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Changes in phytoplankton spatial and temporal dynamics in a Brazilian tropical oligotrophic reservoir after net cage installation

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Abstract This study analyzed the phytoplankton community response and the spatial and temporal variation of abiotic variables caused by fish farming in net cages installed in Ilha Solteira reservoir, São Paulo, Brazil. Water samples were collected monthly (August 2011–July 2013), from the subsurface, at three sites: upstream from farming area (S1), farming area (S2), and downstream from farming area (S3) ($n = 72$). Multivariate analyses (PCA and CCA) were used for the data joint analyses. The activities related to tilapia farming in net cages promoted an increase in nutrient concentrations, as well as changes in the phytoplankton community, such as increased Cyanobacteria biomass, as it is hypothesized in this paper. *Rhodomonas lacustris* Pascher & Ruttner contributed to the highest biovolume along the studied period. However, 1 year after net cage installation, we recorded the highest biovolumes of *Microcystis aeruginosa* (Kützing) Kützing and *Dolichospermum circinalis* (Rabenhorst ex Bornet & Flahault) Wacklin, Hoffmann & Komárek. Both species were associated with higher concentration of ammonium and total phosphorus. The hydrodynamic characteristics of the analyzed system, such as short residence time (21.6 days) and outflow (172 $m^3\ s^{-1}$), probably generated the capacity to assimilate disturbances in water quality caused by the employed production process and are therefore instrumental in mitigating the impact of the organic load (from the feed and fish metabolism) in the studied aquatic system.

Keywords Continental aquaculture · Cryptophyceae · Cyanobacteria · Tilapia

In memoriam: Margarete Mallasen.

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Introduction

By 2050, the world population will reach 9.6 billion inhabitants. In order to meet the simultaneously increasing demand for food, world food production will have to raise by 70 %. Among the multiple alternatives addressing food supply, aquaculture is the animal farming sector that has mostly grown worldwide, coming to an average annual growth of 8.6 % between 1980 and 2012 (FAO 2014).

The world largest aquaculture producer is China with approximately 47.8 million tons. Although it holds the 17th position in the world ranking, with 479,399 tons in 2010 (MPA 2011), Brazilian aquaculture has grown expressively in the past few years, recording a 51 % increase in production between 2009 and 2011. Most aquaculture production in Brazil comes from continental aquaculture, especially from fish farming (87 % of the total production in the country), and Tilapia (*Oreochromis niloticus* L.) comes first as the most produced species (Ostrensky et al. 2008; MPA 2011) countrywide. Production has mainly increased because more fish farming companies are using net cages in the aquaculture areas of hydroelectric reservoirs, as is the case of the studied reservoir in the state of São Paulo (Mallasen et al. 2012).

Super-intensive fish farming systems, as is the case of net cages, present lower implementation costs when compared with semi-intensive systems, and high productivity. However, non-ingested food and fish excreta are directly released in the environment, raising principally nitrogen and phosphorus concentrations in the water (Guo and Li 2003; Guarino et al. 2005; Guo et al. 2009) and sediments (Boyd et al. 2007), which cause artificial eutrophication. Considered as one of the main environmental impacts related to aquaculture, artificial eutrophication interferes with water quality and causes modifications in the structure and dynamics of aquatic communities, especially phytoplankton communities, promoting cyanobacteria and algal blooms (Diaz et al. 2001; Borges et al. 2010; Kaggwa et al. 2011).

Blooms result in great social, economic, and environmental impacts, for example metabolite production (geosmina and 2-methylisoborneol-2-MIB) which lends undesirable odor and taste to both water and fish (Smith et al. 2008); bioaccumulation of cyanotoxins in the fish muscle tissues (Deblois et al. 2008; Eler et al. 2009; Dörr et al. 2010) that poses potential health risks to animals, birds and mammals as well as men whoever consume them; skin lesions and gill clogging result from excessive algae cells, which makes breathing difficult and even kills fishes and can also make the activity itself unfeasible (Seymour 1980; Xavier et al. 1991; Magalhães et al. 2003; Souza et al. 2012).

Despite the expressive growth of fish farming in net cages in Brazil, potential impacts of the activity in water bodies and the efficacy of the phytoplankton community as an indicator of the resulting changes, few studies have evaluated the influence of the involved activities on the structure of the phytoplankton community. Some of these studies were carried out by Borges et al. (2010) and Lins (2011) in tropical reservoirs and by Cavalcante (2010) and Bartozek et al. (2014) in subtropical reservoirs. High values of Cyanobacterial biomass and blooms mainly composed of *Microcystis aeruginosa* were recorded by Lins (2011), near net cages, indicating that intensive fish farming was an important anthropogenic disturbance in the reservoir. On the other hand, studies performed by Cavalcante (2010), Borges et al. (2010), and Bartozek et al. (2014) did not record the significant influence of fish farming on physical and chemical characteristics and on the phytoplankton community. Both Borges et al. (2010) and Bartozek et al. (2014) concluded that variations in the phytoplankton community and the analyzed physical and chemical parameters seem to have been mainly influenced by seasonality, by the small number of net cages, and by the hydrodynamics of the studied environments.

Therefore, the objective of this study was to analyze the phytoplankton community response and the spatial and temporal variation of abiotic variables due to installation of fish farming system for the production of tilapias in large volume net cages in a reservoir. We have tested two hypotheses: (1) there are higher nutrient concentrations in the site with tilapia farming than in the other two sites without farming; (2) net cages installed for tilapia farming will increase nutrient concentrations and consequently promote temporal changes in the Cyanobacteria richness and biomass.

Materials and methods

The study was carried out in the fish farming area, located at the Ponte Pensa aquaculture area in the reservoir of Ilha Solteira power plant, SP, Brazil (Fig. 1). The cage culture is composed of two modules of eight large volume cages, 1200 m^3 each (20 × 200 × 20 m), where 120 tons of tilapias are produced and, on average, 140 tons of food are used monthly.

Ilha Solteira reservoir has a cumulative hydraulic operation system that controls the Parana River flow. The reservoir has a flooded area of 1195 km^2, volume of 210.6 × 108 m^3, and a water average residence time of 47.6 days and is classified as oligotrophic (CESP 2006; Mallasen et al. 2012). The climate in the region is tropical humid, dry in the winter, and the average annual rainfall ranges between 1100 and 1500 mm (Mallasen et al. 2012).

The Ponte Pensa aquaculture area, located in Ilha Solteira reservoir, 20°16′34,96″S and 50°59′02,75″W, was created for fish farming using net cages and it is the first aquaculture area to operate in Brazil. The aquaculture area has a delimited area of 30.88 km^2, an average depth of 10.4 m, an average output of 172 m^3 s, a residence time of 21.6 days, and a supporting capacity of 4599 tons of phosphorous per year (David et al. 2015).

Samples were collected every month for 2 years (August 2011–July 2013) from three collection sites: S1 (750 m downstream from the farming site, 20°16′134″S and 50°59′107″O; average depth of 30 m), S2 (at the farming site, 20°16′452″S and 50°58′812″O; average depth of 27 m), and S3 (650 m upstream from the farming site, 20°16′853″S and 50°58′980″O; average depth of 26 m) (Fig. 1). The sites sampling were defined with GPSMAP 76CS/Garmin. In order to evaluate changes in the phytoplankton community caused by the activities involved in tilapia farming with net cages, collections started five months prior to the installation of the net cages. Thus, sampling began in August 2011 and the cages were installed in January 2012. Water temperature (°C), pH, electrical conductivity (μS cm^{-1}), and dissolved oxygen (mg L^{-1}) were measured in situ on the surface with the YSI Professional Plus (ProPlus) multiparameter meter.

