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Water quality in Ponte Pensa Aquaculture Park, Solteira Island Reservoir, SP, Brazil, where fish are cultivated under great-volume cage system

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ABSTRACT

This study analyzes spatial and temporal variations in physical and chemical water variables due to the influence of fish culture in a cage system (20x20x3 m) in Ponte Pensa Aquaculture Park (Solteira Island Reservoir), before and after cage installation. Water samples were collected on a monthly basis in the subsurface of three sampling sites (August/2011 to July/2013): downstream from the farming site (S1), at the farming site (S2), and upstream from the farming site (S3) (n = 72). Water temperature, pH, dissolved oxygen, transparency, turbidity, electrical conductivity, ammonium ion and total phosphorus were assessed. The principal component analysis (PCA) was applied to joint analysis data. PCA results explained the 61% joint variability in data of the first two components. Fish farming in cages caused significant temporal changes, mainly in January 2013, as well as sudden spatial changes in water physical and chemical variables. Fish culture influenced the quality of the water; such influence was mainly indicated by variations in ammonium ions and in total phosphorus concentrations, which were confirmed through PCA application. PCA results showed two distinct temporal phases: Phase 1 - prior to fish-cage farming, when limnological conditions were characterized by the highest dissolved oxygen concentrations and by high temperatures; Phase 2 - post-production period, when limnological conditions were characterized by the highest total phosphorus and ammonium ion concentrations.

Keywords: ammonium ion, fish farming in cages, total phosphorus.

Influência da piscicultura em tanques-redes de grande volume na qualidade da água do Parque Aquícola Ponte Pensa, Reservatório Ilha Solteira, SP, Brasil

RESUMO

O objetivo do presente estudo é analisar a variação espacial e temporal das variáveis físicas e químicas da água na zona de influência da tilapicultura em tanques-redes (20x20x3 m) no parque aquícola Ponte Pensa (Reservatório de Ilha Solteira), abrangendo os períodos pré e pós-introdução da produção. Amostras da água foram obtidas mensalmente (agosto/2011 a julho/2013) na subsuperfície em três estações de amostragem: jusante da área de criação (S1), local de criação (S2) e a montante (S3) (n=72). Foram avaliadas a temperatura da água, pH, oxigênio dissolvido, transparência, turbidez, condutividade elétrica, íon amônio e fósforo total. Utilizou-se a PCA para análise conjunta dos dados. A PCA explicou 61% da variabilidade conjunta dos dados nos dois primeiros componentes. As atividades da piscicultura em tanques-rede provocaram alterações temporais, detectadas especialmente a partir de janeiro de 2013, e sutis alterações espaciais nas variáveis físicas e química da água. O íon amônio e o fósforo total foram as variáveis que mais indicaram a influência desta atividade na qualidade da água, confirmados pela PCA que demostrou duas fases temporais distintas: Fase 1- em que as condições limnológicas antes da produção de peixes em tanques-rede foram caracterizadas pelas maiores concentrações de oxigênio dissolvido e altas temperaturas; e Fase 2 – período pós-produção, que foi caracterizada pelas concentrações mais elevadas de fósforo total e íon amônio.

Palavras-chave: fósforo total, íon amônio, piscicultura.

1. INTRODUCTION

The global population is estimated to reach 9.7 billion people by 2050, and this population growth has increased the yearly demand for food. This scenario is pushing basic production sectors to increase productivity and to expand their production sites (FAO, 2014). Aquaculture is one of the fastest growing activities in the food industry worldwide; it reached the historical record of 90.4 million tons in 2012, and fish farming in cage systems accounted for 66.6 million tons of this total (FAO, 2014).

According to the Brazilian Institute of Geography and Statistics (IBGE), fish farming in continental waters in the country totaled 507.12 t in 2016; it increased by 4.4% in comparison to the total fish production in 2015 (IBGE, 2016). The farming of tilápias increased by 9.3% in the same period (239.09 milt, in 2016). São Paulo State ranked third among domestic producers at 48.35 t, a 47.5% increase in comparison to the previous year. Santa Fé do Sul, Northwestern São Paulo State, ranked first in the national ranking of counties, with 5.360 t (IBGE, 2016; Barroso *et al.*, 2018). This production growth resulted from the expansion of projects focused on assembling cages for fish farming in aquaculture parks installed in mid- and large-sized hydroelectric power-plant reservoirs (Mallasen *et al.*, 2012).

An aquaculture parks is defined as a continuous physical space within a delimited water medium, which covers a set of similar water sites whose intermediate physical spaces allow the development of other activities along with aquaculture practices. In their turn, aquaculture sites are continuous physical spaces in delimited water media used for aquaculture (Brasil, 2003).

