Temporal and spatial dynamics of phytoplankton near farm fish in eutrophic reservoir in Pernambuco, Brazil

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Abstract

Spatial and temporal variations in phytoplankton communities in continental waters have received attention from limnologists, since they are differently influenced by many physico-chemical and biological factors. This study was undertaken with the aim to identify the environmental variables that influence the temporal and spatial dynamics of the phytoplankton near a fish farm in the Jucazinho reservoir, in a semi-arid region of Northeastern Brazil. Samples were taken from three sampling sites, at two depths during the rainy (Aug 2008, Feb and Mar 2009) and dry (Oct, Nov and Dec 2008) seasons. Phytoplankton was identified, density determined, and biomass values obtained. Concomitantly, abiotic analyses were performed for the characterization of the system. The reservoir was homogeneous with regard to the spatial-temporal variation in hydrological variables: water well oxygenated at the surface and anoxic at the bottom; pH ranging from neutral to alkaline; temperatures always above 25°C; high turbidity; and high electrical conductivity at all sampling sites and both depths. For both seasons, there was limited nitrogen and high concentrations of phosphorus. Cyanophyta species were predominant, generally representing 80% of the phytoplankton biomass throughout practically the entire study, at all sampling sites and both depths. Co-dominance of cyanobacteria belonging to H1, MP, S1 and Sn associations was recorded in most of the months studied, except August 2008, when there was a substitution of the S1 association (Planktothrix agardhii) by the P association (Aulacoseira granulata). Water temperature, precipitation and pH were the parameters with the greatest influence over the temporal variation in phytoplankton, whereas the vertical distribution of the phytoplankton biomass was directly related to the availability of light in the water column. There were no spatial or temporal differences in water quality, likely due to the fact that the sampling sites were near to one another and received the same nutrients stemming from the rations given to the fish as well as their excrement. The predominance of cyanobacteria through the study was certainly due to the influence of the feeding products offered to and excreted from the fish, which eutrophicated the system. In temporal terms, the change in the algal structure is explained by the change in the physical conditions of the water between the surface and bottom, as well as the climatologic conditions, especially the change in wind direction, with the consequent fetch of the water. Rev. Biol. Trop. 60 (2): 581-597. Epub 2012 June 01.

Key words: availability of light, Brazil, climatologic variations, Jucazinho reservoir, phytoplankton associations.

Resumen

Las variaciones espaciales y temporales en las comunidades de fitoplancton en las aguas continentales han recibido la atención de limnólogos, ya que están influenciados de manera diferente por muchos factores físico-químicos y biológicos. El objetivo del presente trabajo fue identificar las variables ambientales que ejercieron influencia sobre la dinámica temporal y espacial de la comunidad fitoplanctónica cerca a una granja piscícola en el represa de Jucazinho, la cual se encuentra en la región semiárida brasileña. Las recolecciones fueron realizadas en tres estaciones de monitoreo a dos profundidades, durante los periodos lluviosos (agosto 2008 y febrero, marzo 2009) y de sequía (octubre, noviembre y diciembre 2008). El fitoplancton fue identificado y su densidad determinada, y posteriormente convertida a biomasa. También se realizaron análisis abióticos para caracterizar el sistema. La represa resultó homogénea en cuanto a la variación espacial-temporal de las variables hidrológicas, agua oxigenada en la superficie y anóxica en el fondo, pH variando entre 8-8.5, temperaturas superiores a 25°C y alta turbidez y electricidad elevadas. En los dos periodos estacionales fueron observadas limitaciones de nitrógeno y elevadas concentraciones de fósforo. Las Cyanophyta fueron predominantes en el ambiente y representaron en general más del 80% de la biomasa fitoplanctónica durante prácticamente todo el periodo de estudio en todas las estaciones y profundidades de recolección. La co-dominancia de cyanobacterias pertenecientes a las asociaciones H1, MP, S1 y Sn, fue registrada durante la mayor parte del periodo de estudio, excepto en... 

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Spatial and temporal variations in the phytoplankton community have received attention from limnologists worldwide for many years. A number of studies on this community have focused on environmental gradients, demonstrating that the availability of light and nutrients exerts the greatest influence over the spatial and temporal dynamics of phytoplankton in temperate, subtropical and tropical environments (Beyruth 2000, Zanata & Espíndola 2002, Diehl 2007, Wondie et al. 2007, Borges et al. 2008, Caputo et al. 2008, Dejenie et al. 2008, Lohrenz et al. 2008, Sarmento et al. 2008). Studies have also demonstrated the importance of other variables to the spatial distribution of phytoplankton in reservoirs, such as temperature, water transparency, water conditions, size and use of the aquatic environment and the structure of the food chain, which can cause horizontal and vertical changes in the structure of this community (Barbiero et al. 1999, Zanata & Espíndola 2002). Others also show the importance of regional climate, hydrological patterns and geo-morphology to the temporal dynamics of phytoplankton, which can cause changes in the availability of nutrients, water flow intensity and the length of time water remains in a reservoir (Tundisi & Matsumura-Tundisi 2008).

Morpho-physiological factors and buoyancy strategies among species are directly related to spatial variation in phytoplankton, especially vertical variation. Reynolds (1984) recognizes three distinct groups of algae: 1) non-mobile algae, with negative buoyancy and considerable sinking velocity; 2) algae with positive buoyancy, which are able to float due to gas vesicles; and 3) mobile algae with neutral buoyancy and structures capable of counteracting the sinking process, such as spines and/or flagellates that allow them to move throughout the water column.

According to Tundisi and Matsumura-Tundisi (2008), studies on the variation and spatial distribution of phytoplankton are important to determine the spatial variability of organisms, and are fundamental to the preparation of sampling programs and the administration of statistical validation methods. This way, the spatial heterogeneity of phytoplankton is considered a structural and functional characteristic of aquatic ecosystems (Armengol et al. 1999).

