Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9283
ISSN on-line: 1807-863X
Doi: 10.4025/actascibiolsci.v35i3.12988

Spatial and temporal fluctuation of phytoplankton functional groups in a tropical reservoir

Lívia Oliveira Ruiz Moreti, Luana Martos, Vânia Mara Bovo-Scomparin and Luzia Cleide Rodrigues*

*Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. *Author for correspondence. E-mail: luziac.rodrigues@gmail.com*

ABSTRACT. Along the horizontal axis of reservoirs are generally recognized three zones (fluvial, transition and lacustrine) with distinct hydrodynamic and physical, chemical and biological properties. Quarterly samplings were conducted in 2002, in the limnetic region from each zone, at different depths of a tropical reservoir. To test the hypothesis that highest biomass (biovolume) of phytoplankton are found in the transition zone, the PERMANOVA analysis was realized. 106 taxa were recorded. Significant differences between biovolume values of the three zones were not verified (*pseudo* F = 0,89; p = 0,55). Higher values of biomass were obtained in lacustrine and transition zones of the reservoir. The functional group (FG) N (*Cosmarium* spp.) was dominant in these zones, in rain period, and related to low phosphorus concentration, high transparency and water column stability. Low biovolume values in reservoir characterized oligotrophic conditions in all zones of the reservoir, most of the period. The dominance of FGs Y, Lo, E, P and A, as evidenced by the CCA, was associated with low light availability and higher nutrients concentrations.

Keywords: functional group, biovolume, horizontal distribution, oligotrophic reservoir.

Variação espacial e temporal dos grupos funcionais do fitoplâncton em um reservatório tropical

RESUMO. Ao longo do eixo horizontal de reservatórios são, em geral, reconhecidas três zonas (fluvial, transição e lacustre) com distinta hidrodinâmica e propriedades físicas, químicas e biológicas. Foram realizadas amostragens trimestrais no ano de 2002, na região limnética de cada zona, em diferentes profundidades, em um reservatório tropical. Para testar a hipótese de que os maiores valores de biovolume fitoplanctônico ocorrem na zona de transição do reservatório, foi realizada a Análise PERMANOVA. Foram registrados 106 táxons. Não foram registradas diferenças significativas entre os valores de biovolume fitoplanctônico das zonas do reservatório (*pseudo* F = 0,89; p= 0,55). Maiores valores de biovolume foram obtidos na zona lacustre e na zona de transição do reservatório. O grupo funcional N (*Cosmarium* spp.), dominante nestas zonas, no período chuvoso, esteve relacionado às baixas concentrações de fósforo, alta transparência e estabilidade da coluna de água. Os baixos valores de biovolume caracterizaram condições oligotróficas em todo o reservatório, na maior parte do período de estudo. A dominância dos FGs Y, Lo, E, P e A, como evidenciado por meio da CCA, esteve associada à baixa disponibilidade de luz e concentrações mais altas de nutrientes.

Palavras-chave: grupo funcional, biovolume, distribuição horizontal, reservatório oligotrófico.

Introduction

Relative depth and retention time are the most important physical characteristics of the reservoirs. These factors determine horizontal water quality differentiation, such as: nutrients concentrations, relative importance of inputs of inorganic and organic matter. Furthermore affect stratification conditions and flows, and the retention of both particulate and dissolved material in these systems (STRASKRABA; TUNDISI, 1999).

Horizontal zonation in reservoirs is usually related with the increase in particulate matter sedimentation from river towards the dam (STRASKRABA; TUNDISI, 1999). The establishment of horizontal compartments results in different behavior regarding abiotic factors, which determine the structure and functioning of the phytoplankton community (KIMMEL et al., 1990).

In general, phytoplankton from deep reservoirs presents a horizontal distribution pattern with greater concentrations in the transition zone of the reservoirs. In the fluvial zone, there is light limitation despite nutrient availability, and afterwards, the relative fertility of the mixing zone decreases towards the dam because nutrients supply, introduced by adjective processes, reduces with distance from the river inflow. Therefore, phytoplankton production becomes more dependent on in situ nutrient regeneration (THORNTON, 1990; TUNDISI et al., 1999).

Identify horizontal gradients in reservoirs is crucial to define the different uses of these systems (NOGUEIRA, 2000). By readily indicate environmental conditions and exhibiting conservative characteristics superior to those of physical and chemical variables, the phytoplanktonic species can be efficient in characterization of these gradients (REYNOLDS, 1980; REYNOLDS et al., 2002).

According to the pattern in which species or groups of species dominate a certain environment, phytoplankton species can also be sorted into functional groups characteristic of particular environmental conditions (REYNOLDS et al., 2002; PADISÁK et al., 2006, 2009). Studies using this approach for to characterize the horizontal distribution of phytoplankton in reservoirs were registered (TRAIN et al., 2005; RODRIGUES et al., 2005; BORGES et al., 2008; BECKER et al., 2009, 2010), however only Train et al. (2005) and Borges et al. (2008) used the functional groups approach in characterization of fluvial, transition

Because of the few studies using functional groups of phytoplankton along horizontal gradients in reservoirs, this study investigated the occurrence of a horizontal gradient of phytoplankton community in Mourão Reservoir, and identified groups of species that match to functional groups proposed by Reynolds. The hypothesis this study is that highest biomass values are found in transition zone and the phytoplankton functional groups are useful for different zones characterization.