The first aquaculture parks to become operational were located in Itaipu (PR), Castanhao (CE), Solteira Island (MS, MG and SP), Furnas (MG), Tres Marias (MG) and Tucurui (PA) reservoirs. These six reservoirs rely on 42 aquaculture parks that together comprise 28,500 hectares of water, whose production capacity is able to supply approximately 269 thousand tons of fish per year to the market (Araújo, 2016).

Nowadays, there are aquaculture parks operating in reservoirs all around the country; 15 sites in Solteira Island Reservoir were categorized as appropriate for aquaculture park implementation, among them, Ponte Pensa Aquaculture park, whose support capacity is to 4.59 t/year (David *et al.*, 2015). Ponte Pensa Aquaculture Park, as well as other ones, were implemented in Brazilian reservoirs based on studies that have taken into account some environmental, sustainable, social and economic aspects. Results in these studies have pointed out good water quality conditions for aquaculture in cage system in these sites (Bueno *et al.*, 2008; David *et al.*, 2015).

Fish farming in cage systems is an intensive production modality, but it has high potential to cause environmental impact, since feed waste and fish excreta are released into the aquatic environment. These discharges increase nitrogen and phosphorus concentrations in the water and lead to artificial eutrophication processes (Guo and Li, 2003; Alves and Baccarin, 2005; Bueno *et al.*, 2008; Guo *et al.*, 2009; Mallasen *et al.*, 2008; 2012).

Fish cage farming influence on water limnological characteristics depends on fish production intensity, on waste dispersion, on the quality of the feed and on the assimilation ability of the environment where the cages are installed in (Borghetti and Ostrenky, 1999; Mallasen *et al.*, 2012; Ayroza *et al.*, 2013).

Some studies (Fernandes *et al.*, 2001; Piedrahita, 2003; Borges *et al.*, 2010, Mallasen *et al.*, 2012) emphasize the importance of assembling cages in reservoirs presenting favorable hydrodynamic characteristics, since these features allow nutrient dispersion from the organic load in the production system and water quality disturbance assimilation in sites used for fish farming. Therefore, the definition of aquaculture parks, such as Ponte Pensa, is essential for aquaculture development planning, since farming sites are delimited based on multidisciplinary studies (morphometry, climatology and hydrodynamics.) aimed at determining hydrodynamically favorable sites for fish farming in cage systems (David *et al.*, 2015).

Studies that have evaluated the influence of fish-cage farming on the limnological characteristics of sites where this system is operational help in better understanding the dynamics of the cage system and its relationship with the environment. Moreover, they highlight the efficiency of hydrodynamic characteristics observed in delimited sites.

The aim of the present study was to analyze spatial (horizontal) and temporal (monthly) variations in water physical and chemical variables in sites influenced by fish farming in great-volume cage systems (1,200 m^3; 20x20x20 m), such as Solteira Island Reservoir (Ponte Pensa Aquaculture Park), before and after farming site implementation. It is worth highlighting that these great-volume cage systems have been recently installed in Brazil.

The evaluation of the environmental variability of abiotic data in relation to the (temporal) months of study and the sampling stations (spatial) was performed through principal component analysis (PCA). The PCA is a multivariate statistical technique that transforms a set of original variables into a smaller set of independent variables called principal components, which in turn retain the maximum information of the total variation contained in the data (Hongyu *et al.*, 2015).

2. MATERIALS AND METHODS

The study was carried out in Fish Farm Geneseas Aquacultura Ltda, which is located in Ponte Pensa Aquaculture Park. This park holds part of Ponte Pensa River, which feeds Solteira Island hydroelectric power plant reservoir, SP, Brazil (Figure 1). The location and characteristics of Solteria Island Reservoir and of Ponte Pensa Aquaculture Park were addressed by Rosini *et al.* (2016).

2.1. Climate Variables

Rainfall and air temperature information for the period between August 2011 and July 2013 in the assessed region was provided by the Integrated Center for Agrometeorological Information (CIIAGRO) of the Department of Agriculture and Supply of São Paulo State.

2.2. Sample collection and collection period

Sample collection started in August 2011, five months before cage system of fish farming was operational. The first cages were installed in Jan/Feb 2012; there were two modules of eight large cages (1,200 m^3; 20x20x3 m) in the site at the end of the experimental period.

A "van Dorn" collecting bottle was used to collect water samples on a monthly basis from the subsurface of sites impacted by fish-cage farming for two years (August 2011 to July 2013) (n=72). The samples were used in the analysis applied to find the limnological conditions (total phosphorus ($\mu g\ L^{-1}$) and the ammonium ion concentration ($\mu g\ L^{-1}$). Three sampling sites were evaluated: S1 (750 m upstream from the site with the cages downstream in the Ponte Pensa River, coordinates 20º16'134" S and 50º59'107" W, mean depth 30m), S2 (the farming site, coordinates 20º16'452" S and 50º58’812” W; mean depth 27 m), and S3 (650 m downstream from the site with cages upstream in the Ponte Pensa River, coordinates 20°16'853" S and 50°58'980" W, mean depth 26 m) (Figure 1). Sampling sites were delimited with GPSMAP 76CS / Garmin.

