrel 2000), is classified as BSWh (B – arid climate; S – weather of the steppes; w – with a wet season in the summer that is late for autumn and may not occur; h – dry and hot).

Air temperature and rainfall data during the study period were provided by the climatological database from the National Institute of Meteorology (INMET 2016) from the PCD 32026 station. Samples of inlet water and effluent were collected monthly to evaluate the following parameters: water temperature (°C), pH, electrical conductivity (μS cm⁻¹), total phosphorus (TP) (mg L⁻¹), total nitrogen (TN) (mg L⁻¹) and dissolved oxygen concentration (mg L⁻¹; hereafter TP, TN and DO) and turbidity (NTU).

Water temperature, pH, electrical conductivity, total dissolved solids (TDS) and turbidity were collected with an Oakton multiparameter probe model PCD 650. Inorganic nitrogen was obtained by summing nitrite, nitrate and ammoniacal nitrogen. Oxygen saturation (%) was obtained as a function of temperature and salinity.

The samples were conditioned in properly identified polypropylene bottles, acidified with H₂SO₄ to pH <2, stored in a cooler, refrigerated and then transported to the laboratory of the Chemistry Department at the Federal University of Pernambuco for further analysis (except for TN, for which samples were sent to the Laboratory of Environmental Technology (LABTAM) at the Pernambuco Technology Institute (ITEP)). For determining dissolved oxygen, the method of Winkler modified by Strickland & Parsons (1972) was used. All samples were analyzed according to APHA (2012). The parameters TP, reactive soluble phosphorus, nitrite, nitrate, ammoniacal nitrogen were analyzed with a digital spectrophotometer (Spencer model SP-70-35).

Statistical analysis was carried out using the IBM SPSS Statistica (version 23). All data were tested for normality of distribution with the Shapiro-Wilk test. The parametric data were statistically subjected to analysis of variance (ANOVA). When significant differences were observed among means, Tukey test HSD (critical α = 0.05) was applied using the IBM Statistica 23 software. For data analysis, the IBM SPSS was used to plot the data in the boxplot format and to calculate the maximum, minimum, mean and standard deviation values.

RESULTS AND DISCUSSION

The summary of the monitored data and standard deviation are shown in Table 1.
In relation to TP, its concentration in the inlet water was 0.2 mg L\(^{-1}\) (April 2015) and in the effluent reached 0.4 mg L\(^{-1}\) (May 2015). Effluent TP was on average 447% higher than inlet TP and was 473% above the CONAMA limit. The concentration of soluble reactive phosphorus (SRP) in the inlet ranged from 0.01 to 0.08 mg L\(^{-1}\) while the SRP concentration of the effluent ranged from zero to 0.12 mg L\(^{-1}\).

TN concentration in the inlet water ranged from 0.70 to 3.25 mg L\(^{-1}\) and in the effluent ranged from 0.75 to 3.41 mg L\(^{-1}\). During most of the dry period, this parameter was not in compliance with the limit established by CONAMA Resolution 430 (Brazil 2011) for the two sampling points, except in April 2015. The effluent presented on average values of TN 103% higher when compared to the inlet water and 189% above the limits recommended by CONAMA Resolution 430 (Brazil 2011).

In the inlet water, nitrite concentration ranged from 0 to 0.67 mg L\(^{-1}\) and in the effluent, after passing through the nurseries, varied from zero to 0.51 mg L\(^{-1}\). Ammonia nitrogen in the inlet water varied between 0.05 to 0.28 mg L\(^{-1}\) and in the effluent ranged from zero to 45 mg L\(^{-1}\). Nitrate concentration both in the inlet water and in the effluent ranged between zero to 0.03 mg L\(^{-1}\). In the inlet water,
the concentration of inorganic nitrogen (nitrite, nitrate and ammoniacal nitrogen) ranged from 0.17 to 0.74 mg L$^{-1}$ and in the effluent ranged from 0.08 to 1.05 mg L$^{-1}$. Nitrite and nitrate concentrations remained in compliance with the limits recommended by CONAMA Resolution 430 (Brazil 2011) (1 mg L$^{-1}$ and 10 mg L$^{-1}$, respectively).

Nitrogen compounds appear under three forms in the aquatic environment. Nitrate is the main form and, when in high concentration, may lead to a process of exaggerated production, called eutrophication. The ammonia nitrogen (ammonia) is a toxic substance not persistent and non-cumulative and that, in low concentration, does not cause any physiological damage to the animals. In high concentrations, the main effects of ammonia on fish are the increase of blood pH; an increase in fish permeability reducing the internal concentration of ions; an increase in oxygen consumption in the tissues, affecting the gill and reducing the ability to carry blood oxygen; histological changes mainly in the kidneys and spleen; and increased susceptibility of fish to disease (Sipaúba-Tavares 1994).

