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Phytoplanktonic associations: a tool to understanding dominance events in a tropical Brazilian reservoir

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RESUMO – (Associações fitoplanctônicas: uma ferramenta para entendimento de eventos de dominância em um reservatório tropical brasileiro). O objetivo deste estudo foi caracterizar as associações fitoplanctônicas, bem como discutir os fatores controladores determinantes da dominância algal em um reservatório eutrófico, Mundaú, Pernambuco, Brasil. As amostras foram coletadas durante dois períodos sazonais, seco (janeiro/2005) e chuvoso (junho/2005). As amostras foram coletadas nas regiões limnética e litorânea, seguidas pela identificação através de literatura específica, e preservadas com formol a 4%. No mesmo momento das coletas dos dados bióticos, alguns parâmetros abióticos como temperatura e transparência da água, oxigênio dissolvido, pH foram obtidos e, em laboratório, foram determinados o fósforo total, nitrogênio total e o Índice de Estado trófico. Os agrupamentos das associações fitoplanctônicas foram feitos a partir da classificação fitossociológica de Reynolds. O reservatório esteve limitado por nitrogênio em ambos os períodos sazonais. No período seco, este sistema apresentou água pouco oxigenada, pH alcalino e relativa turbidez quando comparado com o período chuvoso. O fitoplâncton foi representado por 70 táxons infragenéricos agrupados em 16 associações, sendo a maioria, típica de ecossistemas eutróficos. Este fato é corroborado pela análise quantitativa, os quais evidenciam a dominância de associações S, constituídas exclusivamente por cianobactérias R- estrategistas.

Palavras-chave: associações fitoplanctônicas, reservatórios abastecimento d'água, nordeste do Brasil

ABSTRACT – (Phytoplanktonic associations: a tool to understanding dominance events in a tropical Brazilian reservoir). The aim of this study was to characterize phytoplankton associations, as well as discuss controlling factors determining algal dominance in a eutrophic tropical reservoir, Mundaú, Pernambuco, Brazil. Water samples were collected during the dry period (January/2005) and the rainy period (June/2005). The samples were collected from both limnetic and littoral regions, and the phytoplankton assemblages identified from current literature after preservation in formaldehyde 4%. At the same time as sampling was done, *in situ* measurements of water temperature, transparency, dissolved oxygen, and pH were also taken. Total phosphorus, total nitrogen concentration and the Trophic State Index were subsequently determined in the laboratory. Phytoplankton density (ind. L^{-1}) was estimated using an inverted Zeiss microscope. Grouping of the phytoplankton associations was carried out using the Reynolds phytosociological classification. During the dry period, reservoir water showed low dissolved oxygen concentrations, alkaline pH and was relatively turbid compared to the situation during the rainy season. Reservoir water is limited by nitrogen during both seasonal periods. The Trophic State Index is classified as determining eutrophic conditions. Phytoplankton was represented by 70 infrageneric taxa grouped in 16 functional associations, with the majority typical of eutrophic systems. This fact is supported by quantitative analysis, which shows the dominance of **S** associations comprising exclusively R-strategist cyanobacteria.

Key words: phytoplankton associations, drinking water reservoirs, Northeast Brazil

Introduction

Aquatic ecosystems show spatial and temporal variability promoted by high levels of uncertainty in relation to phytoplankton communities. This variability, a result of biotic and abiotic factors, causes constant reorganization in both relative abundance and composition of phytoplanktonic associations.

Knowledge of phytoplankton population dynamics is relevant because temporal and spatial fluctuations in composition and biomass may be efficient indicators of natural or anthropic alterations in the aquatic ecosystem. Besides, the short generation time of algae (hours or days) makes it possible to understand important processes such as ecological succession, and thus the community provides a useful model for a better

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understanding other types of communities (Harris 1986; Sommer 1989) and of ecosystems in general (Reynolds 1997).