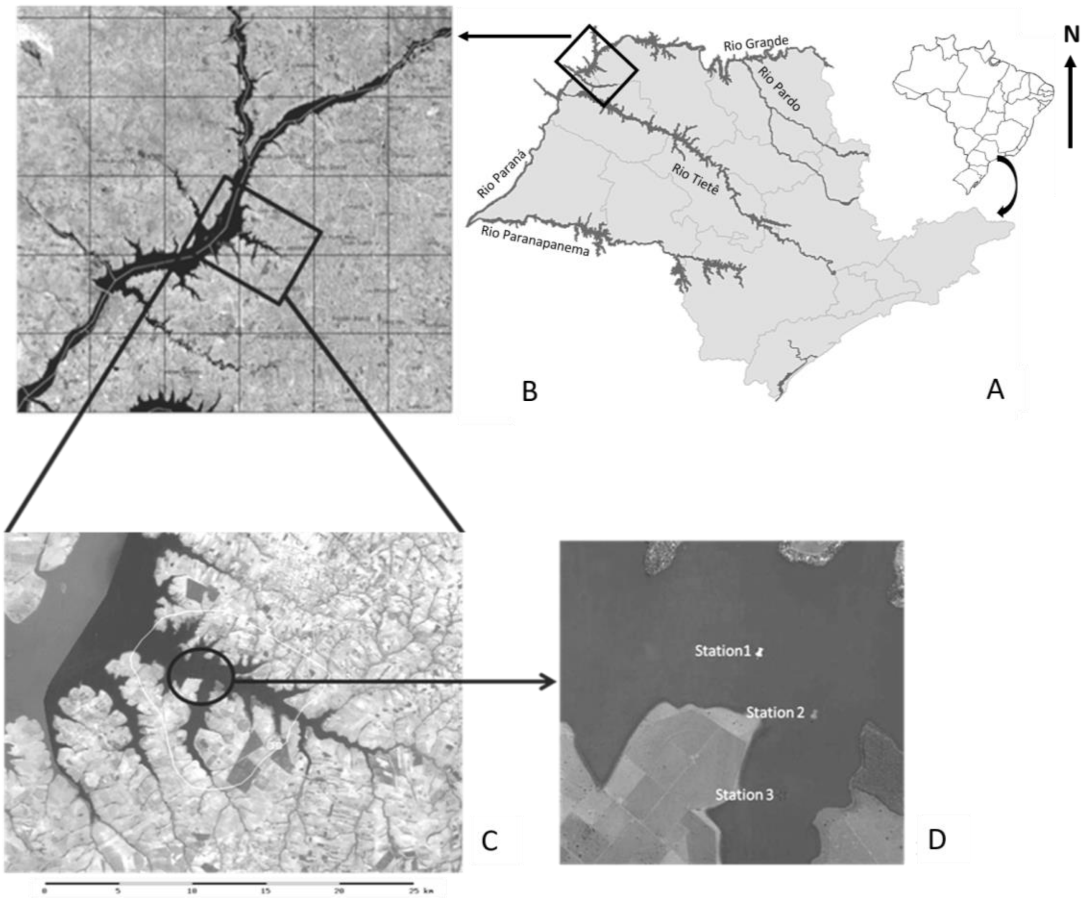

Figure 1. (A) The arrow indicates the location of Solteira Island Reservoir in São Paulo State, Brazil. (B) The rectangle indicates the location of the Ponte Pensa River arm in the Solteira Island Reservoir. (C) Geneseas fish-cage farming site (20º17’ S and 50º58’ W) is delimited by the dark line and the Ponte Pensa River arm is marked by the light line. (D) Location of sampling sites S1, S2 and S3.
Source: Rosini *et al.* (2016).

2.3. Analysis of Water Physical and Chemical Variables

Water temperature profile (ºC), pH, electrical conductivity (µS cm^{-1}), water turbidity (NTU) and dissolved oxygen (mg/L) values were obtained *in situ* with the water quality multiparameter meter YSI Professional Plus (ProPlus). Water transparency (m) was determined based on Secchi disk disappearance depth; total phosphorus (µg L^{-1}) and ammonium ion (µg L^{-1}) concentrations were analyzed based on Valderrama (1981) and Solorzano (1969), respectively.

The collected data were compared to values established by CONAMA Resolution N. 357/2005 (CONAMA, 2005) in order to verify whether or not they remained within the limits for Class II water bodies, which include aquaculture sites.

Monthly data about the amount of consumed feed were provided by Geneseas Aquacultura Ltda to assess feed waste influence on the quality of water.

2.4. Statistical Analysis

Abiotic data were subjected to joint evaluation based on the principal component analysis (PCA); the analyses were carried out in the PC-ORD software, Version 4.0, for Windows (Mccune and Mefford, 2011). Data were transformed through [log (x + 1)].

