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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 25ºC; 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.

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 Diaz *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 predominance of cyanobacteria, such as *Anabaena*, *Microcystis* and *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 (Diaz *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) (07º57'50'' S - 35º44'27'' 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 25º C, mean annual precipitation of 599mm, irregularly distributed rains throughout the year (Albuquerque & Andrade 2002) and a mean wind speed of 5.0m/s.

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 2 103 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.

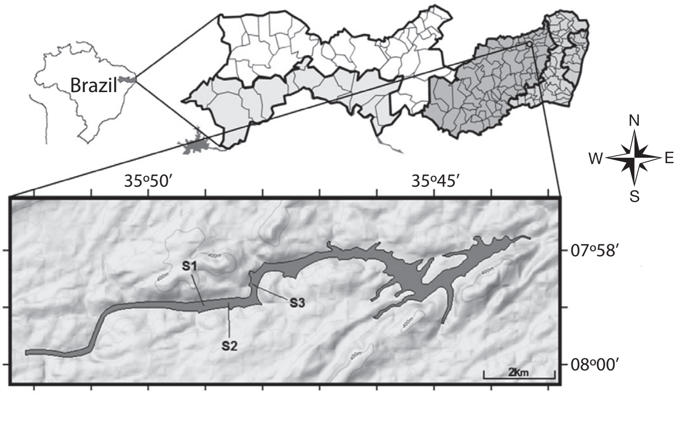

Fig. 1. Jucazinho reservoir and sampling sites.

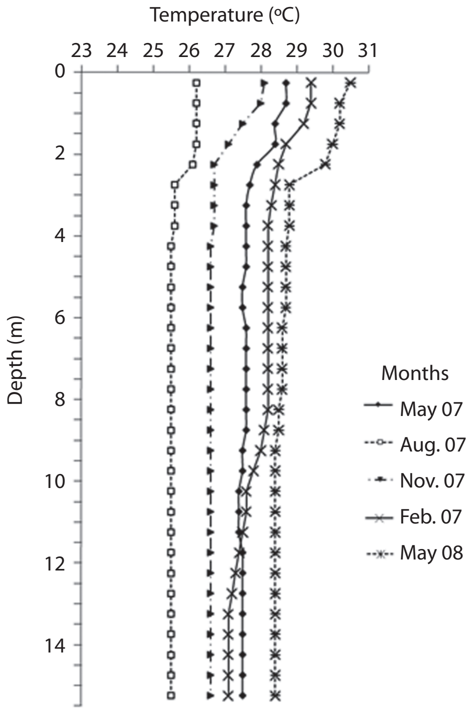

Fig. 2. Temperature profiles in Jucazinho reservoir (Brazil) between August 2007 and August 2008 (Source: Dantas 2010).

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 & Pfiester (1990), Krammer & Lange-Bertalot (1991a,b), Komárek & Anagnostidis (2000), Komárek & Kronberg (2001), John *et al.* (2002) and Komárek & Anagnostidis (2005).

The Utermöhl method (Utermöhl 1958), with an inverted Zeiss microscope (model Axiovert 135M), was used in random fields for the quantitative analysis of the phytoplankton, as proposed by Uhelinger (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/mm^3 (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 Padisák *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=13.16), 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 $\overline{X}$=5.9±0.59 m/s in the dry season and $\overline{X}$ =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 1ºC, except in August 2008, when the mean difference was 0.5ºC, 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 ($\overline{X}$=27.7 ± 1.70º C), dissolved oxygen ($\overline{X}$=7.25±3.99mg/L), electrical conductivity ($\overline{X}$=1648.78±168.31µS/cm), turbidity ($\overline{X}$=50.19±32.45UNT), water transparency ($\overline{X}$=0.99±0.14m) and limit of the euphotic zone ($\overline{X}$=2.66±0.37m), whereas mean pH ($\overline{X}$=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-f).