Material and methods

Study area

Mourão Reservoir was built in 1964, by the damming of the left bank tributary of Ivaí River. It is located in the municipality of Campo Mourão, in the boundary region between the Northwest and Southwest of Paraná State. Among the soil uses of its basin, there are agricultural activities, mainly soybean crops, which generate high input of clayey matter via surface runoff. The reservoir has an area of 11.3 km^2 and a retention time of about 70 days. The mean depth was of approximately 2.7 m in fluvial zone (region of the river inflow), 7.5 m in transition (intermediary region), and 8 m in lacustrine zone (deep lacustrine region near the dam). In the right bank there are remnants of native and secondary forests, and the left bank is occupied by vacation homes (JÚLIO-JUNIOR et al., 2005).

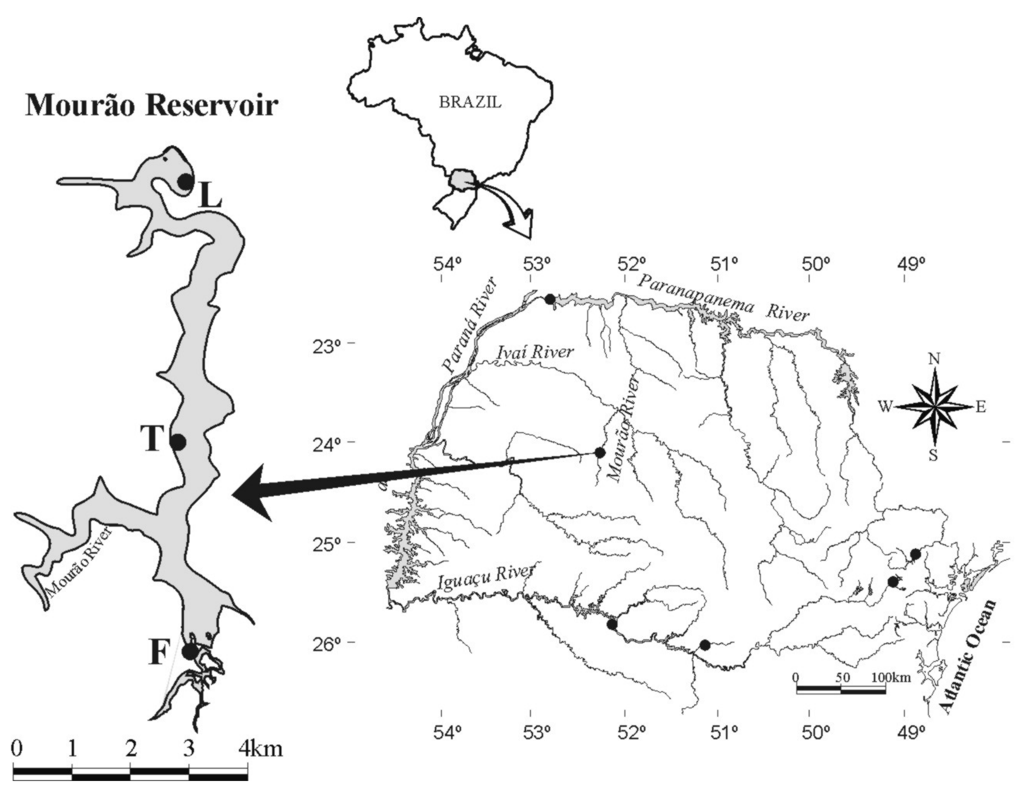

Figure 1. Map and location of sampling stations in Mourão Reservoir (L: lacustrine zone; T: transition zone; F: fluvial zone).

Quarterly samplings were performed in 2002 during dry (June and September) and rainy seasons (March and December). Samples were taken with a Van Dorn sampler at the fluvial (F), transition (T) and lacustrine (L) zones, in the following water layers: at the subsurface (S); above the lower boundary of the mixing zone (Z_{mix}); above the euphotic zone boundary (Z_{eu}); and at approximately 40 cm of the bottom (Z_{max}). The mixing zone (Z_{mix}) was estimated according to the temperature profile of the water column. Euphotic zone (Z_{eu}) was measured using a radiometer. The Z_{eu}:Z_{mix} ratio was used as a light availability index in the mixing zone.

Transparency was measured with a Secchi disc. Water temperature, pH, electrical conductivity and dissolved oxygen were obtained by portable digital potentiometers; concentrations of total phosphorus, soluble reactive phosphorus were determined following the methods described in Golterman et al. (1978). Total nitrogen, as well as nitrate ($N\text{-}NO_3^-$) and ammonium ($N\text{-}NH_4^+$) were determined following the methods described in Mackereth et al. (1978). All abiotic variables were obtained from samples taken simultaneously with the biological ones. Phytoplankton samples were preserved using Lugol's solution.

Phytoplankton quantification followed Utermöhl (1958) and APHA (1995) and sedimentation time was set according to Lund et al. (1958). Phytoplankton biomass, estimated using biovolume, was calculated by multiplying the abundance of each species and the average volume of species. The latter were obtained from geometric models similar to tridimensional forms (SUN; LIU, 2003).

Species with contribution to the phytoplankton biovolume greater than 5% to total biovolume were included in functional groups (FGs) according to Reynolds et al. (2002) and Padisák et al. (2006).