According to Díaz et al. (2001), the amount of dissolved nutrients (especially phosphorus and ammonium), released through the activities of aquaculture may be considered small in comparison to the total nutrient levels from household and industrial effluents. However, fish farms may represent a local source of nutrients in oligotrophic environments. The impact of fish farming activities may indeed be quite significant due to the addition of large amounts of carbon, nitrogen and phosphorus into the environment, thereby stimulating phytoplankton production with the frequent introduction of cyanobacteria, such as Anabaena, Microcystis, size Oscillatoria. However, Chellappa and Costa (2003) found that the introduction of intensive fish farming in the Gargalheiras reservoir in the state of Rio Grande do Norte (Northeastern Brazil), previously dominated by cyanobacteria, provided favorable conditions for the dominance of species of Chlorophyceae, especially Chlorococcales.

The demand of potable water in Northeastern Brazil is huge, especially in semi-arid regions. A number of reservoirs have been constructed to minimize the impact of drought. These water bodies are used for different purposes, especially to supply drinking water to urban populations. However, the consumption of untreated water by communities near these ecosystems is quite common.

Jucazinho has considerable importance among the different reservoirs in Northeastern Brazil. It is the largest drinking-water reservoir in the state of Pernambuco, providing water to over 800,000 inhabitants in the semi-arid region. This system is currently used for different purposes, including the intensive farming of the Nile tilapia (Oreochromis niloticus Linnaeus, 1758), which is an important activity for income generation to the surrounding communities and the diversification of the economy. Nonetheless, intensive fish farming may accelerate the deterioration of water quality by increasing the nutrient content, overnourishing the water and causing changes to the composition and dominance of species of phytoplankton (Díaz et al. 2001), which leads to the development of potentially toxic cyanobacterial blooms (Guo & Li 2003). Moreover, studies have shown that the Nile tilapia exhibits a high potential for fish-induced eutrophication due to its high defecation rates (Datta & Jana 1998, Starling et al. 2002, Lazzaro et al. 2003, Panosso et al. 2007).

While the ecology of reservoirs has been well studied throughout the world (Scheffer 1998), the majority of investigations have been addressed to temperate environments (Moss 1998), whereas studies on reservoirs in semi-arid regions are relatively scarce (Naselli-Flores 2003). The aim of the present study was to test the hypothesis that spatial and temporal variation occurs in the dynamics of the phytoplankton community in an eutrophicated tropical ecosystem.

**Materials and methods**

**Study area:** The Jucazinho reservoir (Fig. 1) (07°57’50” S - 35°44’27” W) is located at 300m above sea level in a semi-arid region of the Caatinga biome between the municipalities of Cumaru, Riacho das Almas and Surubim in the state of Pernambuco (Northeastern Brazil). The region has a warm, semi-arid, low-latitude climate (BSHs), with a mean annual temperature of 25° C, mean annual precipitation of 599mm, irregularly distributed rains throughout the year (Albuquerque & Andrade 2002) and a mean wind speed of 5.0m/s.

**Palabras clave:** disponibilidad de luz, Brasil, variaciones climatológicas, represa Jucazinho, asociaciones del fitoplancton.
Jucazinho is the largest reservoir in the state of Pernambuco, with a volume of 327 million m$^3$, providing water for approximately 800,000 inhabitants. Its maximal depth is 40m and the theoretical residence time is 2103 days. Constructed over granitic rock and litholytic soil, Jucazinho reservoir is currently hypertrophic (Melo-Júnior et al. 2007). Areas of native Caatinga and farmlands surround this ecosystem, on which the main activities are subsistence farming and cattle breeding. In 2006, the Brazilian National Water Agency (ANA, Brazil), allowed the installation of six intensive fish farms to raise the Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) in tank-net systems in this ecosystem. Each farm has a volume of 1,800m$^3$, totaling 10,800m$^3$. Thus, the farms occupy less than 1% of the total volume of the reservoir. Dantas (2010) carried out a study between May 2007 and May 2008 in this same reservoir near the collection sites used in the present study and found that the occurrence of stratification (Zmix<3m) was common throughout the year and that thermal variation between the surface and bottom was more than 1ºC (Fig. 2).

**Sampling and analyses:** Water samples for nutrient analysis and the investigation of the phytoplankton community (taxonomic and density studies), were collected at the same time with two repetitions (n=2) using a vertical van Dorn bottle with a capacity of 3L. The samples were collected from three sampling stations (Fig. 1) at two depths (subsurface and ~0.5m from the bottom) in the dry (Oct, Nov and Dec 2008) and rainy (Aug 2008, Feb and Mar 2009) seasons.

The sampling stations were established near the fish farming tanks in the reservoir. Site 1 (S1) was located 600m upstream from the tanks (S1: 07º59’00.1” S - 35º49’03.9”W); this site has a minimal and maximal depth of 17.5m and 23.9m, respectively. Site 2 (S2) was established 100m downstream from the tanks (07º58’57.5” S - 35º48’39.3” W), and has a minimal and maximal depth of 22.7m and 26.0m, respectively. Site 3 (S3) was established 500m from S2 (07º58’43.4”S - 35º48’25.4”W), and has a minimal and maximal depth of 12.2m and 22.0m, respectively.

Air temperature (ºC), precipitation (mm), wind direction (º) and wind speed (m/s) were obtained from the Brazilian National Meteorology Institute. The following variables were determined in the field: water temperature (ºC) and dissolved oxygen (mg/L) using an oximeter (Schott Glaswerke Mainz, handylab OX1); electrical conductivity (μS/cm) using a conductivity meter (Hanna Instruments HI8733); turbidity of the water (UNT) using a turbidimeter (Hanna Instruments, HI 93703); pH using a potentiometer (Digimed, DMPH-2); and water transparency (m) using a Secchi disk. The limit of the euphotic zone (Zeu) was calculated as 2.7 times the Secchi depth (Cole 1983). The determination of total nitrogen (TN - μg/L) and total phosphorus (TP - μg/L) was performed based on the method described by Valderrama (1981). The TN: TP ratio was calculated based on the method described by Downing & McCauley (1992).