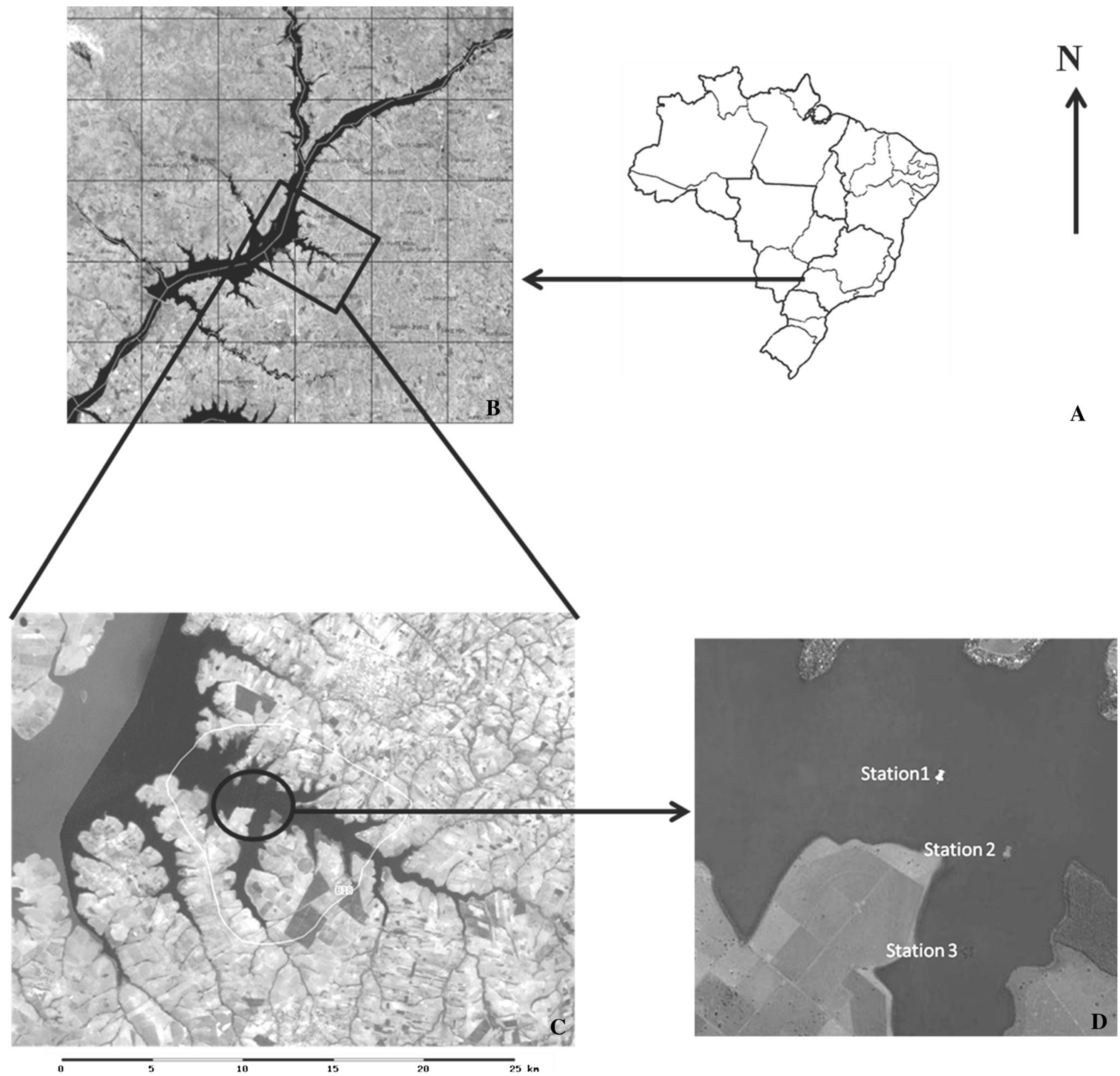


Fig. 1 **a** The *arrow* indicates the location of Ilha Solteira reservoir in São Paulo State, Brazil. **b** The *rectangle* indicates the location of the lateral arm of the Ponte Pensa River in Ilha Solteira reservoir. **c** Geneseas fish farming area (20°17′S and 50°58′O) indicated by the *dark line* and arm area of the Ponte Pensa River by the *light line*. **d** Location of sampling sites: S1 (750 m downstream from the farming site, 20°16′134″S and 50°59′107″O; average depth of 30 m), S2 (at the farming site, 20°16′452″S and 50°58′812″O; average depth of 27 m), and S3 (650 m upstream from the farming site, 20°16′853″S and 50°58′980″O; average depth of 26 m) (Mallasen et al. 2012—modified)

Water transparency (m) was estimated with a Secchi disk (m). Water samples for other abiotic variables were collected in *Van Dorn* sampling bottles. Ammonia, nitrogen, and total phosphorus were analyzed according to the methodology described in APHA (2005).

Phytoplankton samples for taxonomic analysis were collected with a 20 μm-mesh plankton net. The collected material was preserved in 4–5 % formol. Taxonomic analysis was carried out with a Zeiss Axioplan 2 imaging microscope. Samples for the phytoplankton quantitative analysis were collected from the subsurface in collecting bottles and preserved in 1 % acetic Lugol's solution. Quantitative analyses were performed according to the Utermöhl's (1958) method, on a Zeiss Axiovert 25 inverted microscope. A 50-mL sedimentation chamber was employed. The sample sedimentation time was 3 h for each centimeter of the bucket height (Lund et al. 1958). Counting limit was established through the species-rarefying curve and until reaching 100 individuals of the most common species. Each one of the cells, colonies, coenobia, and filaments was considered as an individual.

Richness (R) was considered as the total number of taxa found in each quantitative sample. Biovolume was estimated by multiplying the density of each taxon by the average volume of 30 individuals, depending on the size of the population. Cell volumes were calculated based on geometric models according to Hillebrand et al. (1999) and Fonseca et al. (2014).

Species that presented total relative biovolume above 2 % and together totaled 80 % of the total biovolume were considered as descriptor species.

Information about rainfall was provided by the São Paulo state agrometeorological center CIIAGRO (Centro Integrado de Informações Agrometeorológicas da Secretaria de Agricultura e Abastecimento do Estado de São Paulo).

The joint evaluation of abiotic data was based on the principal component analysis (PCA). The canonical correspondence analysis (CCA) was used to correlate abiotic and biotic variables (descriptor species), using PC-ORD 6.0 for Windows (McCune and Mefford 2011). Data were converted applying [log $(x + 1)$].

Results

Total annual rainfall was 1343 mm in 2011, 964 mm in 2012, and 1089.7 mm in 2013. The lowest rainfall values, below 10 mm, were recorded in winter—August/September of 2011, July/August of 2012, and July of 2013—whereas the highest, above 214 mm, were recorded in summer—January and March of 2013 (Fig. 2a). Rainfall data confirmed the seasonality, humid summer, and dry winter. The average, minimum, and maximum values of physical and chemical variables are shown in Table 1.

The principal component analysis (PCA) explained 56 % of the joint variability of the data on the two first components, indicating the seasonality as the main factor that coordinated the abiotic changes between August/2011 and December/2012. All sampling units of 2011 and most of 2012 are on the negative side of axis 1, associated with the highest values of dissolved oxygen (DO) ($r = 0.7$) and water transparency (Trans) ($r = 0.6$) (Fig. 3). On the other hand, the sampling units of 2013 are clustered on the positive side of axis 1 along with some sampling units of 2012 associated with increased concentrations of ammonium ion (NH 4) ($r = 0.8$) (Fig. 3). The sampling units of October, November, and December 2012 are grouped on axis 2 positive side, associated with increased concentrations of nitrogen and total phosphorus (TN and TP) ($r = 0.7$ and 0.5) and with high water temperatures ($r = 0.5$) (Fig. 3). PCA separated sample units in time scales; the three seasons presented the same standards and the same abiotic responses over the studied period.

Two time phases were identified: Phase 1—with samples taken before the net cages were installed, between August and December 2011 and from January to November 2012, characterized by high concentrations of dissolved oxygen and higher pH and water transparency values (negative side of axis 1, Fig. 3), and Phase 2—corresponding to samples from January to July 2013, 1 year after the installation of the net cages, characterized by higher concentrations of total phosphorus and ammonium ion and high conductivity values (positive side of axis 1, Fig. 3 PCA).

Two hundred and six taxa were identified and distributed in 11 phytoplankton groups. Chlorophyceae (73 taxa) and Cyanobacteria (34 taxa) contributed the most to species richness. In October, November, and December of 2011 and 2012, which correspond to rainy months and high temperatures, the highest richness values were recorded (Fig. 4). In November 2011, the highest richness value, 39 taxa, was recorded in S2 and the lowest values, in August 2012, in S2 and S3, eight and ten taxa, respectively.