The presence of nitrite in water indicates active biological processes influenced by organic pollution. Nitrite is a chemical form of nitrogen usually found in minute quantities in the surface water. Nitrite is unstable in the presence of oxygen, occurring as an intermediate form in the nitrification process, in which ammonia is transformed into (oxidized) by bacteria to nitrite, and then to nitrate (Gorsel & Jensen 1999). The relationship between aquaculture and algal blooms was studied by Mainardes-Pinto & Mercante (2003), who found that the input of nitrogen probably leads to an excessive growth of Euglenas.

Wet period

Air temperature during sampling time ranged from 31.5 °C to 43.8 °C and the monthly average rainfall ranged from 98 mm to 157 mm. The pH of the inlet water ranged from neutral (7.02) to alkaline (7.83) and pH of the effluent remained alkaline (7.48 to 7.53).

Respiration, photosynthesis, fertilization, liming and pollution are the five factors that cause the pH change in water (Sipaúba-Tavares 2013). Rebouças et al. (2015), assessing the tolerance of juvenile of tilapia to acidity, concluded that the species is tolerant to high concentrations of H$_2$S in water (up to 4.4 mg L$^{-1}$). However, water acidification deteriorates the quality of the effluents from the rearing tanks, which can harm more-sensitive native ichthyofauna.

Electrical conductivity was 199.3 μS cm$^{-1}$ and TDS was 115.2 mg L$^{-1}$ in the effluent in January 2016 (wet season).

The highest concentrations of dissolved oxygen in the inlet water occurred in January 2016 (wet season) at 13.62 mg L$^{-1}$. Water temperatures ranged from 27.4 °C to 31.4 °C in the wet season. In fish tanks, it is ideal that the concentration of oxygen is equal to or greater than 5 mg L$^{-1}$ (Online Resource 2, available with the online version of this paper).

Turbidity ranged from 19.9 to 31.7 NTU in the inlet water and ranged from 12.2 to 29.9 NTU in the effluent. The highest turbidity in the inlet water occurred in March 2016 (wet season) with 31.7 NTU. The particles that remain in suspension increase the turbidity of the water, reduce (subsurface) light and consequently photosynthesis.

TP concentration in the inlet water and in the effluent (Online Resource 3) ranged from 0.2 (March 2016) to 4.7 mg L$^{-1}$ (January 2016), respectively, corresponding to an increase of 1,000% in the concentration of TP in the inlet water and 1,175% in the effluent in relation to the CONAMA Resolution 430 (Brazil 2011) limit (Online Resource 4). Approximately 85.3% of the TP samples of the inlet water and 100% of the effluent samples presented values exceeding the CONAMA limits. The concentrations of phosphate forms varied between 0.18 to 0.77 mg L$^{-1}$ in fish culture effluent (Lima et al. 2011). The high concentrations of phosphorus in the intake are a combined result of the geology of the semi-arid region, the small distance between the fish tanks and the catchment (less than 40 m), a severe drought that has affected the region since 2012. As the level of Itaparica reservoir decreases, people start to practice agriculture on its margins and they use fertilizers and chemical products to exterminate plagues and lack of basic sanitation. All those products are released in the water and contribute to the high concentrations of phosphorus in the intake.

Phosphorus and nitrogen are the main nutrients that cause eutrophication of water bodies, and are often a target for regulation and reduction by environmental agencies being considered, by various supervisory bodies, as an element of high polluting capacity (Cooke et al. 2005; Lazzari & Baldisserotto 2008). In aquaculture phosphorus is an essential mineral for fish because it acts in various metabolic processes. However, high levels may compromise the quality of the water, and its lack may cause deficiency in animals. The concentration of phosphorus in the diet should meet the necessary requirements for good performance, without compromising water quality of culture. Sanitary sewers, industrial effluents, fertilizers,
pesticides, chemicals in general, may discharge phosphorus in excessive amounts in receiving water bodies. Phosphorus may occur in water in three different forms: organic phosphates, orthophosphates and condensed polyphosphates or phosphates. However, the third form is not relevant in studies of water quality control, because the polyphosphates undergo hydrolysis, quickly becoming orthophosphates in natural waters (Cheis 2014).

The release of phosphorus from anthropogenic activities (from diffuse and point sources) can result in increased primary production and eutrophication, and enhance the seasonal development of toxic algal blooms, which can significantly impact water quality (Worsfold et al. 2016). Fish nurseries and tanks are shallow, dynamic environments that are directly influenced by climatic conditions and management practices. In general, these systems are dominated by planktonic species that develop rapidly and withstand frequent environmental changes (Sipaúba-Tavares & Braga 1999).