3. RESULTS AND DISCUSSION

Based on rainfall and air temperature data, the assessed region counts on two specific seasons: wet summer and dry winter. The lowest rainfall values (below 10 mm) were recorded in winter - August/September 2011, July/August 2012 and July 2013 -, whereas the highest values for this variable (above 214 mm) were recorded in summer, January 2012 and January/March 2013 (Figure 2).

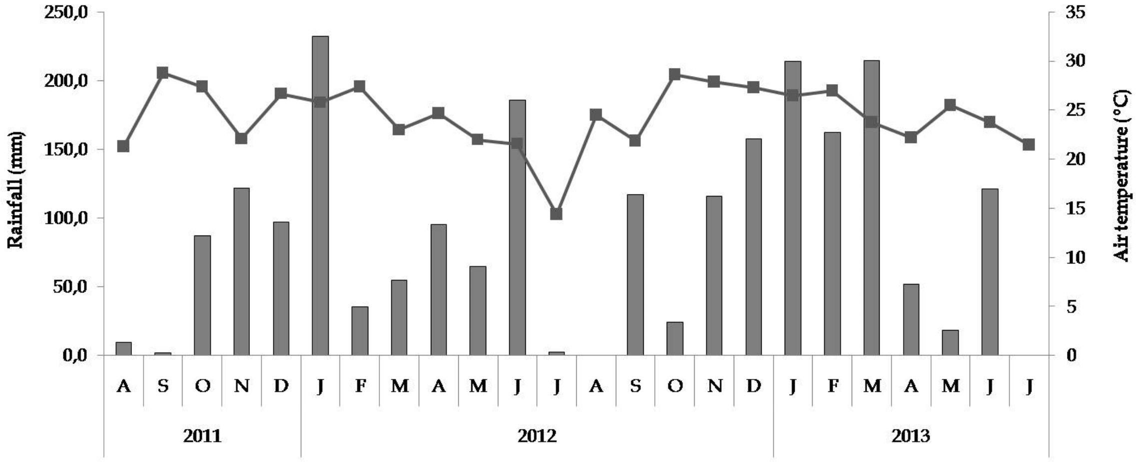

Figure 2. Mean monthly air temperature (ºC) and rainfall (mm) variation in Santa Fé do Sul/SP during the study period.

There were no significant abiotic changes between sampling sites. Water temperature was close to 26.5°C; the lowest temperatures were recorded in July/2012 (22.6°C) and the highest in February/2012 (30.7°C) (Figure 3A).

There was a drop in dissolved oxygen (DO) values at Station 2 in February 2012, after the fish-cage farm became operational. The lowest DO concentrations were observed at this site, mainly after the second half of 2012 (Figure 3B), although the recorded values (above 4.0 mg L^{-1}) remained in the specifications recommended for tropical fish farming (Boyd, 1990; Kubitza, 2000) and within the limit established by CONAMA Resolution N. 357/2005 for Class II water bodies, including aquaculture sites.