Samples for taxonomic and density analyses (n=2) were preserved in acetic Lugol’s solution. Morphometric features of the reproductive and vegetative phases were analyzed under a Zeis microscope (model Axioskop), equipped with a photographic camera and ocular with a measurement grid and identified down to the lowest possible taxonomic level using specific literature, such as Prescott & Vinyard (1982), Komárek & Fott (1983), Komárek & Anagnostidis (1989), Popovský & Pfister (1990), Krammer &
The Utermöhl method (Utermöhl 1958), with an inverted Zeiss microscope (model Axiosvert 135M), was used in random fields for the quantitative analysis of the phytoplankton, as proposed by Uhlinger (1964). Densities were calculated using the method described by Weber (1973); biovolume was calculated using the methods described by Hillebrand et al. (1999) and Sun & Liu (2003), converted to biomass assuming a specific gravity of 1mg/mm³ (Wetzel & Likens 2000) and expressed as mg/L. The species were categorized in the functional groups proposed by Reynolds (1997); Reynolds et al. (2000, 2002) and Padišák et al. (2009). Species diversity was calculated from biomass data using the indices proposed by Shannon & Weaver (1963) and Pielou (1966), respectively. Abundance and dominance were determined using the criteria proposed by Lobo & Leighton (1986).

Analysis of variance (ANOVA) was used with a 5% level of significance to determine the degree of temporal and spatial variation. Canonical correspondence analysis (CCA) was employed to analyze the relationship between algal associations and environmental variables. The significance of the variables that explain the variance in the biotic data (p<0.05) was determined using the Monte Carlo test, with unrestricted 999 permutations. The procedures of the multivariate analysis were carried out using the CANOCO 4.5 program (ter Braak & Smilauer 2002). The Bray-Curtis similarity index was used to establish a similarity matrix (Krebs 1989), based on the composition and biomass of the species between sites and seasons, generating values ranging from 0 (completely different) to 100 (completely similar).

Results

Abiotic variables: Absolute and mean air temperature values were lowest in August 2008 and the highest in January 2009 (Fig. 3). There was a significant difference in precipitation between seasons (F=13.18), with mean monthly rainfall of 93.93±42.80mm in the rainy season and 3.53±4.16mm in the dry season (ANOVA, p<0.05). Wind speed was X̄=5.9±0.59 m/s in the dry season and X̄=4.2±0.45m/s in the rainy season. The predominant wind direction in the region was West to East, except in August 2008, when it was Northeast to Southeast. Mean thermal differences between the surface and bottom were greater than 1°C, except in August 2008, when the mean difference was 0.5°C, demonstrating the occurrence of a mixture phenomenon in the water column at this time. The variations in the other hydrological parameters between the surface and bottom are displayed in Figure 4.

No significant differences were found in spatial variation regarding the majority of abiotic variables, with the exception of water temperature (F=14.94) and dissolved oxygen (F=29.04) (ANOVA, p<0.05). Higher values occurred in the rainy season for mean water temperature (X̄=27.7 ± 1.00°C), dissolved oxygen (7.25±3.99mg/L), electrical conductivity (X̄=164.78±168.31μS/cm), turbidity (X̄=50.19±32.45UNT), water transparency (X̄=0.99±0.14m) and limit of the euphotic zone (X̄=2.66±0.37m), whereas mean pH (X̄=7.99±0.44) was higher in the dry season. Throughout the study, water temperature, dissolved oxygen and pH were higher at the subsurface at all sampling sites. Electrical conductivity was generally greater at the bottom of the reservoir (Fig. 4a-i).

The concentrations of nutrients were always high. The highest total phosphorus content occurred in the rainy season (X̄=343.48±116.26μg/L). There were significant seasonal differences at both the subsurface (F=15.09) and bottom (F=8.49) of the reservoir (Fig. 4d). However, no significant differences were found between sampling sites (ANOVA, p<0.01). There were no spatial or temporal differences in total nitrogen content, thereby demonstrating no distribution pattern for this variable. Total nitrogen was slightly higher in the dry season (X̄=48.00±36.07μg/L) (Fig. 4d). The TN:TP ratio was very low throughout the study, with values above 1.0 only recorded at the subsurface at Site 1 in November and December and at the bottom at Site 2 in November.

Spatial-temporal variation in phytoplankton: The phytoplankton was made up of 53 species and one variety: Chlorophyta (45.28%), Cyanophyta (30.19%), Bacillariophyta (15.09%), Euglenophyta (3.77%), Cryptophyta (3.77%) and Chrysophyta (1.89%). No significant differences were found in the number of species of Bacillariophyta, Chlorophyta and Cyanophyta between rainy and dry seasons.

Spatially, there were no significant horizontal differences in species richness, between the subsurface and bottom. Sites 1 and 3 had the greatest species richness, with 47 and 48 species, respectively, whereas Site 2 had 42 species. Chlorophyta had =18±2.08 species per site; Cyanophyta had =16±1.00 species; Bacillariophyta had =7±1.15 species; Cryptophyta had =2±0.58 species; Chrysophyta had =1±0.00 species per site; and Euglenophyta had =2±0.00 species per site. Vertically, there was greater species richness at the bottom of the reservoir (51 species) in comparison to the subsurface (47 species). High biomass values (Fig. 5a) were recorded throughout the study (X̄=25.28±28.66mg/L), in the rainy season and =39.18±23.92mg/L in the dry season, with no significant seasonal differences. However, there were significant vertical differences (F=33.42), with the biomass values at the subsurface (X̄=55.32±22.86mg/L) on average threefold higher than those at the bottom (X̄=19.15±13.64mg/L) (ANOVA, p<0.01).