The total biovolume of the phytoplankton community did not supersede 2.7 $mm^3 L^{-1}$ and the highest values were recorded in February 2012 and June 2013 (Fig. 5). The increase of Chlorophyceae biovolume (January, February, and March of 2012 in the three sites) was determined by greater contribution of *Coelastrum* sp. (Figs. 5, 6). The increase of Cyanobacteria biomass (May, June, and July of 2013) occurred due to the dominance of *M. aeruginosa* (Kützing) Kützing and *Dolichospermum circinalis* (Rabenhorst ex Bornet & Flahault) Wacklin, Hoffmann & Komárek (Figs. 5, 6). *M. aeruginosa* dominance was also recorded in November 2012 in S3 (Fig. 6c).

Total biovolume was mostly composed of Cryptophyceae due to high density of *Rhodomonas lacustris* Pascher & Ruttner and *Cryptomonas brasiliensis* Castro, Bicudo & Bicudo in nearly all the studied period (Figs. 5, 6). Chlorophyceae contributed the most in hotter months (November, December 2011 and 2012). Cyanobacteria contributed to most of the biovolume, especially in the last three months of the studied period. However, Cyanobacteria were also also significantly found in November 2012 in the S3 station (Fig. 5).

Among the identified taxa, ten species were classified as descriptors, contributing to 88 % of the total biovolume: *Coenocystis quadriguloides* Fott, *Coelastrum* sp., *Thorakochloris nygaardii* Fott, *C. brasiliensis* Castro, Bicudo

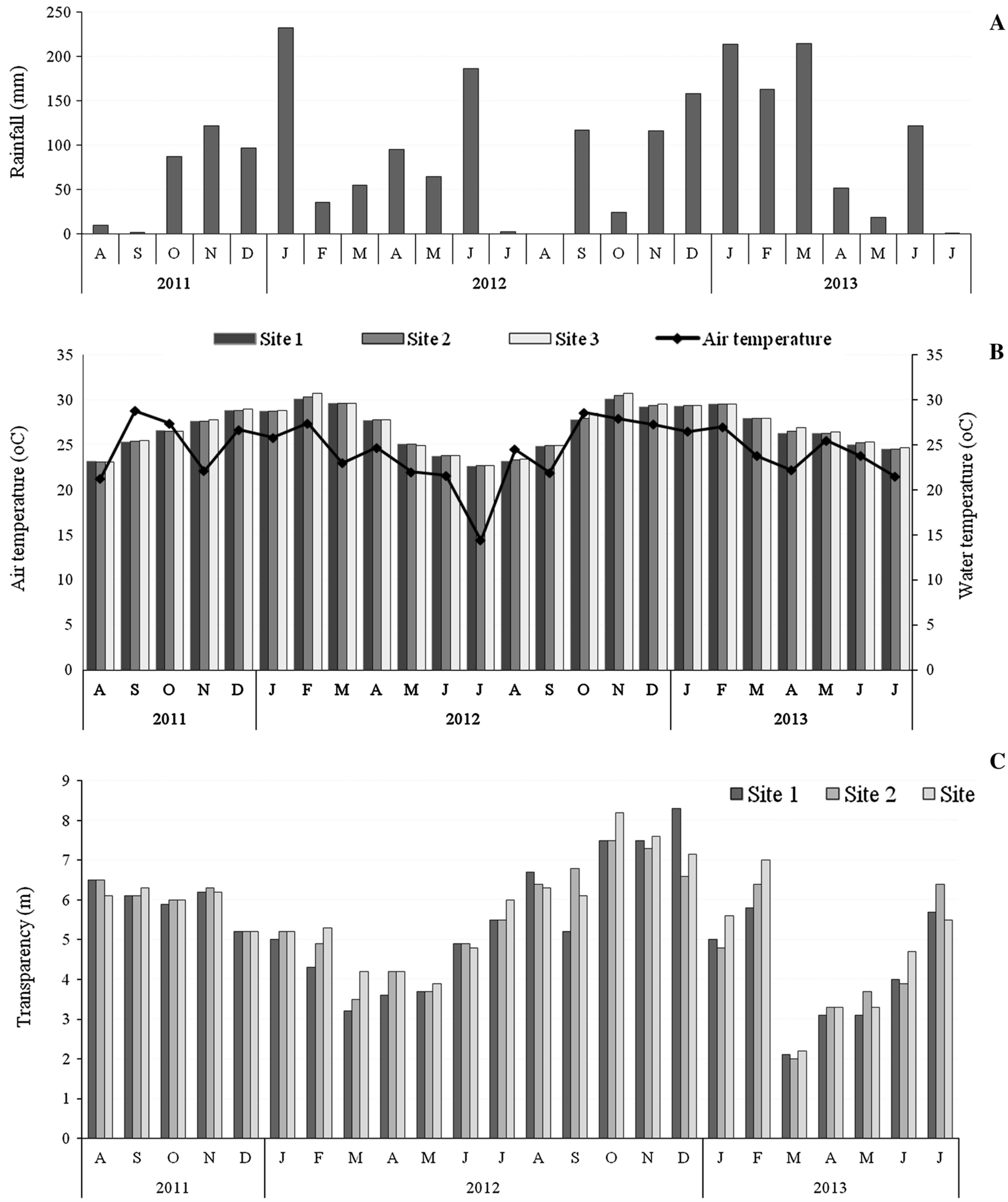


Fig. 2 Monthly rainfall (mm) (**a**) in Santa Fé do Sul, SP region, and air and water temperatures (°C) (**b**) and water transparency (m) (**c**) in sampling sites S1, S2, and S3 during the studied period (*source* CIIAGRO, Centro Integrado de Informações Agrometeorológicas da Secretaria de Agricultura e Abastecimento do Estado de São Paulo)

& Bicudo, *C. curvata* Ehrenberg, *R. lacustris* Pascher & Ruttner, *Anathece* sp., *D. circinalis* (Rabenhorst ex Bornet & Flahault) Wacklin, Hoffmann & Komárek, *M. aeruginosa* (Kützing) Kützing, and *Ceratium furcoides* (Levander) Langhans.

The canonical correspondence analysis (CCA), using six descriptor species of the system and six environmental variables, explained 47 % of the data joint variability in the first two components, presenting statistically significant ($P = 0.001$) Eigenvalue for axis 1 ($\lambda 1 = 0.662$) and axis 2 ($\lambda 2 = 0.251$) according to Monte Carlo test. The species–environment correlation was high and significant for both axes of the CCA ($P = 0.001$). The intra-set correlation and the canonical coefficient indicated that the temperature

Table 1 Physical and chemical variables related to the water in the Ponte Pensa River in Ilha Solteira reservoir and sampling stations (S1 = 1, S2 = 2, and S3 = 3), between August 2011 and July 2013

	Water temperature (C°)	Dissolved oxygen (mg L^{-1})	pH	Conductivity (μS cm^{-1})	Secchi (m)	Turbidez (UNT)	Total nitrogen (μg L^{-1})	N-NH_4 (μg L^{-1})	Total phosphorus (μg L^{-1})
S1									
Mean	27	7	8	48	5	2	368	83	18
Minimum	23	6	7	43	2	1	193	5	0
Maximum	30	9	9	54	8	8	712	189	44
S2									
Mean	27	7	7	48	5	2	398	73	26
Minimum	23	5	7	43	2	1	194	12	3
Maximum	31	9	8	53	8	7	789	179	50
S3									
Mean	27	7	8	48	5	1	324	75	17
Minimum	23	6	7	43	2	1	94	10	3
Maximum	31	9	8	53	8	6	644	196	39

(Temp) ($r = 0.8$) and ammonium (NH_4) ($r = 0.5$) were the most important variables in axis 1 ordination, whereas conductivity (Cond) ($r = 0.9$) stood out in axis 2 ordination (Fig. 7). Sample units from Phase 2 and Phase 1 were ordinated on the positive side of axis 1, associated with higher temperatures and more abundance of *Coelastrum* sp. (Coela, $r = 0.6$) and *T. nygaardii* (Thora, $r = 0.5$). Sampling units related to 2013 were ordinated on the negative side of axis 1, associated with higher concentrations of ammonium and total phosphorus and larger biomass of *M. aeruginosa* (Micro, $r = 0.4$) and *D. circinalis* (Dolic, $r = 0.3$) (Fig. 7).

Discussion

Results of the analyzed abiotic variables suggest the influence of tilapia farming in net cages in relation to time and not in relation to the sampling sites.

The fish farming system with net cages caused temporal changes in the phytoplankton community structure, especially detected as of May 2013, as shown by PCA and CCA. The hydrodynamic characteristics in the farming area, such as short residence time (21.6 days) and water flow (172 $m^3 s^{-1}$) (David et al. 2015) in addition to farming management, probably interfered with the biota and chemical compound distribution, thus explaining the similarity among the sampling sites and attenuation of possible changes in the phytoplankton community structure.