Algal blooms, especially of cyanobacteria such as genera Microcystis, Anabaena, Aphanocapsa and Cylindrospermopsis (Eler et al. 2006, 2009), may cause extensive damage and economic losses, including to fish farmers who can see their crops decimated (Eler et al. 2006; Eler et al. 2009). In addition to environmental problems, some strains can produce cyanotoxins, which can lead to the death of domestic and wild animals, as well as human intoxication (Carmichael et al. 1994).

In fish farming tanks, the excessive proliferation of phytoplankton may cause decrease of oxygen at night, supersaturation during the day and may cause obstruction of fish gill filaments. Inhibition of phytoplankton growth, besides the appearance of products of secondary metabolism of cyanobacteria, are other related problems (Mitchell 1996; Perschbacher et al. 1996; Datta & Jana 1998). Off-flavor is the presence of objectionable tastes and/or odors in food due to cyanobacteria. However, consumers consider that farmed fish tainted by different flavors is unacceptable. Unpleasant and unacceptable tastes and odors, off-flavors, in water and fish are a worldwide problem (Papp 2008). Harmful algal blooms (HABs) episodes are strongly correlated to economic losses in fish market. During HABs, toxins released by phytoplankton may be absorbed by fishes causing closure of fish trade while algae proliferation may cause an oxygen depletion in waterbodies leading to fish mortality (Sanseverino et al. 2016).

SRP concentration in the wet period ranged from 0.06 to 0.16 mg L\(^{-1}\) in the inlet and from 0.01 to 0.11 mg L\(^{-1}\) in the effluent. There are no established limits for SRP. According to Basic Sanitation Research Program (FINEP 2009), phosphorus does not present sanitary restrictions on water quality; however, SRP is an essential nutrient for phytoplankton, and under certain conditions it may lead to eutrophication.

TN concentration in the inlet water ranged from 0.64 to 17.51 mg L\(^{-1}\) (2,736%) and in the effluent ranged from 6.53 to 10.61 mg L\(^{-1}\) (162.5%) (Online Resources 5 and 6). The effluent presented on average values 92% higher when compared to the inlet water and 64% (wet period) above CONAMA Resolution 430 (Brazil 2011) limits. During the entire wet season TN was not in compliance with the limit established by CONAMA (National Council of the Environment).

The origin of nitrogen can be natural (rainwater, organic and inorganic material of allochthonous origin and the fixation of molecular nitrogen) or artificial, the latter coming mainly from domestic, industrial and agricultural effluents (Buzelli & Cunha-Santin 2013). According to the Development Company of the São Francisco and Parnaíba Valleys – CODEVASF (2013), in the hottest period of the year, food consumption and fish growth rate increase, a fact that, associated with the increase in precipitation, may have caused the highest values measured in the months from January 2016 to March 2016. In the wet period (January to March) the fish farmers increase the amount of fish feed so that the fish grow faster to be in the ideal weight to be commercialized. Since the local human population is Christian, fish is a traditional Easter dish in the region, hence the enhanced fish demand and production in the region. The increase of feeding matches the elevated temperatures in this period, explaining the increased concentration of nutrients. We observed that aquaculture interfered more in the dynamics of phosphorus than in those of nitrogen. There was no statistically significant difference for TN between the points monitored during the dry and wet periods (one-way ANOVA: \(F_1, 22 = 4.32, p > 0.05\)).

Nitrite concentration in the inlet water ranged from 0.15 to 0.38 mg L\(^{-1}\) and in the effluent ranged from zero to 0.25 mg L\(^{-1}\). During the study period, nitrite was in compliance with the limits established by CONAMA Resolution 430 (Brazil 2011) (1.0 mg L\(^{-1}\)). Nitrite in high concentrations is a toxic compound that can cause mortality of aquatic organisms in culture systems (Campos et al. 2012).

Ammoniacal nitrogen concentration in the inlet water ranged from 0.01 to 0.85 mg L\(^{-1}\) and in the effluent ranged from 0.01 to 0.21 mg L\(^{-1}\). During both periods, the concentrations of ammoniac nitrogen remained below the limits recommended by CONAMA Resolution 430 (Brazil 2011) (<2.0 mg L\(^{-1}\)). The presence of ammoniacal nitrogen
in the water may indicate decomposing organic matter and an oxygen-poor environment (Silva 2007).

In the inlet water, the concentration of inorganic nitrogen (nitrite, nitrate and ammoniacal nitrogen) during the wet season ranged from 0.19 to 1.27 mg L$^{-1}$ and in the effluent ranged from 0.17 to 0.44 mg L$^{-1}$. CONAMA Resolution 430 (Brazil 2011) does not establish a limit for inorganic nitrogen.