Among sampling sites, there were no significant differences in biomass values at the subsurface in either rainy and dry seasons, whereas significant differences were found at the bottom of the reservoir between Sites 1 and 3 in the rainy season (F=3.51) and between Sites 2 and 3 in the dry season (F=13.62) (ANOVA, p<0.05).

Cyanobacteria and diatoms contributed most to the phytoplankton biomass, with Planktothrix agardhi (Gomont) Anagnostidios and Komárek, Cylindrospermopsis raciborskii (Woloszyńska) Seenayya and Subba Raju, Pseudanabaena catenata Lauterborn and Aureococcus granulata (Ehrenberg) Simonsen accounting for more than 85.0% of the total biomass, on average. However, the relative contribution of these species varied throughout the study. Another 11 species accounted for more than 5% of the total biomass.

Three taxa were dominant: Anabaena sp. (58.7%) at the subsurface of S1 in the dry season (Dec 2008); A. granulata (56.8%) at the bottom of S1 in the rainy season (Aug 2008); and P. agardhi (=72.6±9.11%) at both sampling depths in the rainy season (Feb 2009). With the exception of February 2009 (rainy season), when P. agardhi was dominant, the Jucácinho reservoir was characterized by the co-dominance of P. catenata (=17.92±5.80%), C.raciborskii (=22.38±10.25%) and P. agardhi (=29.08±7.73%) in the dry season at all sampling sites and both depths. In the rainy season (Aug 2008 and March 2009), codominance of P. catenata (=14.15±6.19%), P. agardhi (=15.92±15.92%), A. granulata (=23.59±24.78%) and C. raciborskii (=23.80±5.77%) occurred at all sampling sites and both depths.

Due to the dominance of few species throughout the study, there was low diversity (X̄=2.38±0.57bit/mg). There were no significant differences in species diversity between sampling sites at either depth. However, significant differences were found between seasons (F=16.92) at both the subsurface (F=4.42) and bottom (F=13.26) (ANOVA, p<0.05). Diversity values were generally higher...
in the dry season at both the subsurface (\(=2.75\pm0.38\) bit/mg), and bottom (\(=2.67\pm0.35\) bit/mg), and lower in the rainy season at both the subsurface (\(=2.15\pm0.66\) bit/mg) and bottom (\(=1.97\pm0.46\) bit/mg) (Fig. 5b).

Nineteen functional groups were recorded, with a predominance of groups adapted to conditions of eutrophication. Throughout practically the entire study, there was co-dominance of the S1 (represented by \(P.\) agardhii and \(Geitlerinema\) amphibium (Agardh) Anagnostid.), Sn (represented by \(C.\) raciborski), MP (represented by \(P.\) catenata) and H1 (represented by \(Anabaena\) sp. and \(Aphanizomenon\) sp.) associations, except in August, when the P association (represented by \(A.\) granulata) replaced the S1 group (Fig. 6a and b).

No significant differences were found in the vertical or horizontal distribution of the main phytoplankton groups in the rainy season; biomasses of H1, MP, S1 and Sn were generally greater at the subsurface, whereas the P association had greater biomasses at the bottom. In the dry season, there were significant differences in the biomass of the H1, MP, S1 and SN associations between the subsurface and bottom (\(F=6.71\)) as well as between sampling sites at the bottom of the reservoir (\(F=5.28\)) (ANOVA, \(p<0.05\)). The S1 association generally contributed most to the total phytoplankton biomass at all sampling sites and both depths in the rainy and dry seasons (Fig. 6a and b).

CCA confirmed the significant relationship between the environmental variables and algal associations in the Jucazinho reservoir (\(p<0.01\)). Axes 1 and 2 explained 48.1% of the variation in algal biomass. The correlation between the associations and abiotic variables explained 99.1% of the canonical order on the first two axes (Table 1).

The CCA results revealed both temporal and vertical (subsurface and bottom) variation in the phytoplankton community. Water temperature, electrical conductivity and pH were negatively related to Axis 1 and the variation in these variables separated the sampling units in the dry season from those of the wet season. H1, S1 and Sn cyanobacteria occurred throughout the dry season, whereas P diatoms and MP cyanobacteria occurred in the rainy season (especially in August 2008). The August 2008 sampling units were positively related to Axis 1. This month exhibited a high abundance of P diatoms as well as the lowest water temperature, pH and electrical conductivity values recorded throughout the study. Dissolved oxygen and total phosphorus were related to Axis 2 and differentiated the sampling carried out at the subsurface and bottom, respectively. This analysis also revealed the predominance of H1, Sn and MP associations at the subsurface, the P association at both the subsurface and bottom and S1 at the bottom (Fig. 7).

The similarity analysis revealed no significant differences between sampling sites with regard to phytoplankton composition and biomass at the subsurface (Fig. 8a). At the bottom S2 differed significantly from the other sites (Fig. 8b). Seasonal differences were found only at the subsurface, with August and February (rainy season) separated from the other months (Fig. 8a). But, the clear separation of August in the grouping for both the subsurface (Fig. 8a) and bottom (Fig. 8b) was related to the high abundance of P diatoms in this month.

Other environmental peculiarities that occurred in this period were thermal mixture (Fig. 2), the lowest water temperature (Fig. 4a), electrical conductivity (Fig. 4e) and pH (Fig. 4f) values and a change in wind direction from east to southeast.