Several recent studies have correlated phytoplankton composition with environmental factors in an attempt to propose models and patterns for lakes and reservoirs under distinct trophic states. This advance was motivated by a presupposition worked out by Hutchinson (1961), that phytoplankton community behavior is at variance with the Competitive Exclusion Principle, particularly in eutrophic systems.

This hypothesis, known as the Plankton Paradox (Hutchinson 1961), was revised by Reynolds (1988) who proposed a model for phytoplankton community based on survival strategies C, R and S, of algae groups which are clearly distinct but non-exclusive of each other, thus contradicting the ordinary r-K model of MacArthur & Wilson (1967).

Reynolds *et al.* (2002) classified planktonic algae into 31 functional associations, using as a starting point the existing knowledge of species ecology, phylogenetic interactions, and seasonal variation caused by environmental change. In the broader context, phytoplankton associations and their survival strategies are good tools for characterizing and predicting the dynamics of aquatic ecosystems.

The current study aimed to characterize phytoplankton associations in order to determine the causes of algal dominance in drinking water reservoirs in northeastern Brazil.

Materials and methods

The Mundaú Reservoir lies within the coordinates 08°56'47" S and 36°29'33" W at an altitude of 716 m. This reservoir, intended for public water supply, was constructed with a capacity of 1,968,600 m^3, nowadays receiving part of the urban drainage from Garanhuns, Pernambuco, Northeast Brazil (SHR 2000). Mundaú is a typical shallow tropical reservoir, and is considered to be a eutrophic system.

Phytoplankton samples were collected during the dry season (January 2005) and the rainy season (June 2005), from limnetic and littoral zones, using a plankton net with a 25 µm mesh size. Stations E_1 and E_2 are 9 and 2 meters deep, respectively, the latter being colonized by submerged macrophytes. The samples were preserved in formol 4% and taxonomic identification was done using an optical microscope (Zeiss/Axioskop), to species level or to the highest possible taxonomic resolution using relevant literature for each algal group (Round *et al.* 1990; Sant'Anna 1984; Komarék & Foot 1983; Komárek & Anagnostidis 1999; Komárek & Anagnostidis 2005). Density (ind.L^{-1}) was obtained by Uthermöhl's (1958) method using an inverted microscope (Zeiss Axiovert). Concurrently with biotic variable sampling, *in situ* measurements of abiotic parameters such as water temperature and transparency, dissolved oxygen, and pH were determined. Total nitrogen (mg.NT.L^{-1}) and total phosphorus (mg.PT.L^{-1}) levels were determined by Valderrama's (1981) method. The Trophic State Index (TSI) was calculated according to Carlson (1977) using the mean values of total phosphorus.

The definition of the phytoplankton associations was based on the phytosociological classification of Reynolds *et al.* (2002), whilst survival strategies followed Kruk *et al.* (2002). Quantitative results were handled through descriptive statistics, by the analysis of data variation amplitude, dispersion around average values, as well as variation between stations and seasonal periods. The variance (ANOVA) was calculated for each sampled station with BioEstat 3.0 (Ayres *et al.* 2003), using 5% significance.

Results and discussion

Physical and chemical characteristics are shown in Table 1. In the dry period the reservoir had low oxygen, high pH, and relatively turbid water, when compared to the rainy season. In contrast in the rainy season the water was well oxygenated, with a pH ranging from near neutral to slightly acid, and with elevated turbidy, especially near the sediment surface.

Nutrient analysis revealed that there were no differences between sampling stations. However, differences were observed in the concentration of total nitrogen and phosphorus between the rainy and dry seasons. This situation points to possible pluvial transport and land runoff of nitrogeneous material into the reservoir, and to the possible impact of elevated water temperature on phosphorus cycling during the dry season (Tab. 1).

A Trophic State Index of over 60 proves that the Mundaú reservoir was in a eutrophic state during the study period (Tab. 1).

The phytoplankton flora was composed of 70 infrageneric *taxa* including the Chlorophyta (54.29%), Cyanobacteria (20.00%), Bacillariophyta (14.29%), Euglenophyta (8.57%), Cryptophyta (1.43%) and

Table 1. Abiotic variables in the Mundaú reservoir during the study period (average values and corresponding standard deviations).