Considering the high potential of nutrients released into the reservoir, the consequences for the water quality depend on various aspects like water residence time. During the last 5 years, the study area has had a reduction in rainfall so the reservoir is operating with a minimum in and outflow. Both in the dry and wet period, in most samples of the inlet water and effluent, conductivity (>90 $\mu$S cm$^{-1}$), TP (>0.30 mg L$^{-1}$) and TN were high, indicating eutrophication caused by the excess of nutrients from the fish farm. The other parameters were in compliance with Brazilian legislation.

Several studies have pointed to the negative impacts on water quality from fish farming due to intense eutrophication, or sometimes inadequate release of nutrients (mainly nitrogen and phosphorus). Derived from fish feed, excrements, and associated with the use of antibiotics and hormones, these nutrients are released directly into water bodies, which has led many countries (e.g. Chile and Germany), to prohibit or restrict net cage aquaculture in inland waters in the Northern hemisphere (Gunkel et al. 2015; Matta et al. 2016). Cage aquaculture in inland waters in the Northern hemisphere is facing increasingly stringent regulation and in some countries, such as Germany, prohibition, because of environmental concerns (Rosenthal et al. 1993). The public health hazards related to antimicrobial use in aquaculture include the development and spread of antimicrobial-resistant bacteria and resistance genes and the presence of antimicrobial residues in aquaculture products and the environment (Romero et al. 2012).

The current scenario that can be seen in the activity of fish farming in the Northeast Pernambuco, especially in the São Francisco river, is a panorama of climate change, scarce resources in an area with potential conflict by multiple uses of water; low rainfall, leading to a frequent flow reduction in upstream reservoirs, and a risk to water quality from the large contribution of available nutrients in the ecosystems from agricultural activities, aquaculture and municipal waste (Andrade 2012).

Water limitation is one of the main problems faced in the semiarid region. Though high, water use by fish farming is not that consumptive, which allows for water re-use. This is crucial for water-scarce areas such as the semiarid region of Brazil, where fish farming can be integrated with agriculture, with the effluent from aquaculture potentially being used to irrigate crops (Oliveira & Santos 2015).

Our results show that the excess of fish feed, combined with climatic factors and the intensive production model, caused changes in water quality leading to eutrophication, especially during the wet period. Hence, monitoring is an important tool for control and robust decision-making that ensures a sustainable production system. Matta et al. (2016) analyzed nutrient concentrations (phosphorus and nitrogen) in Itaparica Reservoir by modeling simulations of a hypothetical net cage aquaculture system investigated in half-year cycles. The authors observed a non-negligible impact on water quality for tilapia production of 130 ton year$^{-1}$; that is, after 6 months of simulation they obtained emissions around 8 to 6 $\mu$g P L$^{-1}$ at the source for low and high-water scenarios, respectively.

The mean values of the parameters were subjected to one-way ANOVA to compare differences between periods. Statistically significant differences occurred between dry and wet periods for air temperature, rainfall, electric conductivity, salinity, TDS, TP, soluble reactive phosphorus and TN (Online Resource 7).

To minimize the impact of aquaculture on water bodies and improve the efficiency of water use in semiarid regions, best management practices must be adopted by the producers. Among these practices, fish farmers must select high quality fish feed containing nitrogen and phosphorus in adequate but not excessive amounts, that meet the nutritional requirements of cultivated species, ensure proper management of nurseries including the correct use of fertilizers, feed, liming materials, therapeutic measures and also emergency measures in response to low concentrations of dissolved oxygen that cause great mortalities (Embrapa 2006).

**CONCLUSIONS**

The parameters of conductivity, TP and TN, from inlet water had already entered the nurseries with high concentrations throughout the study period, while dissolved oxygen was low in the dry period. Nitrite, nitrate, ammoniac nitrogen, TDS and turbidity showed low concentrations throughout the study period at the inlet.

Regarding the effluent, conductivity, TP and TN presented high values at the exit of the nurseries. Nurseries
functioned as a stabilization pond for nitrite, reducing its concentration during both the dry and the wet period.

TP was the parameter that presented the greatest potential to degrade water quality, both in the inlet water and in the effluent, peaking at 0.47 mg L\(^{-1}\) in January 2016 (wet season) corresponding to 1,367% above the limit established by CONAMA Resolution 430 (Brazil 2011). This result was possibly due to excessive feeding, harvest (sporadic), reservoir operation, sedimentation of allochthonous sediments and resuspension of sediments at the bottom of the nurseries.

Our data strongly suggest that fish farming decreases water quality. The concentration of phosphorus and nitrogen in the diet should meet the necessary requirements for good performance, without compromising water quality. Due to water limitation, it is necessary to adopt strategies to improve the efficiency of water use in semiarid regions and to adopt best management practices to minimize the negative impacts of aquaculture activity.

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