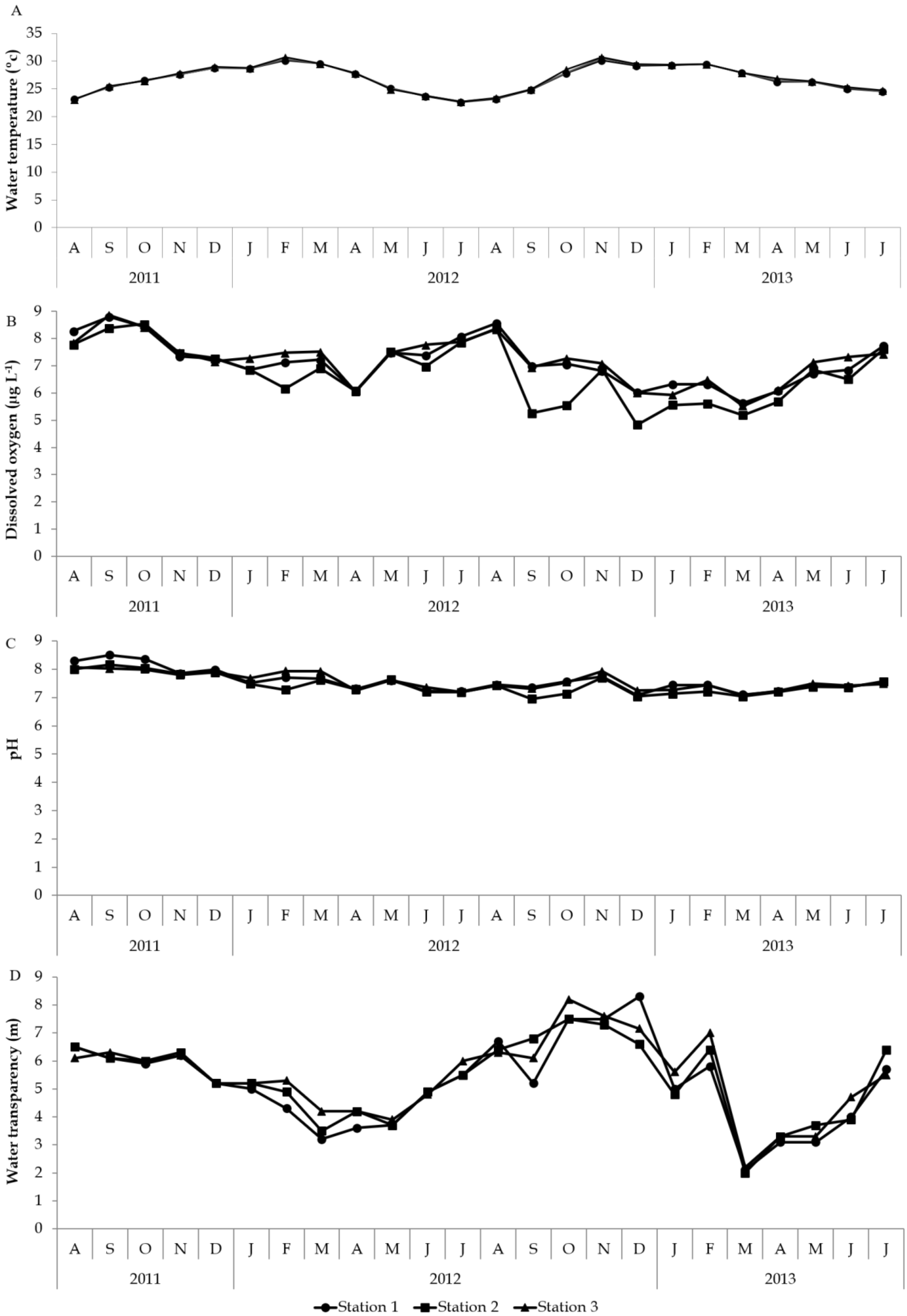

Figure 3. Temporal variation in the assessed variables - water temperature (ºC) (A), dissolved oxygen (mg L^{-1}) (B), pH (C) and water transparency(m) (D) - at the collection sites throughout the study period.

According to the recorded pH Values, water at the site was alkaline; but these values decreased in February 2012 (Figure 3C) and became similar to the ones recorded for dissolved oxygen at Station 2. Transparency values ranged from 2.0 to 8.3 m. There was a decrease of approximately 4.0 m in water transparency in March, April and May 2012 and 2013, in comparison to months analyzed before this time. Water transparency (2.0 m) recorded the lowest values in March 2013 at Station 2 (Figure 3D). Water turbidity varied between 1UNT and 8UNT; different from water transparency, it had significant increase in March, April, May and June 2012/2013 in comparison to the other months (Figure 4A).

Conductivity values were always lower than 55 $\mu S\ cm^{-1}$; however, in May, June and July 2013, there was sudden conductivity increase in comparison to the other months (Figure 4B). Ammonium ion concentrations showed remarkable increase in the last seven collection months at the three collection sites (January to July 2013); rates reached values 100% higher than the ones recorded in previous analyses (Figure 4C). Total phosphorus concentrations also increased throughout the study period, mainly in September 2012. These concentrations were overall higher in 2013 in comparison to values recorded in the same period in 2012 (Figure 4D). Although the analyzed variables recorded little variation in the sampling sites since they became operational (February 2012), total phosphorus concentrations were higher than 30 $\mu g\ L^{-1}$ at Station 2 (fish-cage farming site) (Figure 4D).

With regard to feed quality, 146 tons of feed were supplied on a monthly basis, on average; the largest amounts of it were supplied in the last months of the study period (May, June and July 2013) (Figure 4E).

Principal component analysis (PCA) explained the 61% joint variability in data of the first two components; this outcome indicated seasonality as the factor coordinating the abiotic changes between August 2011 and December 2012. All sampling units in 2011 and most units in 2012 were on the negative side of axis 1, which is associated with the highest dissolved oxygen (DO) (r = 0.8) and pH (pH = 0.6) values (Figure 5). On the other hand, all sampling units in 2013 were grouped on the positive side of axis 1, which is associated with the highest ammonium ion (NH4) (r = 0.8) and total phosphorus (TP) (r = 0.5) concentrations. The highest turbidity (Turb) (r = 0.6) values were associated with the highest conductivity (Cond) (r = 0.4) values, although at a low correlation (Figure 5). Sampling units in January, February, March, October, November and December 2012 were grouped on the positive side of axis 2, which is associated with the highest water temperatures (r = 0.8) (Figure 5).