Mallasen et al. (2012) also detected spatial similarities among the sampling sites in the area of fish farming with net cages and related them to the hydrodynamic characteristics of the arm. Borges et al. (2010) and Bartozek et al. (2014), while analyzing the influence of the activities of fish farming with net cages on the phytoplankton community, reported that the effects of the activities on the water physical and chemical variables depend mainly on the intensity of the farming system, of the depth of the environment, and of the retention time of water.

The high richness recorded during the study was probably favored by rainfall, corroborating some studies on tropical and subtropical reservoirs that showed strong influence of rain on the composition of phytoplankton species (Giani and Figueiredo 1999; Bittencourt-Oliveira 2002; Kaggwa et al. 2011). Bittencourt-Oliveira (2002) attributed the increase in phytoplankton richness in rainy seasons to the highest nutrient concentrations from terrestrial runoff.

In this study, the influence of rainfall on the increased phytoplankton community richness may be associated with detachment of periphytic algae growing on the net of the cages, caused by winds and stronger rains as well as more turbulence in the water. Tucci et al. (2004) described the occurrence of the same event in Salto Grande reservoir, which influenced phytoplankton richness.

The high richness recorded in Chlorophyceae (73) and Cyanobacteria (34) corroborate works that confirmed the contribution in the number of species of these groups in continental waters: Huszar et al. (2000), Tucci et al. (2004), Deng et al. (2007), Dellamano-Oliveira et al. (2008), Fonseca and Bicudo (2008), Romanov and Kirillov (2012), and Zhang et al. (2012), indicating, in general, that they are widely distributed especially in tropical reservoirs.

The contribution of the Cryptophyceae to biovolume alternated with Chlorophyceae and Cyanobacteria along the studied period also corroborate Klaveness (1988, 1989) and Bicudo et al. (2005, 2009), who stated that the increase

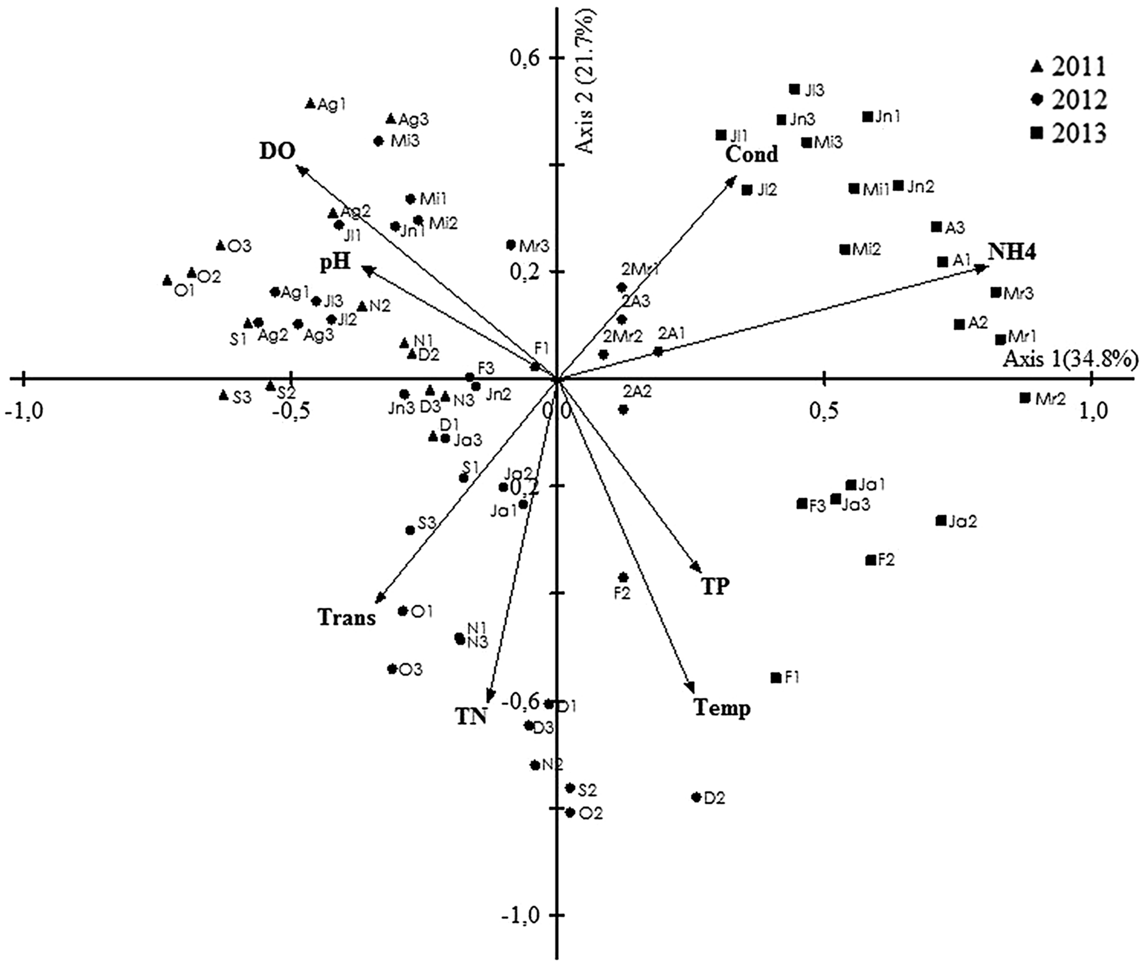


Fig. 3 Principal component analysis (PCA) based on nine limnological variables of 72 sample units (temporal and spatial). Abiotic variables: temperature (Temp), dissolved oxygen (DO), electrical conductivity (Cond), turbidity (Turb), transparency (Trans), pH, total phosphorus (TP), ammonia (NH4), and total nitrogen (TN). Sample units are identified according to the year they were collected as shown: months (*Ja* January, *F* February, *Mr* March, *A* April, *Mi* May, *Jn* June, *Jl* July, *Ag* August, *S* September, *O* October, *N* November, *D* December) and sampling sites (site 1 = 1, site 2 = 2, and site 3 = 3)

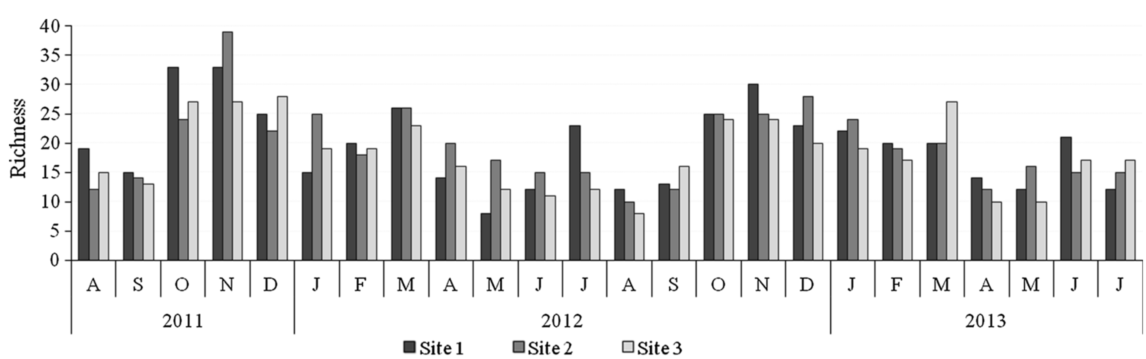


Fig. 4 Monthly variation of taxa richness in the sampling sites during the studied period (S1, S2, and S3)

of Cryptophyceae occurs when other algae groups decrease, characterizing them as "opportunistic," and Borges et al. (2010), who recorded increased Cryptophyceae density when Cyanobacteria density decreased.