Relations between abiotic variables and total phytoplankton biovolume were studied using the Pearson correlation (STATSOFT, 2005). The Permutational Multivariate Analysis of Variance (ANDERSON, 2001) was applied to test differences in biovolume functional groups of reservoirs zones. The relationships between the abiotic data and the phytoplankton biovolume FGs were analyzed through Canonical Correspondence Analysis - CCA (TER BRAAK, 1986). In the CCA analysis were included surface data of seven FGs biovolume, water temperature - WT, pH, alkalinity - Alk, electrical conductivity- Cond, soluble reactive phosphorus - SRP, Dissolved inorganic nitrogen - DIN ($N\text{-}NO_2^-$ + $N\text{-}NH_4^+$ + $N\text{-}NH_3^-$), Z_{mix}:Z_{max} ratio and Z_{eu}:Z_{mix} ratio. The null hypothesis of absence of relationship among matrices (biotic and abiotic) was tested through Monte Carlo procedures. All calculations were carried out using PC-ORD software (McCUNE; MEFFORD, 1999) and the R package (R DEVELOPMENT CORE TEAM, 2013).

Results

Water temperature ranged presented the lowest values in September. Conductivity values presented low variability. pH remained around 7 throughout study period (Table 1). Was registered high availability of light, characterized by Z_{eu}:Z_{mix} ratio superior to 1, in transition and lacustrine zones in rain period (Figure 2). In this period occurred a horizontal gradient in light availability, with increase from river towards the dam. In June, dry period, the highest Z_{eu}:Z_{mix} ratio occurred at fluvial zone. In September the Z_{eu}:Z_{mix} ratio was lower than 1, all across horizontal extent of reservoir. Total circulation of the water column at fluvial zone of the reservoir was verified throughout study period, except in June. Water column was stratified in transition and lacustrine zones in most months, except at lacustrine zone, in September (Figure 2).

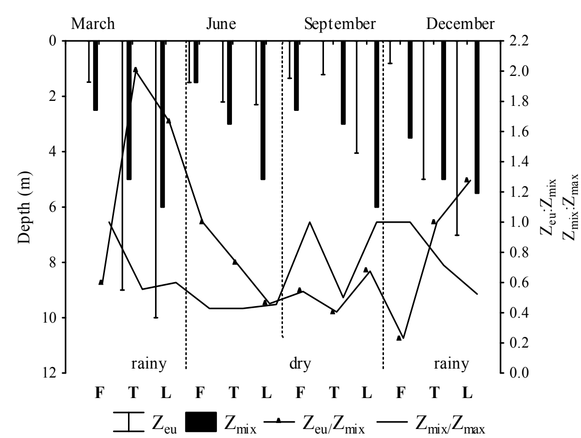

Figure 2. Depth variation of euphotic zone (Z_{eu}), mixing zone (Z_{mix}), Z_{eu}:Z_{mix} and Z_{mix}:Z_{max} ratio at different zones (F: fluvial, T: transition, L: lacustrine) in Mourão reservoir, during study period.

Dissolved oxygen values were higher in dry period, in euphotic zone. TN and DIN concentrations were high principally in dry period (Table 1). TP concentrations were lower than 20 $\mu g\ L^{-1}$ in most samples, and evidenced a horizontal gradient from river towards the dam, in December, when values above 30 $\mu g\ L^{-1}$ were detected at fluvial zone. SRP values were low, presenting homogeneous values along the horizontal and vertical axes of the reservoir. Greatest concentrations of phosphorus forms occurred at deep layer of the reservoir (Table 1).

Table 1. Limnological variables in Mourão Reservoir in 2002. (AT = air temperature; cond.= electrical conductivity; DO = dissolved oxygen; WT = water temperature; DIN = dissolved inorganic nitrogen; TP = total phosphorus ; SRP = soluble reactive phosphorus; TN = total nitrogen.