**Discussion**

In the Jucazinho reservoir, the long water retention time (approximately 6 years), volume and depth of the system as well as the synergism between the high water temperature (above 25.6°C) and high concentrations of total phosphorus (reflecting an accelerated process of eutrophication), were the factors accounting for the homogeneity between sampling sites. However, the heterogeneity between depths with regard to water temperature, dissolved oxygen, turbidity and electrical conductivity was due to the stratification of the water, as previously reported by Dantas (2010). Regarding variations between seasons, the increase in the concentration of total phosphorus was due to the increased precipitation in the rainy season.

Previous studies carried out on relatively small reservoirs located in semi-arid regions in Brazil with volume and water retention time similar to those found at Jucazinho, also report longitudinal homogeneity as well as vertical and seasonal heterogeneity in the abiotic limnological conditions (Chellappa & Costa 2003, Moura et al. 2007a, Dantas et al. 2008). In contrast, heterogeneity in the abiotic conditions are reported for the Salto Grande reservoir, which holds a larger volume of water and is located in a wet subtropical region (Zanata & Espíndola 2002), and Lake Caçó, located in a tropical region of Brazil (Dellamano-Oliveira et al. 2003). According to Armengol et al. (1999) and Tundisi & Matsumura-Tundisi (2008), the homogeneity of environmental conditions directly reflects the spatial dynamics of the phytoplankton community in reservoirs, as physicochemical factors have the greatest effect on the spatial-temporal variation of this community.

The composition of phytoplankton species in the Jucazinho reservoir reveals an accelerated process of eutrophication, with a predominance of cyanobacteria and Chlorophyceae. Studies carried out in other reservoirs of northeastern Brazil demonstrate the quantitative predominance of Cyanophyta and qualitative predominance of Chlorophyta, the latter of which is mainly represented by Chlororoccales (Moura et al. 2007a, b, Chellappa et al. 2008, Dantas et al. 2008, Lira et al. 2009). According to Huszar (2000), Chlororoccales is the order with the greatest species richness in freshwater environments in Brazil. Similar results are reported by Ndebele (2009) in a tropical reservoir in Zimbabwe (Cleveland Dam).

The phytoplankton biomass in the Jucazinho reservoir did not demonstrate a clear relationship with seasonality. However, the biomasses were significantly different between depths, with higher values at the subsurface than at the bottom. While the values recorded for Jucazinho are high, considering the mean biomass obtained for both the subsurface and bottom (37.92mg/L), this value is lower than those reported for eutrophic, subtropical and tropical reservoirs (Huszar 2000, Becker et al. 2010, Sun et al. 2010). Though, considering only the biomass recorded for the subsurface of the Jucazinho reservoir, the value is higher than those recorded for the Chapéu, Pão de Açuca and Ingazeiras reservoirs in northeastern Brazil (Huszar 2000). High biomass values in aquatic environments may be explained by the large availability of nutrients in both temperate and tropical reservoirs (Kimmel et al. 1990, Sarmento et al. 2008), as well as optimal temperature conditions (Moisan et al. 2002, Oberhaus et al. 2007), and long water retention time (Borges et al. 2008). All these conditions occur in Jucazinho, which explains the high values recorded throughout the entire study.

Reservoirs located in tropical ecosystems generally have limited nitrogen (Fyvding & Rast 1989), and the greater availability of this resource may result in an increase in algal density. Some species of cyanobacteria, which was the predominant group in Jucazinho, are endowed with specialized structures for the fixation of atmospheric nitrogen, which gives them a greater competitive advantage under conditions of limited nitrogen availability, and may not exert an influence over the increase in algal density. However, the species of greater numeric importance in the reservoir do not have heterocysts, therefore, the increase in nitrogen was certainly an important factor to the variation in algal density. According to Von Sperling et al. (2008), even with the increase in the density of
cyanoacteria related to the limited nitrogen, the dominance of this group may be the result of an increase in phosphorus. In the present study, nitrogen was not a significant explanatory variable of algal biomass. This finding is related to the large biomass of nitrogen-fixing cyanoacteria in the community (18.2%). Limited nitrogen has been reported to be the cause of an increase in the biomass of cyanoacteria with heterocysts in reservoirs in northeastern Brazil (Dantas et al. 2008).

Diversity is considered an attribute of successional progress (Reynolds 1988, Figueredo & Giani 2001). The relatively low species diversity values recorded for the Jucazinho reservoir may be explained by the high biomass values of few species as well as the homogeneity of the environmental conditions. According to Connell (1978), diversity values are higher when an environment is subjected to constant events of disturbance. In Jucazinho, the species diversity values were lower than those recorded in other systems (Figueredo & Giani et al. 2001, Dellamano-Oliveira et al. 2003, Mora et al. 2007a).

The vertical dynamic of the phytoplankton was mainly related to the depth of the sampling site, with the availability of light a limiting factor to the increase in phytoplankton biomass at the bottom of the reservoir. According to Padisák et al. (2003), cylindrical phytoplankton species have adaptive advantages regarding the gathering of light energy in relation to species with other shapes. Moreover, these organisms, especially those with numerous gas vesicles, are capable of remaining near the surface of the water column for longer periods of time.

According to Reynolds et al. (2002) and Padisák et al. (2009), the dominance of filamentous cyanoacteria of the H1, MP, S1 and Sn associations is common in stratified eutrophic environments, whereas organisms belonging to the P association develop better in mixed environments. The dominance of the P association, formed by Aulacoseira granulata var. granulata, A. angustissima (O.F. Müller) Simonsen, Fragilaria capucina Desmainiéres and Closteriopsis acicularis (Chodat) Belcher and Swale, was associated to high nutrient values (especially total nitrogen), lower temperatures and the complete mixture of the water column. Complete mixture was determined by a difference of less than 1ºC between the subsurface and bottom of the water column in August (rainy season), and was related to a change in wind direction. This finding corroborates those reported by Reynolds (1999), who states that representatives of this group are quite common in tropical and subtropical reservoirs.