Based on PCA records, there were two distinct time phases: Phase 1 – when limnological conditions before the fish cage farm was operational (August and December 2011) were characterized by the highest dissolved oxygen concentrations; Phase 2 - post-production period (January to July 2013), which was characterized by the highest total phosphorus and ammonium ion concentrations and by high conductivity and turbidity values (Figure 5). The first and the last quarter of 2012 were associated with the highest temperatures.

According to PCA results, the analyzed abiotic variables were influenced by seasonality. Other authors also pointed out seasonality as one of the factors influencing variations in abiotic factors, mainly water transparency, in studies similar to the current one (Alves and Baccarin, 2005; Borges et al., 2010; Kaggwa et al., 2011; Ayroza et al., 2013; Bartozek et al., 2014).

Although water transparency values were similar in all sites sampled in March, April and May 2012 and 2013, this variable recorded 4.0 m decrease in comparison to the other months in the same time period. Such decrease was not directly related to phytoplankton density increase, since phytoplankton densities were always very low during the whole period (lower than 1,933 org mL^{-1}, as recorded by Rosini et al. (2016)). Summer rainfall has likely influenced transparency by transporting allochthonous material through runoff, a fact that makes water more turbid due to the suspended material.

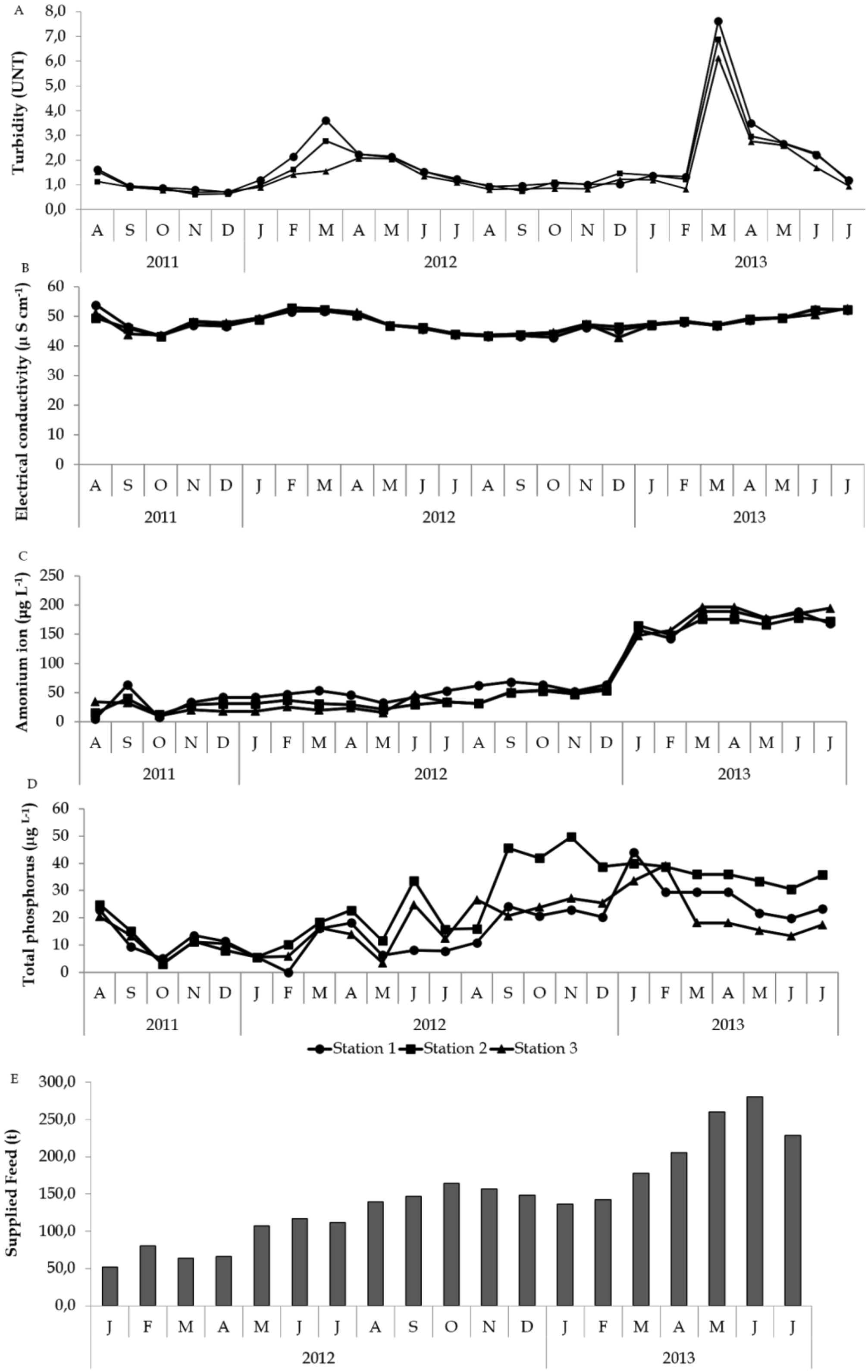

Figure 4. Temporal variation in the assessed variables - turbidity (UNT) (A), electrical conductivity (µS cm^{-1}) (B), ammonium ion concentrations (µg L^{-1}) (C) and total phosphorus (µg L^{-1}) (D) - at the collection sites during the study period; (E) Tons (t) of feed supplied to the cages in Geneseas Aquacultura, during the study period.