The high frequency of Cryptophyceae in the entire study period can be attributed to hydrodynamics in the area of Ponte Pensa arm in the reservoir (Mallasen et al. 2012) as well as light availability (5 m of water transparency) and

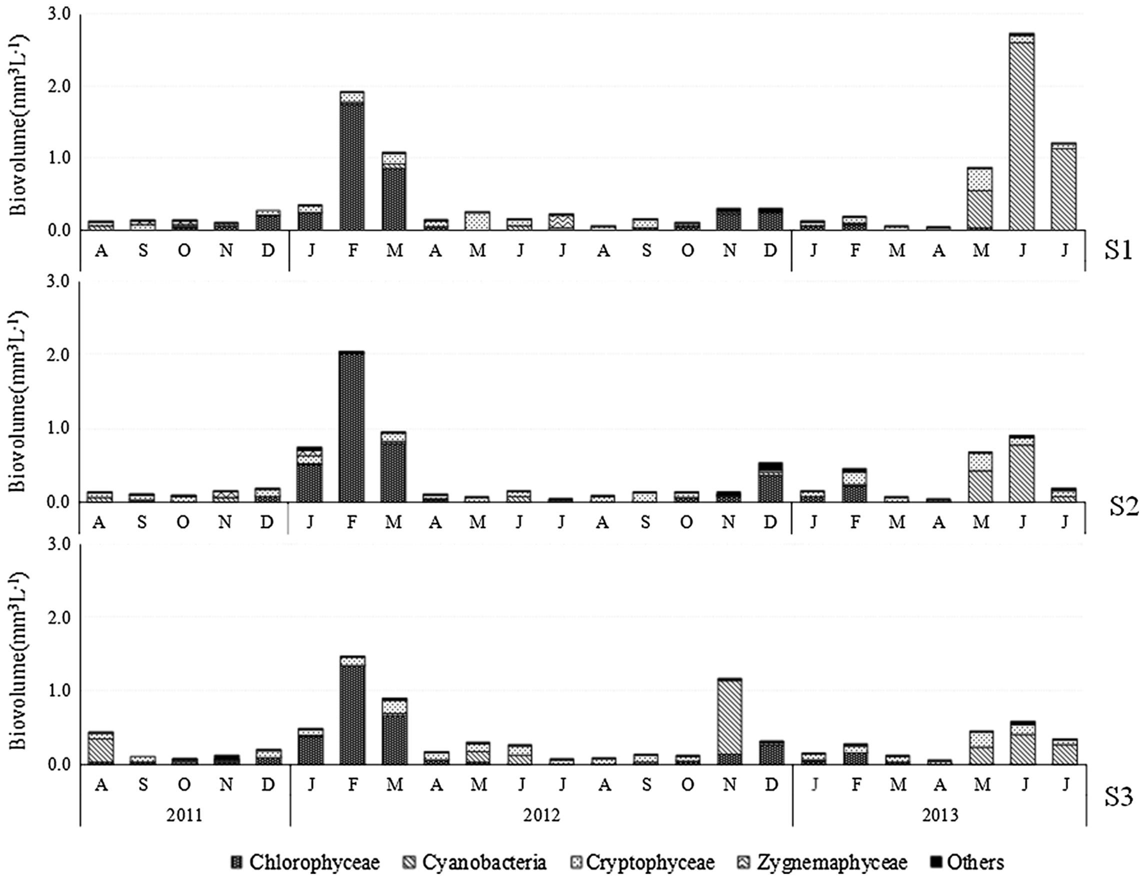


Fig. 5 Monthly variation of total biovolume (mm^3 L^{-1}) of phytoplankton classes in the three sampling sites (S1 = site 1, S2 = site 2, and S3 = site 3)

lower nutrient availability. According to Reynolds et al. (2002), Cryptophyceae species are able to develop in countless types of habitat due to the high surface-to-volume (S/V) ratio and quick growth rate.

In periods of water column mixing with high turbulence, Cryptophyceae can reach their maximum population, as documented by Klaveness (1988) and also as observed in tropical reservoirs by Santos and Calijuri (1998), Silva et al. (2005), Train et al. (2005), Pivato et al. (2006), and Rodrigues et al. (2007). The predominance of Cryptophyceae at Ponte Pensa arm over virtually the entire period may be related to mixing and turbulence conditions as mentioned in the studies referred above. We also considered that the current should be a major force function, since the three sampling sites were similar in the dynamics of environmental variables (David et al. 2015).

According to Bicudo et al. (2009), one particularity of Cryptophyceae is their continuous presence in aquatic ecosystems, i.e., they occur along the entire year, but hardly present as the dominant species. Differently from what was discussed by Bicudo et al. (2009), our results confirm the dominance of Cryptophyceae. *Rhodomonas lacustris* was dominant in over 59 % of the analyzed samples. *R. lacustris* and *C. brasiliensis* are flagellated and nanoplanktonic (6–10 µm) that require high light incidence. Minute species are characterized by relatively easy dispersion, due to their size ($v < 10^3$ µm^3), fast absorption and assimilation of nutrients, and high rates of reproduction ($r_{20} > 10 \times 10^{-6}$ s^{-1}), facilitated by the high sv^{-1} ratio (>0.5 µm^{-1}) (Brasil and Huszar 2011). We have attributed the species dominance to these characteristics which allow these organisms to thrive in turbulent and oligotrophic environments with high incidence of light where concentrations of essential nutrients like nitrogen and phosphorus are low as in the studied environment (Lopes et al. 2005; Oliveira and Calheiros 2000).

The ecological importance of Cyanobacteria is related to their capacity to develop blooms of toxic species especially in tropical eutrophic environments (Huszar et al. 2000; Komárek et al. 2002; Oliver and Ganf 2000; Tucci and Sant'Anna 2003; Honda et al. 2006; Deng et al. 2007; Sant'Anna et al. 2008; Kosten et al. 2012). Despite high concentrations of nitrogen and phosphorus in the food, Cyanobacterial blooms were not recorded. However, in