The dominance of the S1 association, represented by Planktothrix agardhii and Geitlerinema amphibium, was associated to the high nutrient, temperature, pH, electrical conductivity and turbidity values predominating in February and March (rainy season). P. agardhii is a quite common species in lakes and reservoirs throughout the world and can form persistent blooms in shallow environments for several consecutive years (Chorus & Bartram 1999, Poulíková et al. 2004). According to Oberhaus et al. (2007), P. agardhii exhibits optimal growth at temperatures above 20ºC and under low light intensity. This species is also quite tolerant to conditions of high turbulence (Reynolds et al. 2002). Its cylindrical shape and numerous gas vesicles give it adaptive advantages, allowing it to float near the surface of the water column under conditions of intense light when generated by variations in wind speed and direction.

H1, MP and Sn associations were dominant in the dry season, when there were higher nutrient concentrations, a greater concentration of dissolved oxygen and greater wind speed, as these associations generally occur at the subsurface. The H1 association was represented by Anabaena sp. and Anphanizomenon sp. According to Reynolds et al. (2002), the representatives of this group have adaptive advantages over other organisms that occur in environments with low concentrations of nitrogen, as they have the ability to fix atmospheric nitrogen due to specialized cells called akinetes. Although, these organisms are capable of regulating their position in the water column, they are quite sensitive to conditions of mixture and high turbidity. The MP association, represented by Pseudanabaena catenata, is formed by periphytic species that occasionally occur as plankton. This species mainly occurs in very turbulent environments with cloudy water (Padisák et al. 2006, Mora et al. 2007a, Padisák et al. 2009).

Although a nitrogen-fixing filamentous cyanoacteria, such as representatives from H1 and H2 associations, Cylindrospermopsis raciborskii was grouped by Reynolds et al. (2002) in the Sn association due to its environmental preferences similar to organisms pertaining to the S1 and S2 associations, which are formed by non-nitrogen-fixing filamentous organisms. Cylindrospermopsis raciborskii biomass was high throughout the study period, thereby reflecting the eutrophic conditions of the Jucazinho reservoir, which has warm, turbid waters throughout the year. According to Padisák & Reynolds (1998) and Reynolds et al. (2002), C. raciborskii is well adapted to warm, mixed environments and has considerable tolerance to low light intensity. The dominance of this species is commonly observed in eutrophic environments with high turbidity (Figueredo & Giani 2001, Berger et al. 2006).

The co-dominance and high biomasses throughout the study of potentially toxin-producing cyanoacteria belonging to the S1 (P. agardhii and G. amphibium), Sn (C. raciborskii, MP (P. catenata) and H1 (Anabaena sp. and Anphanizomenon sp.), associations are troublesome as the toxins can cause mass mortality in fish, birds, crustaceans and cattle and affect human health through skin, hepatic and neurological intoxication that can lead to death. P. agardhii and G. amphibium produce microcystins and a neurotoxin (β-N-methylamino-L-alanine). C. raciborskii produces anatoxin-a(s), cylindrospermopsin, homoanatoxin and saxitoxins. Anabaena sp. and Anphanizomenon sp. produce anatoxin-a and a(s) and saxitoxins (Funari & Testai 2008).

The absence of a longitudinal gradient in the Jucazinho reservoir demonstrates the advanced process of eutrophication in this environment, which is homogeneous with regard to physicochemical conditions. Despite the low nitrogen values, there was no nitrogen limitation for the phytoplankton community. Thus, the availability of light in the water column is certainly the factor that exerts the greatest influence over the spatial and temporal dynamics of the phytoplankton in this reservoir. In both seasons, there was a dominance of species with morpho-physiological characteristics adapted to low light intensity, which gives them an advantage over organisms that are less adapted to this condition. The factors with the greatest influence over temporal (seasonal) variation in the phytoplankton were water temperature, precipitation and pH, whereas the vertical distribution of the phytoplankton biomass was likely regulated by the availability of light in the water column.

The results of the present study also demonstrate that the temporal change in algal structure is explained by changes in the physical conditions of the water between the subsurface and bottom caused by a change in wind direction and consequent change in the fetch of the water. This event only occurred because the reservoir is very long and relatively narrow. In ecosystems with a more regular morphology, this factor may not exert an influence over the phytoplankton community.

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References

Albuquerque, U.P. & L.H.C. Andrade. 2002. Conhecimento botânico tradicional e conservação em uma área de caatinga no Estado de Pernambuco, Nordeste do Brasil. Acta Bot. Bras. 16: 273-285.

Armengol, J., J.C. Garcia, M. Comerma, M. Romero, J. Dolz, M. Rousa, B.H. Han, A. Vidal & K. Simek. 1999. Longitudinal processes in canyon type reservoir: the case of Sau (N.E. SPAIN), p. 313-345. In J.G. Tundisi & M. Stráskrabka (eds.). Theoretical reservoir ecology and its applications. Brazilian Academy of Sciences and Backhuys, São Paulo, Brazil.

Barbiero, R.P., W.F. James & J.W. Barko. 1999. The effects of disturbance events on phytoplankton community structure in a small temperate reservoir. Freshwater Biol. 42: 503-512.

Beyruth, Z. 2000. Periodic disturbances, trophic gradient and phytoplankton characteristics related to cyanobacterial growth in Guarapiranga Reservoir, São Paulo State, Brazil. Hydrobiologia 424: 51-65.

Becker, V., L. Caputo, J. Ordóñez, R. Marcé, J. Armengol, L.O. Crosetti & V.L.M. Huszar. 2010. Driving factors of the phytoplankton functional groups in a deep Mediterranean reservoir. Water Res. 44: 3345-3354.