The concentrations of nutrients were always high. The highest total phosphorus content occurred in the rainy season ($\overline{X}$ =343.48±116.26µg/L). There were significant seasonal differences at both the subsurface

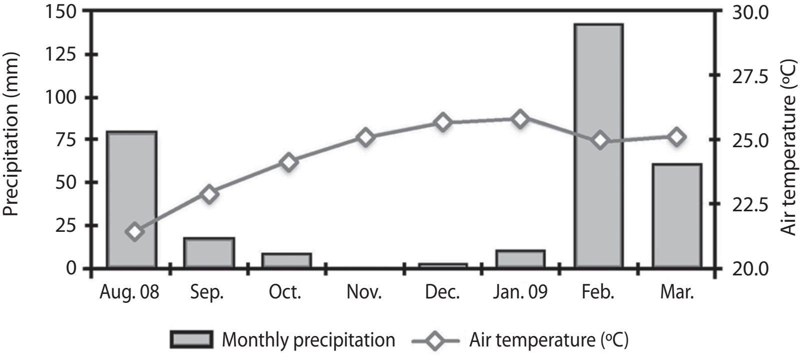

Fig. 3. Mean monthly precipitation and air temperature; data provided by Meteorological Station of the municipality of Surubim - PE (located approximately 15km from Jucazinho reservoir).

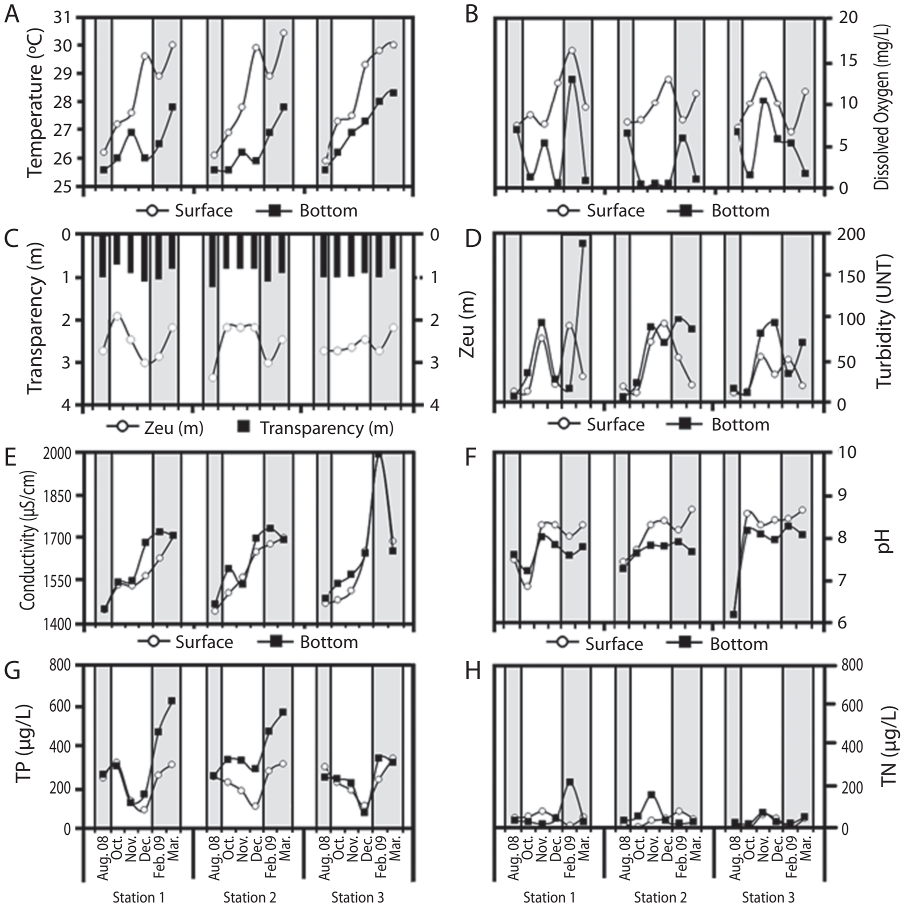

Fig. 4. Spatial-temporal variation of abiotic variables; a - water temperature (ºC); b - dissolved oxygen (mg/L); c - water transparency and limit of the euphotic zone [Zeu (m)]; d - turbidity (UNT); e - electrical conductivity (µS/cm); f – pH; g - total phosphorus [TP (µg/L)]; h - total nitrogen [TN (µg/L)] in Jucazinho reservoir in rainy (Aug 08, Feb and Mar 09) and dry (Oct, Nov and Dec 08) seasons.