	Depth (m)	Secchi (m)	AT (%)	Cond (μS cm^{-1})	pH	DO (mg L^{-1})	WT (%)	DIN (μg L^{-1})	TP (μg L^{-1})	SRP (μg L^{-1})	TN (μg L^{-1})
Rainy period											
March											
Fluvial	S	0.6	25.2	28.5	6.5	7.6	22.6	121.5	8.5	0.6	208.9
	Z_{max}			30.1	6.8	6.8	21.7	146.0	9.8	0.3	196.1
Transition	S	1.2	25.6	24.4	7.7	7.7	26.7	14.8	9.7	0.6	140.9
	Z_{mix}			25.7	6.9	5.9	25.2	15.3	9.1	0.5	124.7
	$Z_{eu} = Z_{max}$			30.1	7.1	4.2	23.5	133.2	12.1	1.3	224.9
Lacustrine	S	1.5	25.6	24.7	7.0	7.3	26.4	7.7	10.1	0.9	175.9
	Z_{mix}			24.7	7.1	7.0	26.1	6.8	8.8	0.9	165.3
	$Z_{eu} = Z_{max}$			24.9	6.5	0.1	24.6	42.9	7.6	1.0	197.8
December											
Fluvial	S	0.3	24.3	23.8	6.9	8.5	24.1	173.0	32.1	1.3	459.7
	Z_{max}			22.3	6.5	5.8	21.4	334.3	41.1	1.7	491.0
Transition	S	1.7	22.9	24.4	6.8	7.6	25.8	115.7	8.6	1.6	307.4
	$Z_{eu} = Z_{mix}$			24.4	7.0	5.9	25.0	156.3	8.5	1.4	333.3
	Z_{max}			23.8	6.5	3.4	23.4	162.5	17.4	1.7	382.7
Lacustrine	S	2.6	22.1	23.7	6.8	7.3	25.6	118.5	5.6	1.4	293.1
	$Z_{eu} = Z_{mix}$			23.9	6.6	5.4	24.6	128.2	5.4	1.4	305.6
	Z_{max}			24.1	6.4	2.4	22.4	164.4	5.3	1.4	287.8
Dry period											
June											
Fluvial	S	0.3	24.8	24.3	6.9	8.2	19.0	537.1	18.7	0.8	272.1
	$Z_{eu} = Z_{mix}$			25.0	6.9	8.0	18.5	228.5	7.5	0.9	252.3
	Z_{max}			24.5	6.8	8.0	18.4	228.4	9.1	1.0	242.5
Transition	S	0.3	25.9	21.4	7.2	8.5	21.6	312.6	10.4	0.7	367.4
	Z_{eu}			21.6	6.9	8.1	19.7	322.7	8.6	1.3	340.3
	Z_{mix}			22.3	6.6	5.9	18.3	300.2	9.2	2.4	342.5
	Z_{max}			22.3	6.6	5.9	18.3	300.2		2.4	343.5
Lacustrine	S	0.5	23.4	19.7	6.9	8.0	20.1	286.1	10.0	1.0	313.1
	Z_{eu}			19.7	6.9	8.0	20.1	286.1		1.0	313.1
	Z_{mix}			20.7	6.7	7.0	18.6	342.7	18.6	0.9	351.3
	Z_{max}			21.0	6.5	6.7	18.3	375.9	22.3	1.2	387.5
September											
Fluvial	S	0.5	16.0	26.6	6.5	8.1	16.7	228.5	16.2	0.7	267.6
Transition	S	0.5	21.4	25.7	6.7	7.6	22.1	132.8	16.2	0.1	184.1
	Z_{mix}			26.7	6.5	6.5	20.3	131.6	13.8	0.6	189.5
	Z_{max}			28.0	6.0	2.1	19.0	151.7	16.2	2.5	173.1
Lacustrine	S	1.5	16.8	23.2	6.8	7.7	20.7	99.5	13.4	0.1	167.2
	$Z_{eu}=Z_{mix}=Z_{max}$			23.5	6.6	5.2	19.7	101.2	13.5	0.1	171.9

A total of 106 taxa were identified, distributed among 9 taxonomic groups. Chlorophyceae was the most representative group (48 taxa). Total phytoplankton biovolume values were low during most of study period, except in March 2002, at epilimnetic layer of lacustrine and transition zones, where we verified values superior to 2 mm^3 L^{-1}.

Horizontal gradient was evidenced for phytoplankton biovolume, with higher values observed in general in the transition zone, as well as a vertical gradient, with greater values at epilimnetic layer, over all reservoir extent (Figure 3), however significant differences between biovolume values of the three zones were not verified (*pseudo* F = 0.89; p = 0.55).

Zygnemaphyceae was massively dominant in March, at transition and lacustrine zones. Dinophyceae occurred in most samples, being dominant at transition zone, in June and December. Cryptophyceae was present throughout study period, with greater contribution in the transition zone, in September, and in fluvial zone, in December. Bacillariophyceae was the main group in biomass at fluvial zone of the reservoir in March, at transition and lacustrine zones, in June. Chlorophyceae presented greater contribution at transition and lacustrine zones, in December.

Nine functional groups (FG) were reported: N, L_o, Y, A, C, P, MP, E and W1 (Table 2). FG N (*Cosmarium* sp.), the most representative in biomass, was dominant in March at transition and lacustrine zones. FG Lo (*Peridinium* sp.) was dominant in euphotic zone, at the transition zone, in June. FG Y (*Cryptomonas* sp.) occurred in most samples and was dominant at fluvial zone, in December, and in transition zone, in September. FG C (*Asterionella* cf. *formosa* and *Aulacoseira ambigua*) was dominant, at fluvial zone, in March, and transition and lacustrine zones, in June.