Berger, C., N. Ba, M. Gugger, M. Bouvy, F. Rusconi, A. Couté, M. Troussellier & C. Bernard. 2006. Seasonal dynamics and toxicity of Cyindrospermopsis raciborskii in Lake Guiers (Senegal, West Africa). FEMS Microbiol. Ecol. 57: 355-366.

Borges, P.A.F., S. Train & L.C. Rodrigues. 2008. Spatial and temporal variation of phytoplankton in two subtropical Brazilian reservoirs. Hydrobiologia 607: 63-74.

Caputo, L., L. Naselli-Flores, L.I. Ordoñez & J. Armengol. 2008. Phytoplankton distribution along trophic gradients with and among reservoirs in Catalonia (Spain). Freshwater Biol. 53: 2543-2556.

Chellappa, N.T. & M.A.M. Costa. 2003. Dominant and coexisting species of Cyanobacteria from a Eutrophicated reservoir of Rio Grande do Norte State, Brazil. Acta Oecol. 24: 3-10.

Chellappa, N.T., J.M. Borba & O. Rocha. 2008. Phytoplankton community and physical-chemical characteristics of water in the public reservoir of Cruzeta, RN, Brazil. Braz. J. Biol. 68: 477-494.

Chorus, I. & J. Bartram. 1999. Toxic cyanobacteria in water: a guide to public health significance, monitoring and management. London, Für WHO durch E & FN Spon-Chapman & Hall, United Kingdom.

Cole, G.A. 1983. Textbook of limnology. Waveland Inc., Illinois, USA.

Connell, J. 1978. Diversity in tropical rain forest and coral reefs. Science 199: 1304-1310.

Dantas, E.W., A.N. Moura, M.C. Bittencourt-Oliveira, J.D.T. Arruda Neto & A.C. de Deus-Cavalcanti. 2008. Temporal variation of the phytoplankton community at short sampling intervals in the Mundaú reservoir, northeastern Brazil. Acta Bot. Bras. 22: 970-982.

Dantas, E.W. 2010. Ecologia da comunidade de algas planctônicas em reservatórios de Pernambuco (Nordeste, Brasil). Tese Doutorado. Universidade Federal Rural de Pernambuco, Departamento de Biologia, Recife, Brazil.

Datta, S. & B.B. Jana. 1998. Control of biomass in a tropical Lake: grazing efficiency of some herbivorous fishes. J. Fish. Biol. 53: 12-34.

Dejenie, T., T. Asmelash, L. De Meester, A. Mulugeta, A. Gebrekidan, S. Risch, A. Pals, K. Van der Gucht, W. Vyverman, J. Nyssen, J. Deckers & S. Declerck. 2008. Limnological and ecological characteristics of tropical highland reservoirs in Tigray, Northern Ethiopia. Hydrobiologia 610:193-209.

Dellamano-Oliveira, M.J., P.A.C. Senna & G.M. Tanigushi. 2003. Limnological characteristics and seasonal changes in density and diversity of the phytoplanktonic community at the Caçó pond, Maranhão state, Brazil. Braz. Arch. Biol. Technol. 46: 641-651.

Díaz, M.M., P.F. Temporetti & F.L. Pedrozo. 2001. Response of phytoplankton to enrichment from cage fish farm waste in Alicura Reservoir (Patagonia, Argentina). Lakes Reservoirs: Res. Manage. 6: 151-158.

Diehl, S. 2007. Paradoxes of enrichment: effects of increased light versus nutrient supply on pelagic producergrazer systems. Amer. Nat. 169: 173-191.

Downing, J.A. & E. McCauley. 1992. The nitrogen: phosphorus relationship in lakes. Limnol. Oceanogr. 37:936-945.

Figueiredo, C.C. & A. Giani. 2001. Seasonal variation in the diversity and species richness of phytoplankton in a tropical eutrophic reservoir. Hydrobiologia 445:165-174.

Funari, E. & E. Testai. 2008. Human health risk assessment related to cyanotoxins exposure. Crit. Rev. Toxicol. 38: 97-125.

Guo, L. & Z. Li. 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.

Hillebrand, H., C.D. Dürselen, D. Kirschel & U.P.T. Zohary. 1999. Biovolume calculation for pelagic and benthic microalgae. J. Phycol. 35: 403-424.

Huszar, V.L.M. 2000. Fitoplâncton, p. 91-104. In R.L. Bozelli, F.A. Esteves & F. Roland (eds.). Lago Batata: impacto e recuperação de um ecosistema amazônico. UFRJ/SBL, Rio de Janeiro, Brazil.
Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13: 131-144. [Links]

Pouliková, A., P. Hasler & M. Kitner. 2004. Annual cycle of Planktothrix agardhii (GOM.) Anagn. & Kom. Nature Population. Int. Rev. Hydrobiologia 89: 278-288. [Links]

Popovsky, J. & L.A. Pfiester. 1990. Dinophyceae (Dinoflagellida), p. 1-271. In H. Ettl, J. Gerloff, H. Heynig & D. Mollenhauer (eds.). Süßwasserflora von Mitteleuropa. Gustav Fisher, Stuttgart, Germany. [Links]

Prescott, G.W. & W.C. Vinyard. 1982. A synopsis of North American Desmids. University of Nebraska, Nebraska, USA. [Links]

Reynolds, C.S. 1984. Phytoplankton periodicity: the interactions of form, function and environmental variability. Freshwater Biol. 14: 111-142. [Links]

Reynolds, C.S. 1988. The concept of ecological succession applied to seasonal periodicity of freshwater phytoplankton. Verh. int. Ver. Limnol. 23: 683-691. [Links]

Reynolds, C.S. 1997. Vegetation processes in the pelagic: a model for ecosystem theory. Germany Ecology Institute, Munich, Germany. [Links]