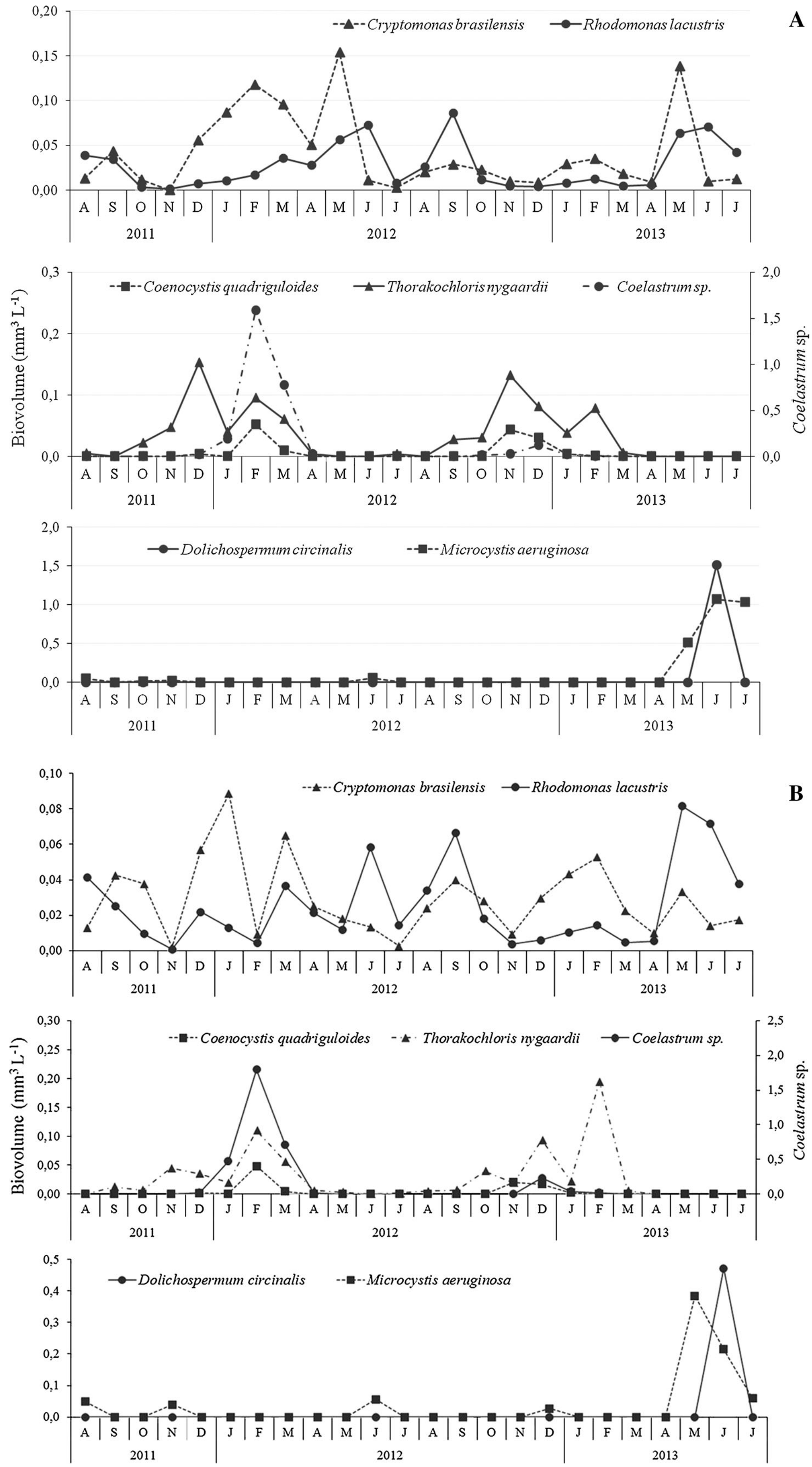
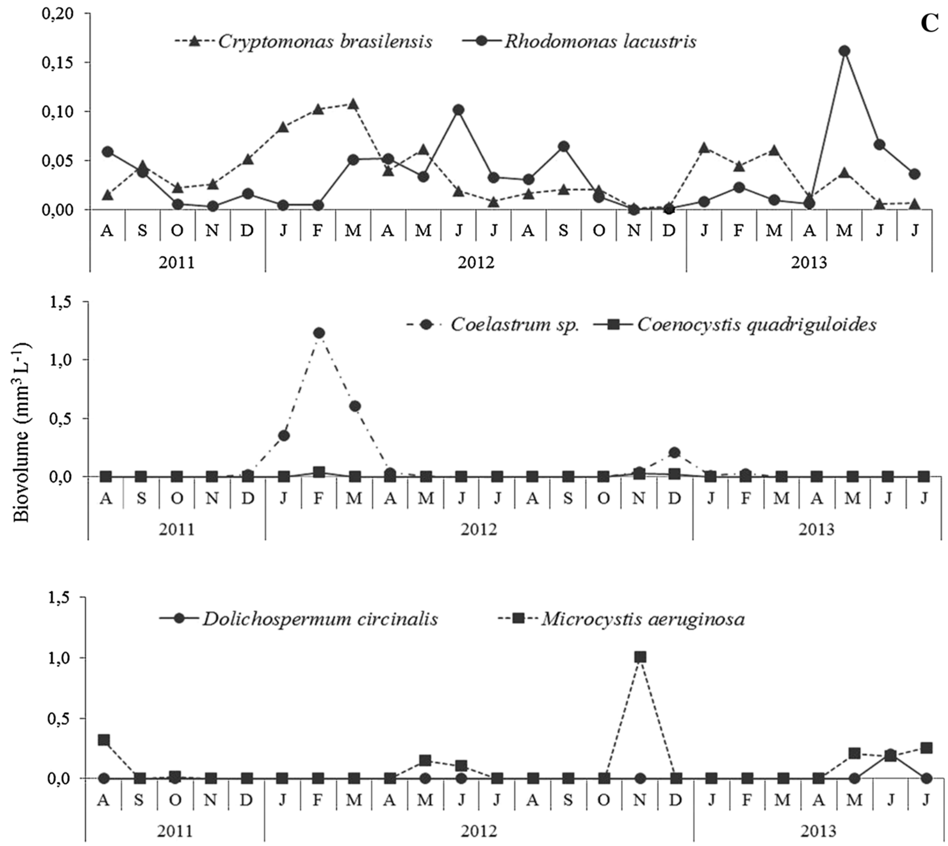


Fig. 6 Temporal variation of descriptor species in the three sampling sites: S1 (**a**), S2 (**b**), and S3 (**c**). Scales with different magnitudes

Fig. 6 continued



November of 2012 and over the last three months of the study period, higher biovolumes of Cyanobacteria were recorded, due to the dominance of *M. aeruginosa* and *D. circinalis*. *Microcystis* and *Dolichospermum* have the highest number of toxic species in Brazil. However, toxic events of these genera have a different distribution. Blooms of *Microcystis* toxic species occur both in tropical and subtropical regions, whereas data on *Dolichospermum* toxic bloom occurrence are restricted to subtropical regions. Therefore, *Microcystis* species seem to have greater tolerance to different climates and environmental conditions than do the species of *Dolichospermum* (Sant'Anna et al. 2008).

Despite being widely distributed in continental waters, *Microcystis aeruginosa* reaches high densities in eutrophic conditions, characterized by low chemical and thermal stability, low turbulence, and irradiance (Michard et al. 1996; Oliver and Ganf 2000), whereas *D. circinalis* can reach high densities both in stratification conditions in the water column (Reynolds et al. 2002; Westwood and Ganf 2004) and in the water column mixing (Becker et al. 2004; Bovo-Scomparin and Train 2008).

The studied environment does not present favorable trophic conditions for the ample development of both species. However, in the last six months of the study period, i.e., 1 year after the beginning of the tilapia farming, increased concentrations of ammonia and total phosphorous were recorded, conditions that might have been favorable to the increase of biomass of these species. This statement can be confirmed through CCA which indicates strong association of these species with increased concentrations of total phosphorus and ammonium ion.

Our results indicate that the activities related to tilapia farming using the net cage system promoted increased concentrations of nutrients in the water, especially ammonium ion and total phosphorus, and consequently changes in the structure of the phytoplankton community attested by the increase in the Cyanobacterial biomass in the last three months of the study period.

We have concluded that in time the structure and dynamics of the phytoplankton community were influenced by the production of tilapia in net cages. However, changes in sampling seasons were not recorded. Changes were observed in chemical variables such as increased concentrations of ammonia and total phosphorous. In time, changes in abiotic variables were reflected, although subtly, in the community structure and dynamics. One year after the net cages were installed, in 2013, the greatest biovolume of *M. aeruginosa* and *D. circinalis* was recorded compared with the other identified species, and these two