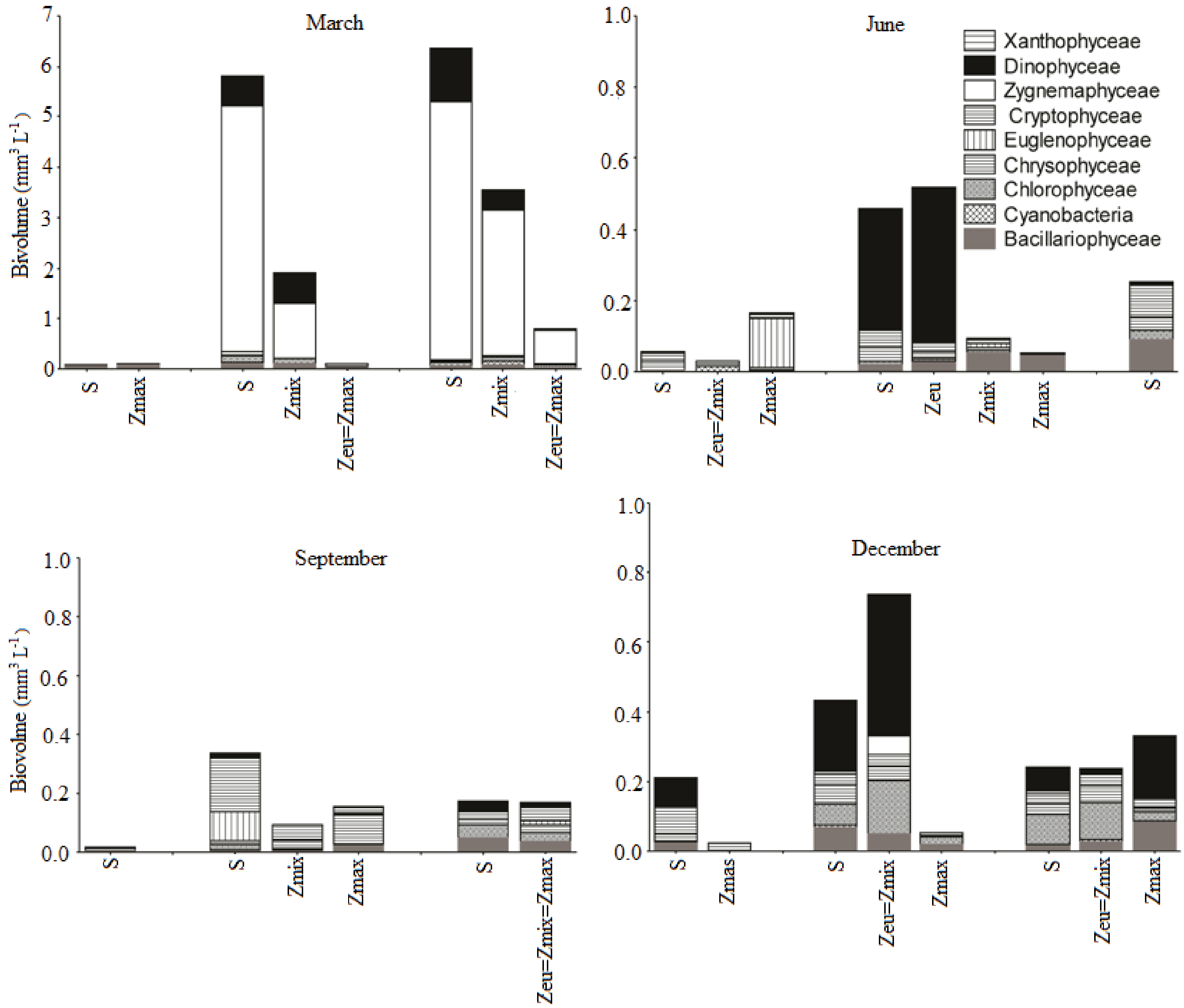

Figura 3. Biovolume values of taxonomic groups recorded in different zones (fluvial, transition, lacustrine) and sampling depths (S, Z_{eu}, Z_{mix}, Z_{max}; $Z_{eu} = Z_{mix}$; $Z_{mix} = Z_{max}$), during study period. (Note different scales)

Table 2. Biovolume % (> 5% of total) of principal phytoplankton taxa and their respective functional groups (FG) in different zones and sampling depths (S, Z_{eu}, Z_{mix}, Z_{max}; $Z_{eu} = Z_{mix}$; $Z_{mix} = Z_{max}$) in Mourão reservoir, during study period. (Months= M, J, S, D)

Taxonomic groups/species	FG	Fluvial Region		Lacustre Region		Transição Region	
		rainy	dry	rainy	dry	rainy	dry
BACILLARIOPHYCEAE							
Thalassiosira sp.	A	D - S (11)	S - S (9)	D - Z_{mix} (9), Z_{max} (14)	J - S (10), Z_{eu} (10), Z_{mix} (16), Z_{max} (15)	D - S (12), Z_{max} (32)	J - Z_{mix} (17)
Urosolenia eriensis (H. L. Sm.) Round e Craw.	A	M - Z_{max} (16); D - S (5)			S - S (19), Z_{max} (12)		S - S (9)
Asterionella cf. *formosa* Hassal	C	M - Z_{max} (62)			J - Z_{max} (46)		
Aulacoseira ambigua (Grunow) Sim. var. *ambigua*	C	M - S (22)		D - Z_{max} (6)	J Z_{eu} (19), Z_{mix} (17), Z_{max} (21); S - Z_{max} (8)	M - Z_{max} (12)	J - Z_{max} (38); S - Z_{max} (13)
Aulacoseira granulata (Ehrenb.) Sim. var. *granulata*	P				J - S (9), Z_{eu} (12), Z_{mix} (28), Z_{max} (13); S - S (5)		J - Z_{mix} (9), Z_{max} (25)
Diatoma sp.	MP				J - S (9), Z_{eu} (11), Z_{mix} (16)		J - Z_{mix} (19)
Eunotia sp.	MP	M - S (39)					
CHRYSOPHYCEAE							

Continue...