(F=15.09) and bottom (F=8.49) of the reservoir (Fig. 4g). 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 ($\overline{X}$=48.00±36.07µg/L) (Fig. 4h). 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 or differences 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 $\overline{X}$=18±2.08 species per site; Cyanophyta had $\overline{X}$=16±1.00 species; Bacillariophyta had $\overline{X}$=7±1.15 species; Cryptophyta had $\overline{X}$=2±0.58 species; Chrysophyta had $\overline{X}$=1±0.00 species per site; and Euglenophyta had $\overline{X}$=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 ($\overline{X}$=35.28±28.66mg/L in the rainy season and $\overline{X}$=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 ($\overline{X}$=55.32±22.86mg/L) on average threefold higher than those at the bottom ($\overline{X}$ =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 agardhii* (Gomont) Anagnostidis and Komárek, *Cylindrospermopsis raciborskii* (Woloszynska) Seenaya and Subba Raju, *Pseudanabaena catenata* Lauterborn and *Aulacoseira 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. agardhii* ($\overline{X}$=72.6±9.11%), at both sampling depths in the rainy season (Feb 2009). With the exception of February 2009 (rainy season), when *P. agardhii* was dominant, the Jucazinho reservoir was characterized by the co-dominance of *P. catenata* ($\overline{X}$=17.92±5.80%), *C. raciborskii* ($\overline{X}$=22.38±10.25%) and *P. agardhii* ($\overline{X}$=29.08±7.73%) in the dry season at all sampling sites and both depths. In the rainy season (Aug 2008 and March 2009), co-dominance of *P. catenata* ($\overline{X}$=14.15±6.19%), *P. agardhii* ($\overline{X}$=15.92±15.92%), *A. granulata* ($\overline{X}$=23.59±24.78%) and *C. raciborskii* ($\overline{X}$ =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 ($\overline{X}$=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=5.42) and bottom (F=13.26) (ANOVA, p<0.05). Diversity values were generally higher in the dry season at both the subsurface ($\overline{X}$=2.75±0.38bit/

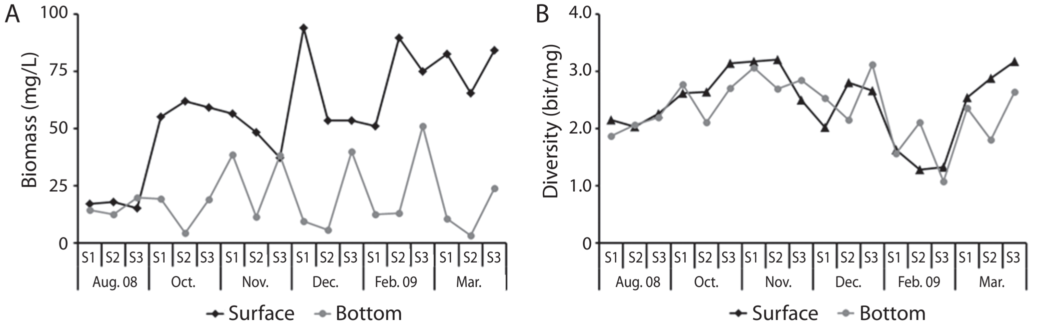

Fig. 5. Spatial and temporal variation in total biomass (a) and species diversity (b) of phytoplankton in Jucazinho reservoir in rainy (Aug 08, Feb and Mar 09) and dry (Oct, Nov and Dec 08) seasons; a and c - surface data; b and d - bottom data.

mg), and bottom ($\bar{X}$=2.67±0.35bit/mg), and lower in the rainy season at both the subsurface ($\bar{X}$=2.15±0.66 bit/mg) and bottom ($\bar{X}$ =1.97±0.46bit/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) Anagnostidis), **Sn** (represented by *C. raciborskii*), **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 89.1% 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

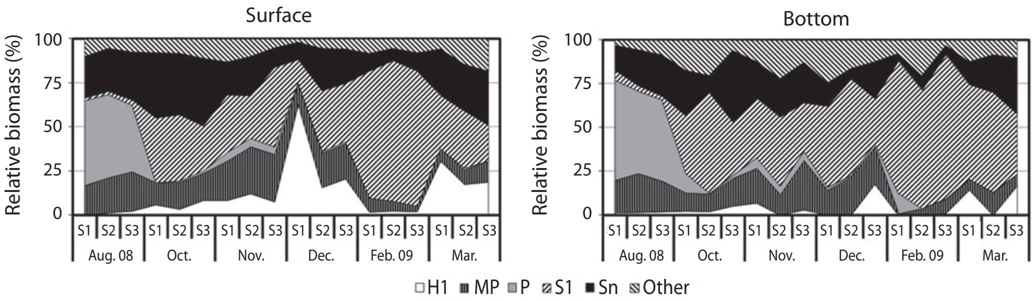

Fig. 6. Seasonal variation in main phytoplankton groups at subsurface (a) and bottom (b) of Jucazinho reservoir in rainy (Aug 2008, Feb and Mar 09) and dry (Oct, Nov and Dec 08) seasons.