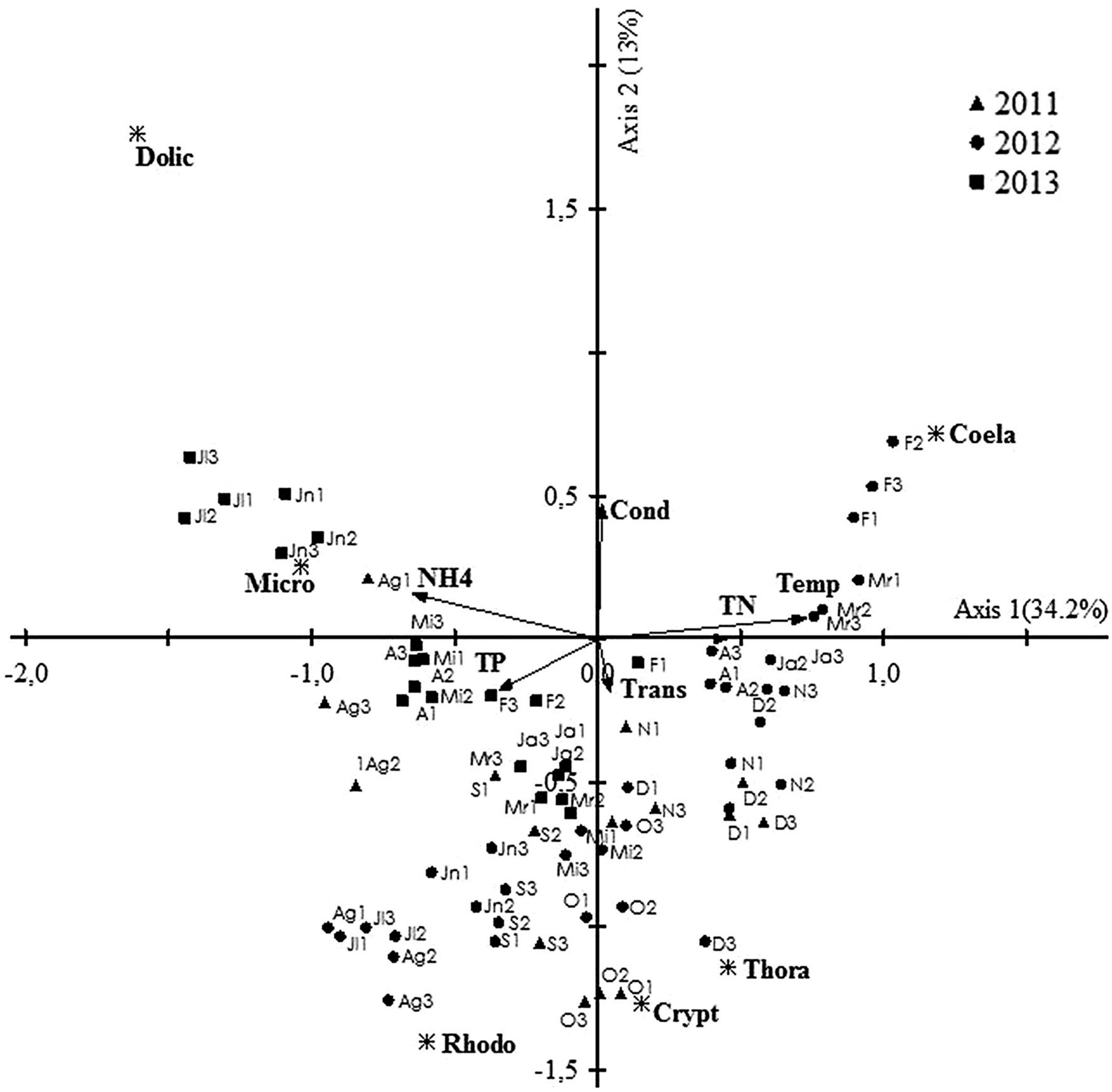


Fig. 7 Ordination according to CCA (axes 1 and 2) of 72 sampling units generated from the six descriptor species in the system and six abiotic variables: temperature (Temp), electrical conductivity (Cond), transparency (Trans), total phosphorous (TP), ammonium (NH4), and total nitrogen (TN). Species: *Rhodomonas lacustris* (Rhodo), *Cryptomonas brasiliensis* (Crypto), *Coelastrum* sp. (Coela), *Thorakochloris nygaardii* (Thora), *Microcystis aeruginosa* (Micro), and *Dolichospermum circinalis* (Dolic). Sampling units are identified according to collection year as shown: months (*Ja* January, *F* February, *Mr* March, *A* April, *Mi* May, *Jn* June, *Jl* July, *Ag* August, *S* September, *O* October, *N* November, *D* December) and sampling stations (S1 = 1, S2 = 2, and S3 = 3)

cyanobacteria species were associated with higher concentrations of ammonia and total phosphorous. The hydrodynamic characteristics of the analyzed system, such as short residence time (21.6 days) and outflow (172 $m^3\ s^{-1}$), probably facilitated the assimilation of disturbances in the water quality caused by the employed production process and, therefore, serve as determinant in attenuating the impact of the organic load (from feed and fish metabolism) in the studied aquatic system.

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References

American Public Health Association (APHA) (2005) Standard methods for the examination of water and wastewater, 27th edn. American Public Health Association, Washington

Bartozek ECR, Bueno NC, Rodrigues LC (2014) Influence of fish farming in net cages on phytoplankton structure: a case study in a subtropical Brazilian reservoir. Braz J Biol 70:145–155

Becker VL, Cardoso S, Marques MD (2004) Development of Anabaena Bory (Cyanobacteria) blooms in a subtropical shallow lake, south Brazil. Acta Limnol Bras 16:306–317

Bicudo DC, Ferragut C, Crossetti LO, Bicudo CEM (2005) Efeito do Represamento sobre a Estrutura da Comunidade Fitoplanctônica do Reservatório de Rosana, Baixo Rio Paranapanema, Estado de São Paulo. In: Nogueira MG, Henry R, Jorcin A (eds) Ecologia de Reservatórios: Impactos Potenciais, Ações de Manejo e Sistemas em Cascata. Rima, São Carlos, pp 349–377

Bicudo CEM, Ferragut C, Massagardi MR (2009) Cryptophyceae population dynamics in an oligo-mesotrophic reservoir (Ninféias Pond) in São Paulo, southeast Brazil. Hoehnea 36:99–111

Bittencourt-Oliveira MC (2002) A comunidade fitoplanctônica do Rio Tibagi: uma abordagem preliminar de sua diversidade. In: Medri MM, Bianchini E, Shibatta OA, Pimenta JA (eds) A Bacia do rio Tibagi. FUEL, Londrina, pp 373–402

Borges PA, Train S, Dias JD, Bonecker CC (2010) Effects of fish farming on plankton structure in a Brazilian tropical reservoir. Hydrobiologia 649:279–291

Bovo-Scomparin VM, Train S (2008) Long-term variability of the phytoplankton 75 community in an isolated floodplain lake of the Ivinhema River State Park, Brazil. Hydrobiologia 610:33–344

Boyd CE, Tucker C, Mcnevin A, Bostick K, Clay J (2007) Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. Fish Sci 15:327–360

Brasil J, Huszar VL (2011) The role of the functional traits on the phytoplankton ecology in inland waters. Oecol Aust 15:799–834

Cavalcante DP (2010) Criação de peixes nativos em tanques-rede: Influência sobre a qualidade de água e sobre as populações planctônicas do reservatório da usina hidrelétrica Itá. Tese de Doutorado, Universidade Federal de Santa Catarina, Florianópolis

Companhia Energética de São Paulo (CESP) (2006) 40 Peixes do Brasil: CESP 40 anos, Rio de Janeiro

David GS, Carvalho ED, Lemos DEL, Silveira NA, Dallĭ Aglio-Sobrinho M (2015) Ecological carrying capacity for intensive tilápia (*Oreochromis niloticus*) cage aquaculture in a large hydroelectrical reservoir in Southeastern Brazil. Aquac Eng 66:30–40

Deblois CP, Aranda-Rodriguez R, Giani A, Bird DF (2008) Accumulation in liver and muscle of tilapia in two large Brazilian hydroelectric reservoirs. Toxicon 51:435–448

Dellamano-Oliveira MJ, Vieira AAH, Rocha O, Colombo V, Sant'Anna CL (2008) Phytoplankton taxonomic composition and temporal changes in a tropical reservoir. Fundam Appl Limnol/Archiv für Hydrobiologie 171:27–38

Deng DG, Xie P, Zhou Q, Yang H, Guo LG (2007) Studies on temporal and spatial variations of phytoplankton in Lake Chaohu. J Integr Plant Biol 49:409–418

Diaz MM, Temporetti PF, Pedrozo FL (2001) Response of phytoplankton to enrichment from cage fish farm waste. In: Alicura Reservoir (Patagonia, Argentina). Lakes Reserv 6:151–158

Dörr FA, Pinto E, Soares RM, Azevedo SMFO (2010) Microcystins in South American aquatic ecosystems: occurrence, toxicity and toxicological assays. Toxicon 56:1247–1256

Eler MN, Campagna AF, Minillo A, Ribeiro MAP, Espindola ELG (2009) Water quality, toxicity and gill lesions caused by intraperitoneally administered water-bloom crude extract in *Bryconcephalus* (Günter, 1896; Characidae) from fee-fishing ponds in São Paulo state, Brazil. Acta Limnol Bras 21:89–100

Fonseca BM, Bicudo CEM (2008) Phytoplankton seasonal variation in a shallow stratified eutrophic reservoir (Garças Pond Brazil). Hydrobiologia 600:267–282

Fonseca BM, Ferragut C, Tucci A, Crossetti LO, Ferrari F, Bicudo DC, Sant'Anna CL, Bicudo CEM (2014) Biovolume of Cyanobacteria and algae from Brazilian tropical reservoirs with different trophic status. Hoehnea 41:9–30

Food and Agriculture Organization of the United Nations (FAO) (2014) The state of world fisheries and aquaculture. Rome. http://www.fao.org/3/a-i3720e.pdf. Accessed May 22, 2014

Giani A, Figueiredo CC (1999) Recorrência de padrões sazonais do fitoplâncton num reservatório eutrófico. In: Henry R (ed) Ecologia de reservatórios: estrutura função e aspectos sociais. FAPESP/FUNDIBIO, Botucatu, pp 653–685

Guarino AWS, Branco CWC, Diniz GP, Rocha R (2005) Limnological characteristics of an old tropical reservoir (Ribeirão da Lages Reservoir, RJ, Brazil). Acta Limnol Bras 17:129–141

Guo L, Li Z (2003) Effects of nitrogen and phosphorus from fish cage-culture on the communities of a shallow lake in middle Yangtze River basin of China. Aquaculture 226:201–212

Guo L, Zhongjie L, Xie P, Ni L (2009) Assessment effects of cage culture on nitrogen and phosphorus dynamics in relation to fallowing in a shallow lake in China. Aquacult Int 17:229–241