...continuation

Taxonomic groups/species	FG	Fluvial Region		Lacustre Region		Transição Region	
		rainy	dry	rainy	dry	rainy	dry
Mallomonas sp.	E		J - S (45), Z_{mix} (27)	D - Z_{mix} (5)	J - S (14), Z_{eu} (5)	D S (7)	J - Z_{eu} (8), Z_{mix} (9)
CRYPTOPHYCEAE							
Cryptomonas brasiliensis Castro, Bic. e Bic.	Y		J - S (6)		J - S (23), Z_{eu} (26), Z_{max} (13)		J - S (5); S - S (14), Z_{mix} (20)
Cryptomonas marssonii Skuja	Y	M - Z_{max} (12)	J - S (11)			D - Z_{max} (6)	S - Z_{mix} (10)
Cryptomonas sp.	Y	M - S (6); D - Z_{max} (5); D -S (25), Z_{max} (96)	J - S (20), Zmix (18); S - S (17)	D - Z_{mix} (5)	J - S (9), S - S (14), Z_{max} (12)	D - Z_{max} (6)	J - Z_{mix} (11), Z_{max} (5); S - S (22), Z_{mix} (23), Z_{max} (8)
DINOPHYCEAE							
Peridinium sp.	L_O			M - S (16), Z_{mix} (10), D - Z_{max} (54)		M - S (5), Z_{mix} (25); D - S (27), Z_{eu} (48)	J - S (64), Z_{eu} (79)
Peridinium sp1	L_O	M - Z_{max} (12); D - S (40)	J - S (7); S - S (22)	D - S (27)	S - S (20), Z_{max} (9)	M - S (5), Z_{mix} (7); D - S (20), Z_{eu} (7)	J - S (10), Z_{eu} (5); S - S (6)
EUGLENOPHYCEAE							
Lepocinclis caudata (Cunha) Conrad	W_1		J - Z_{max} (78)				
ZYGNEMAPHYCEAE							
Cosmarium sp.	N			M - S (69), Z_{mix} (61), Z_{max} (29)		M - S (71), Z_{mix} (35)	
Staurastrum tetracerum (Kütz.) Ralfs ex Ralfs	N			M - S (8), Z_{mix} (13), Z_{max} (32)		M - S (9), Z_{mix} (18), Z_{max} (49)	

Monte Carlo test of the first canonical axis ($p < 0.005$), were significant, with a percentage of variance explained 45% of the species-environmental variation. Axis 1 (0.59) which showed the strongest relationship between functional groups and environmental variables (0.99), was principally correlated with Z_{eu}:Z_{mix} rate (0.88), Z_{mix}:Z_{max} rate (-0.23), pH (0.44), water temperature – WT (0.87), dissolved oxygen – DO (-0.45), conductivity – Cond. (0,44) and dissolved inorganic nitrogen- DIN (-0.79) (Figure 4).

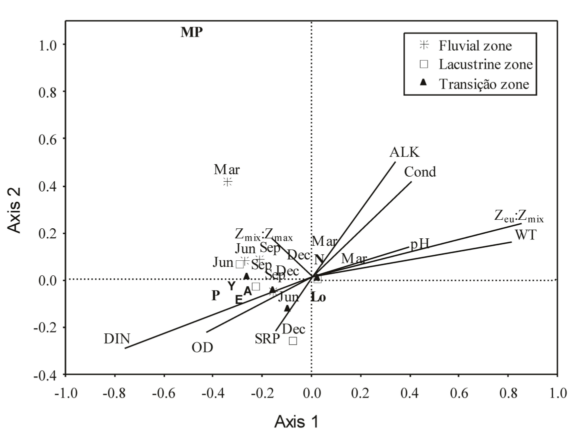

Figure 4. Score dispersion of locations for sampling time and abiotic variables and biovolume of principal phytoplanktonic GFs along the first two CCA axes.

CCA diagram evidenced low scores dispersion in relation to horizontal and temporal distribution. To the right of the diagram, transition and lacustrine zones were discriminated from fluvial zone only in March. This result was influenced by higher Z_{eu}:Z_{mix} ratio and higher biomass values of Zygnemaphyceae, represented by FG N . The separation of the others FGs, at left of the diagram, was influenced principally by the higher DIN.

Discussion

The discrete horizontal gradient in phytoplankton biovolume observed for Mourão Reservoir, with the highest values at transition and lacustrine zones may be associated to the high retention time. Shallow and small reservoirs, with longer retention time usually present higher values of phytoplankton biovolume in these regions (RODRIGUES et al., 2005; TRAIN et al., 2005).

Oligotrophic conditions were verified during most of the study period, in all reservoir zones, according to the criteria proposed by Reynolds (1980), considering the values of phytoplankton biovolume. This result may be ascribed to lack of nutrients, especially soluble reactive phosphorus, since Mourão Reservoir presented high light availability (Z_{eu}:Z_{mix} ratio > 1), mainly in transition and lacustrine zones. In these zones, the total biovolume of phytoplankton were positively correlated with the Z_{eu}:Z_{mix} ratio ($r= 0.61$; $p < 0.05$, $n = 25$).

The lower Z_{eu}:Z_{mix} ratio found in the fluvial zone, in most of the study period, can explain the low biovolume values recorded. The fluvial zones of reservoirs are, in general, characterized by high velocity of water flow and low light availability, which are limiting factors for phytoplankton development (KIMMEL et al., 1990; PIVATO et al., 2006; SALMASO; ZIGNIN, 2010). In this way, higher values of phytoplankton biovolume at fluvial zone in June may be assigned to high light availability (Z_{eu}:Z_{mix} = 1) and stability of water column (Z_{eu}:Z_{max} = 0.4), as a result of low rainfall during this period.

Greater values of phytoplankton biovolume observed in rainy period, in transition and lacustrine zones, characterized eutrophic conditions. These values were associated to high light availability. The dominance of the FG N (*Cosmarium* spp.) in this period, as evidenced by CCA, can be ascribed to survival strategies of this functional group, which is typical of oligo-mesotrophic environments, with high transparence and species sensitive to destratification (REYNOLDS et al., 2002). *Cosmarium* spp. was grouped in FG N_A by Souza et al. (2008), because these authors recorded these taxa in atelomictic condictions. The methodology used for us did not allow assuring that occurred events of atelomixis.