	Dry season				Rainy season			
	E_1		E_2		E_1		E_2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Transparency (m)	0.30		0.35		0.30		0.30	
Temperature (°C)	27.42	0.54	27.92	0.76	23.45	0.24	23.48	0.39
O_2 diss. (mg L^{-1})	0.98	0.75	1.28	0.86	7.00	0.77	6.37	0.81
pH	8.28	0.14	8.29	0.12	7.28	0.12	7.10	0.11
Turbity (NTU)	34.42	2.33	34.75	2.32	54.37	6.99	40.15	9.96
NT (µg L^{-1})	56.94	7.07	54.84	15.09	124.56	49.65	155.84	40.82
PT (µg L^{-1})	104.94	6.80	102.06	13.85	75.63	7.70	85.47	11.85
IET	66.87	1.06	66.39	2.06	62.12	1.53	63.84	1.93

Dinophyta (1.43%) (Fig. 1). The coexistence of taxons with the three ecological strategies proposed by Reynolds' (1988) model was observed, and they were grouped into 16 functional associations (Tab. 2, 3).

The reservoir phytoplankton net samples (Tab. 3) included seven distinct cyanobacteria associations (Lo, Lm, M, S_1, S_2, Sn and Z), four chlorophyte associations (F, J, P and X_1), four for phytoflagellates (Lo, W_1, W_2 and Y) and three diatom associations (B, D and P).

The majority of functional associations found in the Mundaú reservoir is typical of eutrophic systems or in those with a high trophic level (Tab. 3), thus explaining the coexistence of several taxons. However, three functional groups (B, Lo and W_2) are more