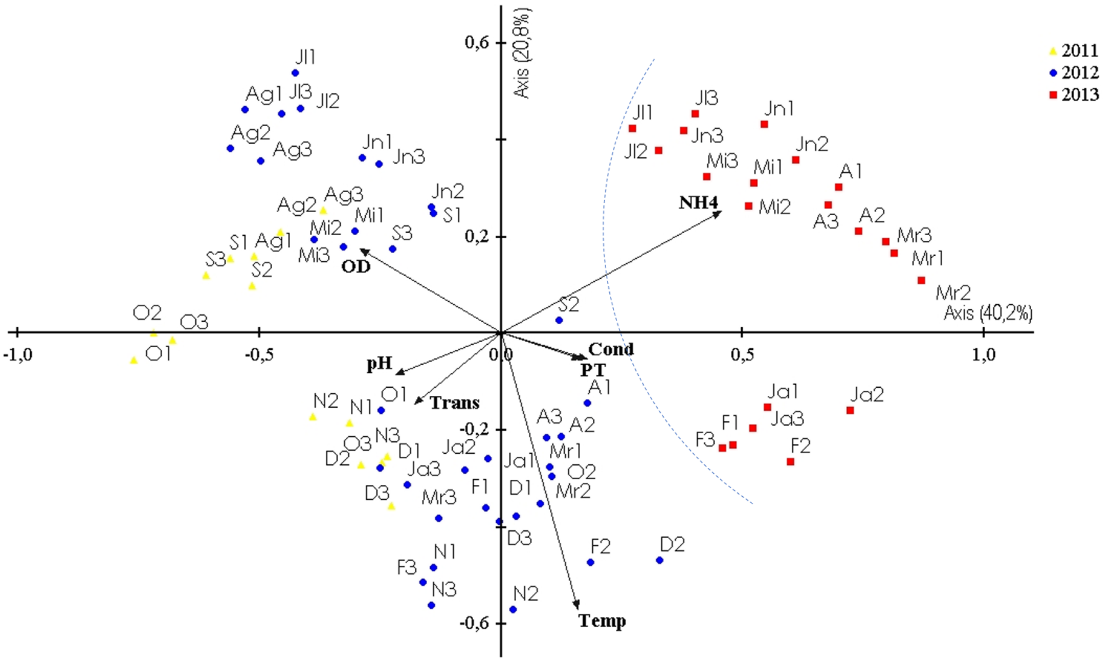

Figure 5. Principal components analysis (PCA) based on seven limnological variables of 72 sampling units (temporal and spatial). Abiotic variables: temperature (Temp), dissolved oxygen (DO), electrical conductivity (Cond), turbidity (Turb), pH, total phosphorus (TP) and ammonium ion (NH_4). Sampling units were identified based on collection year (Δ = 2011, ○ = 2012, □ = 2013), month (Ja: January, F: February, Mr: March, A: April, My: May, Jn: June, Jl: July, Aug: August, S: September, O: October, N: November, D: December) and sampling site (Station 1 = 1, Station 2 = 2 and Station 3 = 3).

Although rainfall influence on transparency should be taken into consideration, fish-cage farming influence should not be ruled out, since there was a decrease in transparency in the last months of the study period (March to June 2013) in comparison to transparency values recorded in the same months in 2012. Despite the high rainfall values observed in February and March 2013, the amount of consumed feed almost doubled in the same months of 2012; this outcome may have contributed to increase the concentration of suspended solids, both due to feed residue and to increased volume of fish feces. These results corroborate Ayroza *et al.* (2013), who recorded higher concentrations of total dissolved solids, high turbidity values and lower water transparency as the amount of feed supplied to fish farms working under cage systems increased.

Dissolved oxygen values were similar to the ones recorded by Mallasen *et al.* (2012) in the same study site chosen for the present research and by Américo *et al.* (2013), who conducted their research in the São Jose dos Dourados River, an area influenced by cages assembled in the Solteira Island Reservoir. Dissolved oxygen values were higher than those recommended for tropical fish farming (4 mg L^{-1}) (Boyd, 1990; Kubitza, 2000) and within the limit established by CONAMA Resolution N. 357/2005 for Class II water bodies, including aquaculture sites. After the introduction of the first cages in the farming sites in February 2012, DO values dropped at Station 2, which was used for fish farming. Several studies (Demir *et al.*, 2001; Veenstra *et al.*, 2003; Alves and Baccarin, 2005; Bristow *et al.*, 2008; Degefu *et al.*, 2011; Kaggwa *et al.*, 2011; Ayroza *et al.*, 2013) have already recorded DO concentration reduction in cage farming sites.