Dominance of the FG L_0 (*Peridinium* sp.) in June, at epilimnetic layer of transition zone, was also associated to thermal stratification conditions and discrete nutrients segregation, with higher PSR concentration at Z_{max}. This group is adapted to a wide environmental variability, as established by Reynolds et al. (2002), and is common in lakes medium to large, shallow to deep, and oligotrophic to eutrophic.

Highest biovolume values of the FG Y (*Cryptomonas* spp.), in three zones, principally in dry period, were related with the low light availability, higher concentrations of DIN, PSR, and high Z_{eu}:Z_{mix} ratio, as evidenced by the CCA, which emphasizes the opportunistic traits of this group, as already reported by several authors (TRAIN et al., 2005; BOVO-SCOMPARIN; TRAIN, 2008; BORGES et al., 2008; 2010; SILVA et al., 2005; RODRIGUES et al., 2009).

Conclusion

Results herein obtained evidenced a horizontal gradient in the reservoir, with higher values of phytoplankton biovolume in transition and lacustrine zones, which can be attributed to the proximity and similar environmental characteristics between these zones. So, the hypothesis that highest biovolume of phytoplankton are found in the transition zone was not supported by analysis realized. The phytoplankton structure with dominance of the FGs Y and Lo during most of the study period, characterized the oligotrophy conditions, the pattern of circulation and light availability of the reservoir.

Acknowledgements

The authors are grateful to the Núcleo de Pesquisas em Limnologia, Ictiologia e Aqüicultura (Nupélia) of Universidade Estadual de Maringá, for logistic support; to researchers from Nupélia Limnology Laboratory; to Agência Nacional de Águas (ANA) and Companhia Paranaense de Energia (COPEL); to CNPq/PRONEX for financial support; to CAPES, and to anonymous reviewers for suggestions on the manuscript.

References

APHA-American Public Health Association. **Standard methods for the examination of water and wastewater**. 19th ed. Washington D.C.: APHA, 1995.

ANDERSON, M. J. A new method for non-parametric multivariate analysis of variance. **Austral Ecology**, v. 26, n. 1, p. 32-46, 2001.

BECKER, V.; CAPUTO, L.; ORDÓÑEZ, J.; MARCÉ, R.; ARMENGOL, J.; CROSSETTI, L. O.; HUSZAR, V. L. M. Driving factors of the phytoplankton functional groups in a deep Mediterranean reservoir. **Water Research**, v. 44, n. 11, p. 3345-3354, 2010.

BECKER, V.; HUSZAR, V. L. M.; CROSSETTI, L. O. Responses of phytoplankton functional groups to the mixing regime in a deep subtropical reservoir. **Hydrobiologia**, v. 628, n. 1, p. 137-151, 2009.

BORGES, P. A. F.; TRAIN, S.; DIAS, J. D.; BONECKER, C. C. Effects of fish farming on plankton structure in a Brazilian tropical reservoir. **Hydrobiologia**, v. 649, n. 1, p. 279-291, 2010.

BORGES, P. A. F.; TRAIN, S.; RODRIGUES, L. C. Spatial and temporal variation of phytoplankton in two subtropical Brazilian reservoirs. **Hydrobiologia**, v. 607, n. 1, p. 63-74, 2008.

BOVO-SCOMPARIN, V. M.; TRAIN, S. Long-term variability of the phytoplankton community in an isolated floodplain lake of the Ivinhema river State Park, Brazil. **Hydrobiologia**, v. 610, n. 1, p. 331-344, 2008.

GOLTERMAN, H. L.; CLYMO, R. S.; OHSTAD, M. A. M. **Methods for physical and chemical analysis of freshwater**. Oxford: Blackwell Scientific Publication, 1978.

JÚLIO-JÚNIOR, H. F.; THOMAZ, S. M.; AGOSTINHO, A. A.; LATINI, J. D. Distribuição e caracterização dos reservatórios. In: RODRIGUES, L.; THOMAZ, S. M.; AGOSTINHO, A. A.; GOMES, L. C. (Ed.). **Biocenoses em reservatórios**: padrões espaciais e temporais. São Carlos: Rima, 2005. p. 1-16.

KIMMEL, B. L.; LIND, O. T.; PAULSON, L. J. Reservoir primary production. In: THORNTON, K. W.; KIMMEL, B. L.; PAINE, F. E. (Ed.). **Reservoir limnology**: ecological perspectives. New York: John Wiley and Sons, 1990. p. 133-193.

LUND, J. W. G.; KIPLING, C.; LE CREN, E. D. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. **Hydrobiologia**, v. 11, n. 2, p. 143-170, 1958.

MACKERETH, F. Y. H.; HERON, J.; TALLING, J. J. **Water analysis**: some revised methods for limnologist. Ambleside: Freshwater Biology Association, Scientific Publication, 1978.

McCUNE, B.; MEFFORD, M. J. **PC-ORD**, version 4.0, Multivariate analysis of ecological data, MjM Software Design. Oregon: Gleneden Blach, 1999.