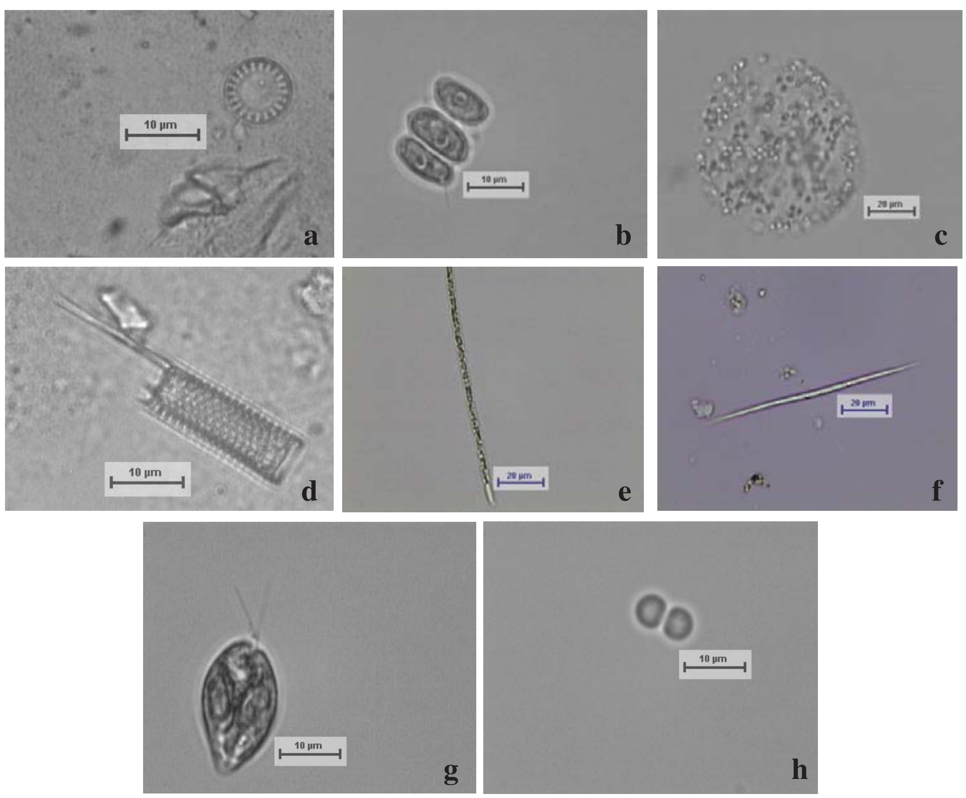

Figure 1. Representative phytoplanktonic associations found in the Mundaú reservoir, Northeast Brazil. a. Association B (*Cyclotella meneghiniana*). b. Association J (*Scenedesmus bicaudatus*). c. Association M (*Microcystis aeruginosa*). d. Association P (*Aulacoseira granulata*). e. Association Sn (*Cylindrospermopsis raciborskii*). f. Association X_1 (*Closteriopsis acicularis*). g. Association Y (*Cryptomonas* sp.). h. Association Z (*Chroococcus turgidus*).

Table 2. Phytoplankton functional assemblages found in the Mundaú reservoir, Pernambuco, Brazil, and possible surviving ecological spectra. (? = not determined)

Assemblages	Habitat	Tolerancy	Sensitivity	Ecological strategies
B	Mesotrophic and mixed waters	Light deficiency	High pH	CR
D	Turbid waters, eutrophic and shallow waters	Flushing	Nutrient deficiency	R
F	Epilimnion with high light	Low nutrient and high turbidity	CO_2 deficiency	CS
J	Eutrophic ecosystem and shallow waters	?	Light deficiency	CR
Lm	Epilimnion of eutrophic lakes	C deficiency	Flushing and light deficiency	S
Lo	Mesotrophic ecosystem	Nutrient deficiency	Flushing	S
M	Mixed layers and eutrophic ecosystem	High light	Flushing and light deficiency	S
P	Epilimnion eutrophic	Mild light, C deficiency	Stratification and Si deficiency	R
S_1	Mixed waters, turbid and shallow waters	Light deficiency	Flushing	R
S_2	Mixed waters, turbid and shallow waters	Light deficiency	Flushing	R
Sn	Mixed, warm and shallow waters	Light and C deficiency	Flushing	R
W_1	Ecosystems rich in organic nutrients	?	Grazing	R/CR/CRS
W_2	Mesotrophic ecosystem, shallow waters	?	?	R/CR/CRS
X_1	Eutrophic ecosystems, mixed layers and shallow waters	Stratification	Low nutrients and Grazing	C
Y	Eutrophic ecosystems	Light deficiency	Grazing	CRS
Z	Mixed and low turbid layers	Light deficiency	Light deficiency and Grazing	C

closely related to less eutrophic systems, making them less competitive *vis-à-vis* the remaining groups. The J, Lm, M and Z associations do not tolerate a reduced photic layer, the F group is sensitive to high pH, while P organisms are not resistant to stratification. These factors could be contributing to the rarity of these taxons in the community.

As revealed by both sampling periods, reduced water transparency was a hindrance factor for the C-strategists, which showed a preference for high nutrient rates as well as optimum light availability. The same unfavorable conditions were verified for the X_1 association.

Turning now to the other functional groups, we note that the organisms grouped in S_1, S_2 and Sn are, generally speaking, non-palatable to zooplankton (Gragnani *et al.* 1999). In contrast, the organisms in W_1 e Y were the most affected, because they are extremely sensitive to zooplankton predation. Although the conditions were not unfavorable to those from the D association, they gain no advantage from zooplankton occurrence (Reynolds *et al*. 2002) and, therefore, algae belonging to the D association are likely to be present in the system only as subdominants. Finally, organisms from the Sn association would be favored over the remaining groups because they are better strategists in a high temperature system such as the Mundaú reservoir.

Phytoplankton population density ranged from 3.62×10^7 to 1.82×10^8 ind.L^{-1}, and was mostly comprised of cyanobacteria (Fig. 2).