TABLE 1
Statistical summary and correlation coefficients between phytoplankton associations and abiotic variables on first two CCA axes in Jucazinho reservoir, state of Pernambuco, Brazil

	Axis 1	Axis 2
Eigenvalues	0.200	0.173
Accumulated variance in biotic data (%)	25.8	48.1
Accumulated variance in association-environment relation (%)	47.8	89.1
Association-environment correlation	0.735	0.799
Monte Carlo test		
Significance of first canonical axis – *p*	0.005	
Significance of all canonical axes – *p*	0.001	

	Canonical coefficient		Intra-set correlation	
	Axis 1	Axis 2	Axis 1	Axis 2
Water temperature (°C)	-0.64	-0.25	-0.88	-0.31
Dissolved oxygen	-0.18	-0.32	-0.25	-0.40
Electrical conductivity	-0.51	0.43	-0.70	0.54
pH	-0.46	-0.08	-0.63	-0.11
Turbidity	-0.21	0.30	-0.29	0.38
Total phosphorus	-0.08	-0.04	-0.11	-0.05
Total nitrogen	0.02	0.46	0.02	0.57

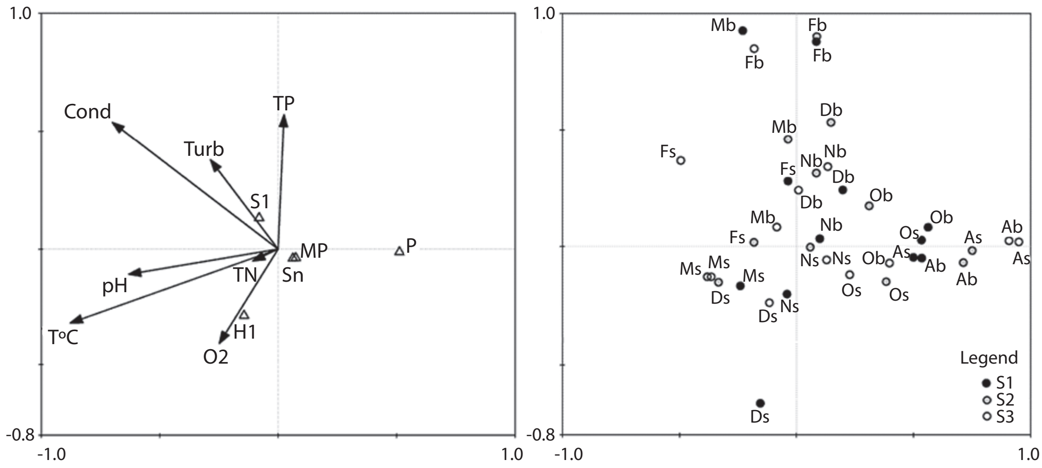

Fig. 7. Canonical correspondence analysis plot of samples showing correspondence of main phytoplankton groups biomass and abiotic variables in Jucazinho reservoir, Brazil; units identified based on months (A=august; O=October; N=November; D=December; F=February and M=March) and depth (s=subsurface and b=bottom); Circles indicate study area (Sites 1, 2 and 3); triangles indicate main phytoplankton groups (H1, MP, P, S1 and Sn); abbreviations: TºC=water temperature; O_2=dissolved oxygen; pH=pH; Cond=electrical conductivity; Turb=turbidity; TP=total phosphorous; TN=total nitrogen.