NOGUEIRA, M. G. Phytoplankton composition, dominance and abundance as indicators of environmental compartmentalization in Jurumirim Reservoir (Paranapanema river), São Paulo, Brazil. **Hydrobiologia** v. 431, n. 2-3, p. 115-128, 2000.

PADISÁK, J.; BORICS, G.; GRIGORSZKY, I.; SORÓCKZI-PINTÉR, É. Use of phytoplankton assemblages for monitoring ecological status of lakes within the water framework directive: the assemblage índex. **Hydrobiologia**, v. 553, n. 1, p. 1-14, 2006.

PADISÁK, J.; CROSSETTI, L. C.; NASELLI-FLORES, L. Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. **Hydrobiologia,** v. 621, n. 1, p. 1-19, 2009.

PIVATO, B. M.; TRAIN, S.; RODRIGUES L. C. Dinâmica nictemeral das assembléias fitoplanctônicas em um reservatório tropical (reservatório de Corumbá, estado de Goiás, Brasil), em dois períodos do ciclo hidrológico. **Acta Scientiarum. Biological Sciences**, v. 28, n. 1, p. 19-29, 2006.

R DEVELOPMENT CORE TEAM. **R**: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2013.

REYNOLDS, C. S. Phytoplankton assemblages and their periodicity in stratifying lake systems. **Holartic Ecology**, v. 3, n. 3, p. 141-159, 1980.

REYNOLDS, C. S.; HUSZAR, V.; KRUK, C.; NASELLI-FLORES, L.; MELO, S. Towards a functional classification of the freshwater phytoplankton. **Journal of Plankton Research**, v. 24, n. 5, p. 417-428, 2002.

RODRIGUES, L. C.; TRAIN, S.; BOVO-SCOMPARIN, V. M.; JATI, S.; BORSALLI, C. C. J.; MARENGONI, E. Interannual variability of phytoplankton in the main rivers of the upper Paraná River floodplain, Brazil: influence of upstream reservoirs. **Brazilian Journal of Biology**, v. 69, n. 2, p. 501-516, 2009. (suppl.)

RODRIGUES, L. C.; TRAIN, S.; PIVATO, B. M.; BOVO-SCOMPARIN, V. M.; BORGES, P. A. F.; JATI, S. Assembléias fitoplanctônicas de trinta reservatórios do estado do Paraná. In RODRIGUES, L.; THOMAZ, S. M.; AGOSTINHO, A. A.; GOMES, L. C. (Ed.). **Biocenoses em reservatórios**: padrões espaciais e temporais. São Carlos: Rima, 2005. p. 57-72.

SALMASO, N.; ZIGNIN, A. At the extreme of physical gradients: phytoplankton in highly flushed, large rivers. **Hydrobiologia**, v. 639, n. 1, p. 21-36, 2010.

SILVA, C. A.; TRAIN, S.; RODRIGUES, L. C. Phytoplankton assemblages in a Brazilian subtropical cascading reservoir systen. **Hydrobiologia**, v. 537, n. 1-3, p. 99-109, 2005.

SOUZA, M. B. G.; BARROS, C. F. A.; BARBOSA, F.; HAJNAL, É.; PADISÁK, J. Role of atelomixis in replacement of phytoplankton assemblages in Dom Helvécio Lake, South-East Brazil. **Hydrobiologia**, v. 607, n. 1, p. 211-224, 2008.

STATSOFT INC. **Statistica** (Data Analisys Software System), version 7.1. 2005. Available from: <http://www. statisoft.inc>. Access on: June 31, 2011.

STRASKRABA, M.; TUNDISI, J. G. **Theoretical Reservoir Ecology and its Applications**. São Carlos :International Institute of Ecology, Brazilian Academy of Sciences and Backhuys Publishers, 1999. p. 565-597.

SUN, J.; LIU D. Geometric models for calculating cell biovolume and surface area for phytoplankton. **Journal of Plankton Research**, v. 25, n. 11, p. 1331-1346, 2003.

TER BRAAK, C. J. F. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. **Ecology**, v. 67, n. 5, p. 1167-1179, 1986.

THORNTON, K. W. Sedimentary processes. In: THORNTON, K. W.; KIMMEL, B. L.; PAINE, F. E. (Ed.). **Reservoir limnology**: Ecological perspectives. New York: John Wiley and Sons, 1990. p. 133-194.

TRAIN, S.; JATI, S.; RODRIGUES, L. C.; PIVATO, B. M. Distribuição espacial e temporal do fitoplâncton em três reservatórios da bacia do rio Paraná. In: RODRIGUES, L.; THOMAZ, S. M.; AGOSTINHO, A. A.; GOMES, L. C. (Ed.). **Biocenoses em reservatórios**: padrões espaciais e temporais. São Carlos: Rima, 2005. p. 73-85.

TUNDISI, J. G.; MATSUMURA-TUNDISI, T.; ROCHA, O. Theoretical basis for reservoir management. In: TUNDISI, J. G.; STRASKRABA, M. (Ed.), **Theoretical reservoir ecology and its applications**. São Carlos: International Institute of Ecology; Brazilian Academy of Sciences; Backhuys Publishers, 1999. p. 505-528.

UTERMÖHL, H. Z. Vervollkommung der quantitativen phytoplankton-methodic. **Mitteilungen Internationale Vereinigung für Theoretische und Angewandte Limnologie**, v. 9, n. 1, p. 1-38, 1958.

Received on March 28, 2011.
Accepted on November 18, 2011.

License information: This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.