All groups other than the phytoflagellates exhibited statistical differences in density between the seasonal periods at both sampling stations (Tab. 4), and dry season densities were always higher than those for the wet season (Fig. 2). Chlorophyta in E_2 was the only one with higher densities in the rainy season. Turbidity is one of the main factors regulating the development of zooplankton communities, with high turbidity thus contributing to the selection of smaller organisms (Pollard *et al*. 1998). This could be the reason for the greater development of zooplankton palatable algae in the rainy season, particularly those from the W_1, X_1 and Y associations.

Regarding differences between sampling stations (Tab. 5), the cyanobacteria always had higher densities in E_1, independent of seasonal period (Fig. 2). Other algae groups had statistical differences between stations only in the dry season, with the highest densities occurring in E_2. The littoral region represents a niche

Table 3. Average data for taxons (10^6ind. L^{-1}) found in the Mundaú reservoir, Pernambuco, Brazil, during the study period. (*=Taxons found only through qualitative analysis).

Assemblages	Taxon	E_1		E_2	
		Dry season	Rainy season	Dry season	Rainy season
	Cyanobacteria				
Z	*Chroococcus limneticus* Lemmermann	-	0.13	0.30	0.08
Z	*C. minutus* Kützing	3.48	1.21	1.24	1.50
Z	*C. turgidus* Kützing	0.70	1.00	1.55	3.44
Sn	*Cylindrospermopsis raciborskii* (Wolz.) Seenayya et Subba-Raju	82.88	41.94	59.12	27.45
S_1	*Geitlerinema amphibium* (Agardh ex Gomont) Anagnostidis	7.19	6.75	4.13	4.80
Lo	*Merismopedia minima* Beck	1.47	0.64	0.31	0.26
Lo	*M. punctata* Meyen	1.65	0.69	0.86	0.38
M	*Microcystis aeruginosa* (Kützing) Kützing	0.76	0.88	0.11	0.85
Lm	*M. flos-aquae* (Wittr) Kirchn	0.11	0.32	0.03	0.12
Lm	*M. panniformis* Komárek *et al.**	-	-	-	-
Lm	*M. wesenbergii* (Komárek) Komárek	-	0.03	-	0.04
S_1	*Pseudanabaena catenata* Lauterborn	0.77	0.22	0.04	0.08
S_2	*Raphidiopsis mediterranea* Skuja	2.58	1.89	0.84	1.21
S_2	*Spirulina* sp.*	-	-	-	-
	Chlorophyta				
J	*Actinastrum hantzschi* Lagerheim *i*	0.00	0.03	0.03	0.08
J	*Ankistrodesmus gracilis* (Reinsch) Korsikov	0.01	0.03	-	-
F	*Botryococcus protuberans* W. & G.S. West	0.03	-	-	-
X_1	*Chorella vulgaris* Chodat	0.68	4.64	6.10	3.71
X_1	*Closteriopsis acicularis* (G.M. Smith) Belcher & Swale	0.01	-	0.04	-
P	*Closterium parvulum* Nägeli	0.20	0.07	0.19	0.04
J	*Coelastrum microporum* Nägeli	0.04	0.03	-	-
J	*C. pseudomicroporum* Korsikov	0.17	0.13	0.01	0.15
J	*Crucigenia quadrata* Morren	0.27	0.22	0.03	0.04
J	*Dictyosphaerium ehrembergianum* Naegeli	-	-	0.16	0.04
J	*D. pulchellum* Wood	0.46	0.28	0.50	0.21
J	*Golenkinia radiate* Chodat*	-	-	-	-
F	*Kirchneriella lunaris* (Kirchn.) Möebius	0.17	0.72	1.06	0.30
F	*K. obesa* (W. West) Schmidle	0.36	0.15	0.42	0.22
J	*Micractinium pusillum* Fresenius*	-	-	-	-
X_1	*Monoraphidium arcuatum* (Korsikov) Hindák	0.40	2.21	2.24	2.10
X_1	*M. circinales* (Nygaard) Nygaard	1.34	0.01	0.22	-
X_1	*M. contortum* (Thret) Komárkova-Legnerová	1.49	1.18	1.33	0.82
X_1	*M. griffithii* (Berkel) Komárkova-Legnerová	0.36	1.50	0.30	0.70
X_1	*M. pusillum* (Printz) Komárkova-Legnerová	0.58	0.43	0.73	0.28
F	*Oocystis lacustris* Chodat	-	-	0.05	-
J	*Pediastrum tetras* (Ehrenberg) A. Braun	0.01	-	-	-
J	*Scenedesmus acuminatum* (Langerheim) Chodat	0.03	0.04	0.01	0.04
J	*S. acuminatum* var. *bernardiii* (G.M. Smith) Dedussenko	-	0.06	-	0.04
J	*S. acutus* Meyen	-	0.04	-	0.03
J	*S. arcuatum* Lemmermann	0.02	0.04	-	-
J	*S. bicaudatus* (Hansgirg) Chodat *	-	-	-	-
J	*S. ecornis* (Ehrenberg) Chodat	0.02	-	-	0.03
J	*S. quadricauda* var. *parvus* G.M. Smith	0.46	0.10	0.25	0.01
J	*Tetraedron caudatum* (Corda) Hansgirg*	-	-	-	-
J	*Tetraedron gracilis* (Reinsch) Hansgirg	0.02	-	-	-
J	*T. incus* (Teiling) G.M. Smith	0.09	0.01	0.11	-
J	*T. mediocris* Hindák	0.01	-	-	-
J	*T. minimum* (A. Braun) Hansgirg	0.18	0.18	0.15	0.07
J	*T. triangulare* (Chodat) Komárek	0.33	0.13	0.18	0.08
J	*T. victoriae* Wolosynska	-	0.01	-	-
J	*Tetrastrum elegans* Playfair	0.02	0.07	0.05	0.01