Hillebrand H, Dürselen CD, Kirschtel D, Pollingher U, Zohary T (1999) Biovolume calculation for pelagic and benthic microalgae. J Phycol 35:403–424

Honda RY, Mercante CTJ, Vieira JMS, Esteves KE, Cabianca MAA, Azevedo MTP (2006) Cianotoxinas em pesqueiros da Região Metropolitana de São Paulo. In: Esteves KE, Sant'Anna CL (eds.) Pesqueiros sob uma visão integrada de meio ambiente saúde pública e manejo. Rima, São Paulo, pp 105–120

Huszar VLM, Silva LHS, Marinho MM, Domingos P, Sant'Anna CL (2000) Cyanoprokaryote assemblages in eight productive tropical Brazilian waters. In: Reynolds CS, Dokulil M, Padisak J (eds) The trophic spectrum revisited: the influence of trophic state on the assembly of phytoplankton communities Kluwer. Academic Publishers, Dordrecht, pp 67–77

Kaggwa MN, Liti DM, Schagerl M (2011) Small tropical reservoirs and fish cage culture: a pilot study conducted in Machakos district, Kenya. Aquacult Int 19:839–853

Klaveness D (1988) Ecology of the Cryptomonadida: a first review. In: Sandgren CD (ed) Growth and reproductive strategies of freshwater phytoplankton. Cambridge University Press, New York, pp 105–133

Klaveness D (1989) Biology and ecology of the Cryptophyceae: status and challenges. Biol Oceanogr 6:257–270

Komárek J, Komárková-Legnerová J, Sant'Anna CL, Azevedo MTP, Senna PAC (2002) Two common *Microcystis* species (Chroococcales, Cyanobacteria) from tropical America, including *M. panniformis* sp. nov. Cryptogam Algol 23:159–177

Kosten S, Huszar VL, Bécares E, Costa LS, Donk E, Hansson L, Jeppesen E, Kruk C, Lacerot G, Mazzeo N, Meester LDB, Moss B, Lürling M, Nõges T, Romo S, Scheffer M (2012) Warmer climates boost cyanobacterial dominance in shallow lakes. Glob Change Biol 18:118–126

Lins RPM (2011) Estrutura e dinâmica da comunidade fitoplanctônica em um reservatório eutrófico do trópico semiárido brasileiro. Universidade Federal de Campina Grande, Campina Grande, Tese de Doutorado

Lopes MRM, Bicudo CEM, Ferragut C (2005) Spatial and temporal variation of phytoplankton in a shallow tropical oligotrophic reservoir, southeast Brazil. Hydrobiologia 542:235–247

Lund JWG, Kipling C, Legren ED (1958) The invert microscope method of estimating algal numbers and the statistical basis of estimations by counting. Hydrobiologia 11:143–170

Magalhães VF, Marinho MM, Domingos P, Oliveira AC, Costa SM, Azevedo LO, Azevedo SMFO (2003) Microcystins (cyanobacteria hepatotoxins) bioaccumulation in fish and crustaceans from Sepetiba Bay (Brasil, RJ). Toxicon 42:289–295

Mallasen M, Carmo CF, Tucci A, Barros HP, Rojas NET, Fonseca FS, Yamashita EY (2012) Water quality in Cage system fish farm in Ilha Solteira reservoir, SP. Boletim do Instituto de Pesca 38:15–30

McCune B, Mefford MJ (2011) PC-ORD. Multivariate analysis of ecological data. Version 6.0 MjM Software. Gleneden Beach, Oregon

Michard M, Aleya L, Verneaux J (1996) Mass occurrence of the Cyanobacteria *Microcystis aeruginosa* in the Hypereutrophic Villerest Reservoir (France): usefulness of the biyearly examination of N/P and P/C couplings. Archivfür Hydrobiologie 135:337–359

Ministério da pesca e aquicultura (MPA) (2011) Boletim Estatístico da Pesca e Aquicultura. Brasília: Ministério da Pesca e Aquicultura. http://www.mpa.gov.br/index.php/imprensa/noticias/2140-mpa-lanca-boletim-estatistico-da-pescae-aquicultura-2011. Accessed May 22, 2014

Oliveira MD, Calheiros DF (2000) Flood pulse influence on phytoplankton communities of the south Pantanal floodplain, Brazil. Hydrobiologia 427:101–112

Oliver RL, Ganf GG (2000) Freshwater blooms. In: Whitton BA, Potts M (eds) The ecology of Cyanobacteria: their diversity in time and space. Kluwer Academic Publishers, Dordrecht, pp 149–194

Ostrensky A, Borghetti JR, Soto ED (2008) Aqüicultura no Brasil: o desafio é crescer. SEAP/FAO, Brasília

Pivato BM, Train S, Rodrigues LC (2006) Nictemeral variation of phytoplanktonic assemblages in a tropical reservoir (Corumbá reservoir, Goias State, Brazil), during two periods of the hydrological cycle. Acta Sci Biol Sci 28:19–29

Reynolds CS, Huszar VLM, Kruk C, Naselli-Flores L, Melo S (2002) Towards a functional classification of the freshwater phytoplankton. J Plankton Res 24:417–428

Rodrigues SC, Torgan L, Schwarzbold A (2007) Composição e variação sazonal da riqueza do fitoplâncton na foz de rios do delta do Jacuí, RS, Brasil. Acta Bot Bras 21:707–721

Romanov RE, Kirillov VV (2012) Analysis of the seasonal dynamics of river phytoplankton based on succession rate indices for key event identification. Hydrobiologia 695:293–304

Sant'Anna CL, Azevedo MTP, Werner WR, Dogo CR, Rios FR, Carvalho LR (2008) Review of toxic species of Cyanobacteria in Brasil. Algol Stud 126:249–263

Santos ACA, Calijuri MC (1998) Survival strategies of some species of the phytoplankton community in the Barra Bonita Reservoir (São Paulo, Brazil). Hydrobiologia 367:139–152

Seymour EA (1980) The effects and control of algae blooms in fish ponds. Aquaculture 88:1–20

Silva CA, Train S, Rodrigues LC (2005) Phytoplankton assemblages in a Brazilian subtropical cascading reservoir system. Hydrobiologia 537:99–109

Smith JL, Boyer GL, Zimba PV (2008) A review of cyanobacterial odorous and bioactive metabolites: impacts and management alternatives in aquaculture. Aquaculture 280:5–20

Souza SMG, Mathies VD, Fioravanzo RF (2012) Off-flavor by geosmine and 2-methylisoborneolin aquaculture. Semina Ciências Agrárias 33:835–846

Train S, Jati S, Rodrigues LC, Pivato BM (2005) Distribuição Espacial e Temporal do Fitoplâncton em Três Reservatórios da Bacia do Rio Paraná. In: Rodrigues L, Thomaz SM, Agostinho AA, Gomes LC (eds) Biocenoses em Reservatórios: Padrões Espaciais e Temporais. Rima, São Carlos, pp 73–85

Tucci A, Sant'Anna CL (2003) *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya & Subba Raju (Cyanobacteria): weekly variation and relation with environmental factors in an eutrophic lake, São Paulo, SP, Brazil. Revista Brasileira de Botânica 26:97–112

Tucci A, Deberdt J, Deberdt GLB (2004) Análise da comunidade fitoplanctônica do reservatório de Salto Grande (Americana, SP): uma revisão dos estudos desenvolvidos em sistemas eutróficos. In: Espíndola ELG, Leite MA, Dornfeld CB (eds.) Reservatório de Salto Grande (Americana, SP): caracterização, impactos e propostas de manejo. Rima, São Carlos, pp 107–153

Utermöhl H (1958) Zur Vervolkomnung der quantitativen Phytoplankton: methodik. Mitteilungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie 9:1–38

Westwood KJ, Ganf GG (2004) Effect of mixing patterns and light dose on growth of *Anabaena circinalis* in a turbid, low land river. River Res Appl 20:115–126

Xavier MB, Mainardes-Pinto CSR, Takino M (1991) *Euglena sanguinea* Ehrenberg Bloom in a fish-breeding tank (Pindamonhagaba, São Paulo, Brasil). Algol Stud 62:133–142

Zhang M, Yu Y, Yang Z, Shi XL, Kong FX (2012) The distribution of phytoplankton along trophic gradients and its mediation by available light in the pelagic zone of large eutrophic lakes. Can J Fish Aquat Sci 69:1935–1946