Conductivity values did not exceed 55 µS cm^{-1}. According to CETESB (2009), conductivity values above 100 µS cm^{-1} indicate impacted environments; therefore, the herein-assessed environment was not characterized as impacted during the study period.

Similar to the study by Minello *et al.* (2010), electrical conductivity values tended to increase during the rainy season, different from what was observed by Alves and Baccarin (2005). Some authors argue that rainfall has a diluting effect, and such dilution could decrease the electrical conductivity values (Alves and Baccarin, 2005; Crossetti and Bicudo, 2005). However, the input of a larger volume of water can increase the amount of dissolved solids transported to the reservoirs through the leaching process; that is likely why higher DO values were recorded in the rainy season. Although there was seasonal influence on electrical conductivity, there was fish-cage farming influence, mainly in the last three months of the study (May to July 2013). The increased conductivity recorded in 2013 in comparison to the same period in 2012 may have happened due to increased ammonium ion concentrations. Higher ammonium ion concentrations can be related to the larger volumes of fish feces and excreta in the water, which result from the installation of new cages and, consequently, from increased fish density in the study site, and from greater feed supply.

Feed waste and fish excreta decompose into ammonium, and total ammonium results from ionized ammonium (NH_4^+) and from non-ionized ammonium NH_3 (Rojas and Sanches, 2006). The presence of dissolved ammonium ions (NH_4^+) mainly depends on pH; when pH is close to 7, or neutral, ammonium is in its ionized form (NH_4^+); when pH is close to 9.5, approximately 50% of the ammonium in the water is in the NH_3 form, and 50% of it is in the NH_4^+ form; when pH is higher than 11, ammonium is in its non-ionized form (NH_3), which is a toxic form for fish and other living things (Koren *et al.*, 2000).

Based on the recorded pH values, ammoniacal nitrogen was within the appropriate range to keep the balance between NH_4^+ and NH_3 fractions, with prevalence of the ionized form (NH_4^+).

Ammoniacal nitrogen concentrations were below the value recommended for fish production - 0.6 mg L^{-1} - (Boyd, 1990); however, there was a gradual increase in the concentration of ammonium ions one year after the cages were installed. There was more than 100% increase in comparison to values recorded for previous months, probably due to the increased ammonium excretion by the fish (feces and urine). The increased amount of feed supplied in the last months of the study confirmed this information and corroborated the herein-recorded results. Villarreal and Torres (2011) and Fu-Guang *et al.* (2009) reported that 60% to 80% of the total nitrogen excreted corresponds to ammonium.

The increased organic matter, nitrogen and phosphorus concentrations in the water are some of the main aspects to be taken into consideration in fish-cage farming, mainly because of the feed fish do not ingest, and because of fish feces and urine (Guo and Li, 2003; Mercante *et al.*, 2004; Alves and Baccarin, 2005; Guo *et al.*, 2009; Américo *et al.*, 2013). Accordingly, increased total phosphorus concentrations in the water are a major issue and has been documented by several studies carried out in sites used for fish-cage farming (Guo and Li, 2003; Alves and Baccarin, 2005; Bristow *et al.*, 2008; Bueno *et al.*, 2008; Guo *et al.*, 2009; Mallasen *et al.*, 2012). The results recorded here corroborate the aforementioned studies, since there was a gradual increase in total phosphorus concentrations after the fish farm in cage system was operational. The highest phosphorus concentrations were recorded in Station 2, which showed values higher than the ones established by CONAMA Resolution 357 for water used for aquaculture (30 μg L^{-1}), thus indicating the remarkable influence of aquaculture activities on the quality of the water.

Results confirmed by PCA showed that ammonium ions, total phosphorus, turbidity and electrical conductivity were the cage-farming variables having the strongest influence on the quality of the water in Ponte Pensa Aquaculture Park. Based on this outcome, the highest ammonium ion and total phosphorus concentrations, and electrical conductivity were observed in the last seven months of the study, when there was increased feed supply (farming intensification). These values suggest increased fish production and, consequently, increased feed waste, as well as larger volumes of feces and excreta.

4. CONCLUSIONS

Fish farming in cage systems located in Ponte Pensa Aquaculture Park, Solteira Island Reservoir, Santa Fe do Sul County, Brazil, caused significant temporal and sudden spatial changes in water physical and chemical variables. Ammonium ion and total phosphorus concentrations increased over time, mainly at fish-cage farming sites.

Short residence time (21.6 days) and flow rate (172 m^3s^{-1}) likely allowed exporting nutrients downstream (Paraná River) and improved the capacity of the environment to assimilate disturbances in the quality of the water caused by the production process. Along with fish-cage farming management, these variables were decisive to mitigate the impact of fish feed and metabolism organic load on the studied aquatic system and on the spatial similarity between sampling sites.

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