continue

Table 3 (continuation)

Assemblages	Taxon	E_1		E_2	
		Dry season	Rainy season	Dry season	Rainy season
	Bacillariophyta				
P	*Aulacoseira granulata* (Ehrenberg) Simosen	0.01	-	0.01	-
P	*A. granulata* var. *angustissima* Müller	0.06	0.03	0.04	-
B	*Cyclotella meneghiniana* Kützing	2.24	0.42	1.99	0.46
D	*Cocconeis* sp.	0.01	-	-	-
D	*Gomphonema angustatum* (Kützing) Rabenhorst*	-	-	-	-
P	*Melosira* sp.	-	0.19	-	-
D	*Navicula cuspidata* Kützing	0.01	-	-	-
D	*Nitzschia* sp.	0.02	0.01	0.08	-
D	*Pleurosigma* sp.	-	0.01	-	-
D	*Synedra rumpens* Kützing	17.69	1.60	30.13	1.18
	Euglenophyta				
W_1	*Euglena oxyuris* Schmarda*	-	-	-	-
W_1	*Euglena* sp.	-	0.03	-	0.01
W_1	*Lepocinclis* sp.*	-	-	-	-
W_1	*Phacus* sp.*	-	-	-	-
W_2	*Trachelomonas oblonga* Lemmermann	0.02	0.04	-	0.03
W_2	*T. volvocina* Ehrenberg	0.01	0.01	0.01	0.04
	Cryptophyta				
Y	*Cryptomonas ovata* Ehrenberg	0.08	0.39	0.26	0.44
	Dinophyta				
Lo	*Gymnodinium* sp.	0.01	-	0.04	-

for the coexistence of other taxons, since it generally contains macrophytes that provide a substrate for the colonization of periphytic communities. Sládecková (1962) showed that the organisms in these hosting compartments, particularly in the periphyton, are able to find ideal conditions not only for protection against predators, but also because these compartments constitute a nutrient rich microcosm. Another important factor prevailing in the littoral region is its shallowness, which enables light to reach the sediment surface, while also maintaining good vertical circulation (Tundisi 1990). These factors contributed to the success of light-strategy dependent algae, such as the C- and S-strategists, as well as facilitating the resuspension of diatom frustules. Thus, the littoral region encompasses a spectrum of favorable conditions for the coexistence of Chlorophyta, Euglenophyta, Cryptophyta and Bacillariophyta, from the functional groups F, X_1, W_1, W_2, Y and D, respectively.