Reynolds, C.S. 1999. Phytoplankton assemblages in reservoirs, p. 439-456. In J.G. Tundisi & M. Straškraba. Theoretical reservoir ecology and its applications. São Carlos, International Institute of Ecology, Brazilian Academy of Sciences and Backhuys, Brazil. [Links]

Reynolds, C.S., M. Dokulil & J. Padišak. 2000. Understanding the assembly of phytoplankton in relation to the trophic spectrum: where are we now? Hydrobiologia 424: 147-152. [Links]

Reynolds, C.S., V. Huszar, C. Kruk, L. Naselli-Flores & S. Melo. 2002. Towards a functional classification of the freshwater phytoplankton. J. Plank. Res. 24: 417-428. [Links]

Ryding, S. & W. Rast. 1989. The control of eutrophication of lakes and reservoirs. UNESCO, Paris, France. [Links]

Sarmento, H., F. Unrein, M. Isumbisho, S. Stenuite, J.M. Gasol & J.P. Descy. 2008. Abundance and distribution of picoplankton in tropical, oligotrophic Lake Kivu, eastern Africa. Freshwater Biol. 53: 756-771. [Links]

Scheffer, M. 1998. Ecology of shallow lakes. Chapman and Hall, London, United Kingdom. [Links]

Shannon, C.E. & W. Weaver. 1963. The mathematical theory of communication. Illinois University, Urbana, Illinois, USA. [Links]

Starling, F.L.R.M. 1993. Control of eutrophication by Silver Carp (Hypophthalmichthys molitrix) in the tropical Paranoá Reservoir (Brasilia, Brazil): a mesocosm experiment. Hydrobiologia 257: 143-152. [Links]

Sun, Y., X. Wang, R. Hu & B. Han. 2010. Seasonal variation of phytoplankton communities in xiangang reservoir, a tropical shallow high-yield fishery reservoir in South China. Chin. J. Appl. Environm. Biol. 16: 228-234. [Links]

Sübwasserflora von Mitteleuropa. Gustav Fisher, Stuttgart, Germany.

Utermöhl, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Mitt. Int. Ver. Fuer Theor. und Ang. Limnol. 9: 1-38. [Links]

Valderrama, G.C. 1981. The simultaneous analysis of total nitrogen and total phosphorus in natural Waters. Mar. Chem. 10: 109-122. [Links]

von Sperling, E.V., A.C.S. Ferreira & L.N.L. Gomes. 2008. Comparative eutrophication development in two Brazilian water supply reservoirs with respect to nutrient concentrations and bacteria growth. Desalination 226: 169-174. [Links]

Weber, C.I. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73-001. National Environmental Research Center, Office of Research & Development, U.S. Environmental Protection Agency. Cincinnati, Ohio, USA. [Links]

Wetzel, R.G. & G.E. Likens. 2000. Limnological analyses. Springer, New York, USA. [Links]

Wondie, A., S. Mengistu, J. Vijverberg & E. Dejenie. 2007. Seasonal variation in primary production of a large high altitude tropical lake (Lake Tana, Ethiopia): effects of nutrient availability and water transparency. Aquat. Ecol. 41: 195-207. [Links]

Zanata, L.H. & E.L.G. Espíndola. 2002. Longitudinal processes in Salto Grande reservoir (Americana, SP, Brazil) and its influence in the formation of compartment system. Braz. J. Biol. 62: 347-361. [Links]
This study aims to analyze the effects of nutrients and predation by zooplankton on phytoplankton biomass (chlorophyll a) in a eutrophic reservoir in Brazil (Apipucos Reservoir, State of Pernambuco), through experiments in microcosms. For this, samples of water were placed in 1 L Erlenmeyer flasks and kept for seven days. M. F. Knowlton and J. R. Jones, “Temporal and Spatial Dynamics of Suspended Sediment, Nutrients, and Algal Biomass in Mark Twain Lake, Missouri,” Archiv für Hydrobiologie, Vol. 135, No. 2, 1995, pp. 145-178. [30]. The phytoplankton community was characterized to determine the temporal and spatial variations in a cascade system. In places where connectivity is maintained, diatom species were presented, while in reservoirs had a clear dominance of chlorophytes and cyanophytes related to nutrient enrichment and wastewater discharges. A total of 112 species were identified, 38% were Chlorophyceae, 35% Bacillariophyceae, 13% Cyanophyceae and 13% Euglenophyceae. Microcystis aeruginosa and Anabaena variabilis (cyanophytes) were abundant in reservoirs. Spatial and Temporal Changes in the Phytoplankton Community in a Cascaded Reservoir System: San Juan River, Queretaro, Mexico. < Previous Article. Next Article >. Temporal and spatial dynamics of phytoplankton near farm fish in eutrophic Temporal and spatial dynamics of phytoplankton near farm fish in eutrophic reservoir in Pernambuco, Brazil. Structure and dynamics of phytoplankton community in the Botafogo reservoir Structure and dynamics of phytoplankton community in the Botafogo reservoir-Pernambuco-Brazil. The aim of this work was to study the phytoplankton community composition at limnetic environment in Pernambuco, Brazil. Samplings were carried out from April/2001 to March/2002. Samples to analyses the biotic variables were taken using a recipient with a large overture, at the subsurface and with a Van Dorn bottle at the bottom. Spatial and temporal variations in particle-bound pesticide contamination, natural environmental variables, and benthic abundance were measured during the dry summer season within a temporarily open estuary (Lourens River). This study focused on the effect of particle-associated pesticides on the dynamics of the benthic community (including epi-benthic, hyper-benthic, and demersal organisms) by comparing two runoff events, differing in their change in pesticide concentration and environmental variables. The aim of this paper is to determine temporal and spatial structure of phytoplankton occurrence chosen coastal areas between November 2014 and September 2016. All three studies regions the same dominants, abundance and biomass were observed.