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)

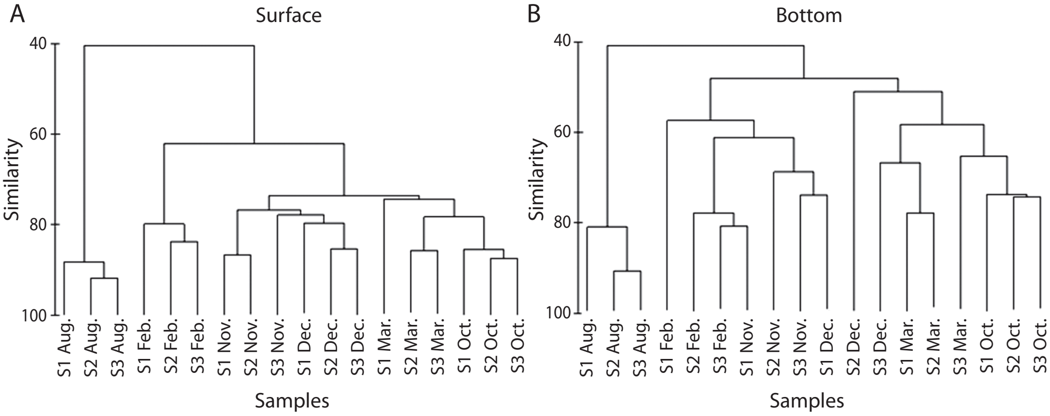

Fig. 8. Similarity analysis of phytoplankton composition and biomass between sampling sites at subsurface (a) and bottom (b) of Jucazinho reservoir.

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 25.6ºC) 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 physiochemical 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 Chlorococcales (Moura *et al.* 2007a, b, Chellappa *et al.* 2008, Dantas *et al.* 2008, Lira *et al.* 2009). According to Huszar (2000), Chlorococcales 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 threefold 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 Açúcar 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 (Ryding & 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 heterocytes, 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 cyanobacteria 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 cyanobacteria in the community (18.2%). Limited nitrogen has been reported to be the cause of an increase in the biomass of cyanobacteria with heterocytes 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 Connel (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, Moura *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 cyanobacteria 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. granulata* var. *angustissima* (O.F. Müller) Simonsen, *Fragilaria capucina* Desmazières 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, Poulíčková *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 even under conditions of intense water flow 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 *Aphanizomenon* 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, Moura *et al*. 2007a, Padisák *et al*. 2009).

Although a nitrogen-fixing filamentous cyanobacterium, 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 cyanobacteria belonging to the **S1** (*P. agardhii* and *G. amphibium*), **Sn** (*C. raciborskii*), **MP** (*P. catenata*) and **H1** (*Anabaena* sp. and *Aphanizomenon* sp.), associations are troublesome as the toxins produced by these algae 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 (ß-N-methylamino-L-alanine). *C. raciborskii* produces anatoxin-a(s), cylindrospermopsin, homoanatoxin and saxitoxins. *Anabaena* sp. and *Aphanizomenon* 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 physiochemical 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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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 la represa de Jucazinho, la cual se encuentra en la región semiárida brasilera. 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 espacio-temporal de las variables hidrológicas, agua oxigenada en la superficie y anóxica en el fondo, pH varía neutro-alcalino, temperaturas superiores a 25°C y conductividad y turbidez elevadas. En los dos periodos estacionales fueron observadas limitaciones de nitrógeno y elevadas concentraciones de fósforo. Las Cyanophytas 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 recolecta. La co-dominancia de cianobacterias pertenecientes a las asociaciones **H1**, **MP**, **S1** y **Sn,** fue registrada durante la mayor parte del periodo de estudio, excepto en ago/2008, cuando ocurrió una sustitución de la asociación **S1** (*Planktothrix agardhii*) por **P** (*Aulacoseira granulata*) en la represa. Los factores que tuvieron más influencia sobre la variación temporal del fitoplancton fueron temperatura del agua, precipitación pluvial y pH. La distribución vertical de la biomasa fitoplanctónica estuvo directamente relacionada con la disponibilidad de luz en la columna de agua. No se encontraron diferencias espaciales ni temporales en la calidad del agua, seguramente porque los putos de muestreo eran cercanos y recibieron la misma carga de nutrientes provenientes del concentrado de los peces y de la excreción de estos mismos. La predominancia de cianobacterias a lo largo de todo el estudio seguramente fue debida a la influencia de los productos del alimento suministrado a los peces y sus excrementos que eutrifican el sistema. Temporalmente, el cambio en la estructura de las algas es explicado por la modificación de las condiciones físicas del agua entre superficie y fondo, provocado por el cambio en la dirección del viento con la consecuente alteración del *fetch* del agua.

Palabras clave: disponibilidad de luz, Brasil, variaciones climatológicas, represa Jucazinho, asociaciones del fitoplancton.

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