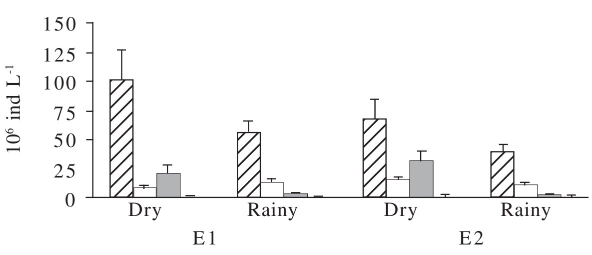

Figure 2. Spatial and seasonal variation in algal densities of the main phytoplankton groups found in the Mundaú reservoir, Pernambuco, Brazil (average values and corresponding standard deviations) (▨= Cyanophyta; □ = Chlorophyta; ■ = Bacillariophyta; ■ - Others).

Table 4. Results of ANOVA test of significance for the density of algae groups between seasonal periods in the Mundaú reservoir.

	E1		E2	
	F	p	F	p
Cyanobacteria	16.768	0.002	15.400	0.003
Chlorophyta	9.282	0.012	9.269	0.012
Bacillariophyta	26.690	0.000	101.809	0.000
Phytoflagellates	36.047	0.000	0.934	0.641

As far as *taxa* are concerned, *Cylindrospermopsis raciborskii* (Woloszinska) Seenayya et. Subba-Raju was dominant with a total density of organisms higher than 50% (Tab. 3). This species belongs to the Sn association, thus corroborating qualitative inferences for system dominance events by phytoplankton association studies supported by the Reynolds theory.

Table 5. Results from ANOVA test of significance for the density of algal groups between sampling stations in the Mundaú reservoir.

	Dry season		Rainy season	
	F	p	F	p
Cyanobacteria	7.025	0.023	10.850	0.008
Chlorophyta	30.603	0.000	2.821	0.121
Bacillariophyta	7.155	0.022	2.623	0.134
Phytoflagellates	1.456	0.254	0.106	0.749

Other taxons were sub-dominated in the ecosystem with densities higher than 5% (Tab. 3). *Synedra rumpens* Kützing belongs to the D association, and reached densities greater than 20%, particularly in the dry season and in E_2. This taxon was favored by the shallowness of the littoral region, because it is common in shallow, turbid and eutrophic waters (Reynolds *et al.* 2002).

Two other cyanobacteria were prominent in the quantitative analysis: *Geitlerinema amphibium* (Agardh ex Gomont) Anagnostidis, belonging to the S_1 association, and *Chroococcus turgidus* Kützing, from the functional group Z. The former was abundant throughout the investigative period, with densities higher than 5% (Tab. 3). The presence of the functional group S was appropriate to the system's conditions particularly since it tolerates low light regimes (Reynolds *et al.* 2002), an overriding factor in the community structure. *Chroococcus turgidus* Kützing, on the other hand, was present at higher density particularly in the rainy season in E_2, where physical conditions probably played a more important role in controlling the structure of the zooplankton community, as discussed above.

Chlorella vulgaris Chodat was abundant in the rainy season. It belongs to the X_1 association, which is related to eutrophic and shallow systems (Reynolds *et al.* 2002). Happey-Wood (1988) considers it to be a zooplankton palatable algae, with a tendency to be dominant in turbulent systems. The mixing condition in the rainy season was the driving factor for the development of this association in the system.

Environmental conditions promote the dominance of S associations exclusively constituted by R-strategist cyanobacteria. Therefore, the use of functional associations to study phytoplankton associations was efficient at determining dominance events in the tropical reservoir under investigation.

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