Influence of the hydrological changes on the phytoplankton structure and dynamics in a subtropical wetland-lake system.

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ABSTRACT: Influence of the hydrological changes on the phytoplankton structure and dynamics in a subtropical wetland-lake system. The hydroperiod-phytoplankton response in wetlands-lake coastal system is proposed in this study. The samples were taken monthly in three subsystems (North, transition and South) of Taim's Hydrologic System (THS), since March to December in 2001. Only five species, two diatoms (Aulacoseira granulata and Synedra acus) and three cyanobacteria (Aphanocapsa delicatissima, Cylindrospermopsis raciborski and Planktolyngbya contorta) were related to water dynamics from 333 phytoplankton species identified to the THS. Diatoms species showed high densities in Mangueira Lake (north zone) during spring, when the highest wind velocity and water level were registered. On the other hand, cyanobacteria species were abundant in Mangueira Lake during calm periods and low water level. In the subsystems North and transition, none spatial phytoplankton patterns were identified as observed in South subsystem. Subsystems North and transition are constituted by small lakes where the wind force is not strong enough to drive hydrodynamics process. Therefore, in Mangueira Lake (South subsystem from THS) the hydrodynamic was the force which drove phytoplankton structure.
Key-words: water level, wind, cyanobacteria, diatoms, structure.

RESUMO: O hidroperíodo na dinâmica da comunidade fitoplanctônica em um sistema lagoa-banhado subtropical. A resposta do fitoplâncton ao hidroperíodo em um sistema costeiro lagoa-banhado é proposta neste estudo. As amostras foram tomadas mensalmente em três subsistemas (norte, transição e sul) do Sistema Hidrológico do Taim (SHT), de março a dezembro de 2001. Das 333 espécies fitoplanctônicas identificadas para o SHT somente cinco espécies, duas diatomáceas (Aulacoseira granulata e Synedra acus) e três cianobactérias (Aphanocapsa delicatissima, Cylindrospermopsis raciborski e Planktolyngbya contorta) estiveram relacionadas com a dinâmica da água. Espécies de diatomáceas mostraram elevadas densidades na Lagoa Mangueira (zona norte) durante a primavera, quando os valores mais altos de velocidade do vento e nível d'água foram registrados. Por outro lado, espécies de cianobactérias foram abundantes na Lagoa Mangueira durante períodos calmos e baixo nível d'água. Nos subsistemas norte e de transição um padrão espacial não foi identificado para o fitoplâncton como observado no subsistema sul. Subsistemas norte e de transição são formados por pequenas lagoas onde a força do vento não é forte o suficiente para afetar os processos hidrodinâmicos. Portanto, na Lagoa Mangueira (subsistema sul do SHT) a hidrodinâmica foi a força que regula a estrutura do fitoplâncton.
Palavras-chave: nível d'água, vento, cianobactéria, diatomácea, estrutura.

Introduction

Hydrodynamic processes and biological changes occur on different spatial and temporal scales, leading to the discussion on temporal and spatial scales as well as the sampling scale and the relation between physical and biological scales (Legendre & Demers, 1984). The interaction becomes more complex in systems that combine the function of a dominant force, such as intense winds, with wetlands and lakes intertwined in space. In aquatic systems hydrodynamic processes are affected by the water body morphometrics (Wetzel, 1993), especially the size of the lake and its orientation regarding the direction of the predominant winds, as well as the topography of the lake bottom and the average depth.

In complex systems comprised of shallow lakes, a wetland and wetland-lakes, such as the Taim Hydrological System (THS) the hydrodynamics and the hydrological signature can play an important role in the biological communities structuring. The system has been divided in three subsystems: North-Flores Lake, Central-Wetland Taim and wetland-lakes Nicola and Jacaré; and South-Mangueira Lake. The connectivity and water dynamics between different subsystems (wetland, lakes and wetland-lakes) is intense and essentially governed by winds (Paz, 2003). The Taim Hydrological System has two eventually conflicting functions: (1) conservation, through the Taim Ecological Station; and (2) the supply of water for rice production. In recent decades, the Taim system has undergone an unregulated manipulation, irrigation and outflow control for conservation, of its hydrological signature and its present situation no longer represents natural conditions. Over this same period, the biological communities may have undergone alterations as a result of this change to such an extent that their current features may be different from their original features. Whether influenced by human or natural stressors, alterations in the Taim Hydrological System includes stabilization and changes in the inundation period, as well as increases and reductions in inundation (Motta Marques & Villanueva, 2001).

The knowledge on the phytoplankton community of aquatic environments in the Taim Hydrological System is derived from taxonomic studies. Some of these studies addressed floristic surveys in the subsystems while others studied taxonomic aspects of specific classes, families and genera of algae (Alves da Silva, 1988; Werner & Rosa, 1992; Rosa & Miranda-Kiesslich (1988, 1989). Diatoms in the Taim Wetland system were the most known group where Callegaro & Salomoni (1988), Flôres et al. (1999), Ludwig et al. (2004) and Lobo et al. (1992) carried out the main studies. Studies on the algal communities from floodplain shallow lakes are relatively scarce when compared to other regions in the world (Izaguirre et al., 2004). Studies such as those by García de Emiliani (1997), Huszar & Reynolds (1997), Huszar (2000), Melo & Huszar (2000), O' Farrell et al. (2003), Nõges et al. (2003) and Izaguirre et al. (2004) are among the few that addressed the composition and response of the phytoplankton community regarding interactions with water level in shallow lakes.

The lakes in Taim Hydrological System are characterized as being shallow environments, standing alone or inside a large wetland, and are subjected to strong winds. The result is a great water column homogeneity and resuspension of sediment which can limit the photic zone by restricting light and select the occurrence of phytoplankton groups. Changes in phytoplankton biomass are not clearly associated to pulse release of nutrients from the sediment to the upper layers of the water during ressuspension events or the direct inoculation of algae from the lake bottom, or even both these factors (Carrick et al., 1993).

If hydrological conditions in wetlands change, even if slightly, biological communities may respond with substantial changes both in species richness and the productivity of the ecosystem. The conservation of wetlands structure and functions demands water level fluctuation (Motta Marques & Villanueva, 2001). Because the wetland and lakes in the Taim Hydrological System are physically associated and the water dynamics defines the connection between them, one can suppose that the phytoplankton community, like the other biological communities, may respond to water level changes. Thus, understanding the phytoplankton community is basic to the general comprehension of the zonation of this complex system with standing alone lakes, wetland-lakes, and a wetland. The aim of the present study was to assess the structure and dynamics of phytoplankton in integrated standing alone lakes and wetland-lakes as a system's potential physical compartment indicator.

Material and methods

Sampling Site

The Taim Hydrological System (THS), site 7 of the Long Term Ecological Research of the Brazilian network (LTER=PELD/CNPq), is located in the southern part of the state of Rio Grande do Sul (32°20' and 33°00' S, and 52°20' and 52°45' W). The area system is 2,254 km², contains the federal Taim Ecological Station (ESEC-Taim, 33,935 ha), and is situated on a narrow strip of land between the Atlantic Ocean and Mirim Lake (Fig. 1). The system encompass sand dunes, natural fields, rice fields, shallow lakes, a wetland and wetland-lakes. The region is associated to a subtropical climate.

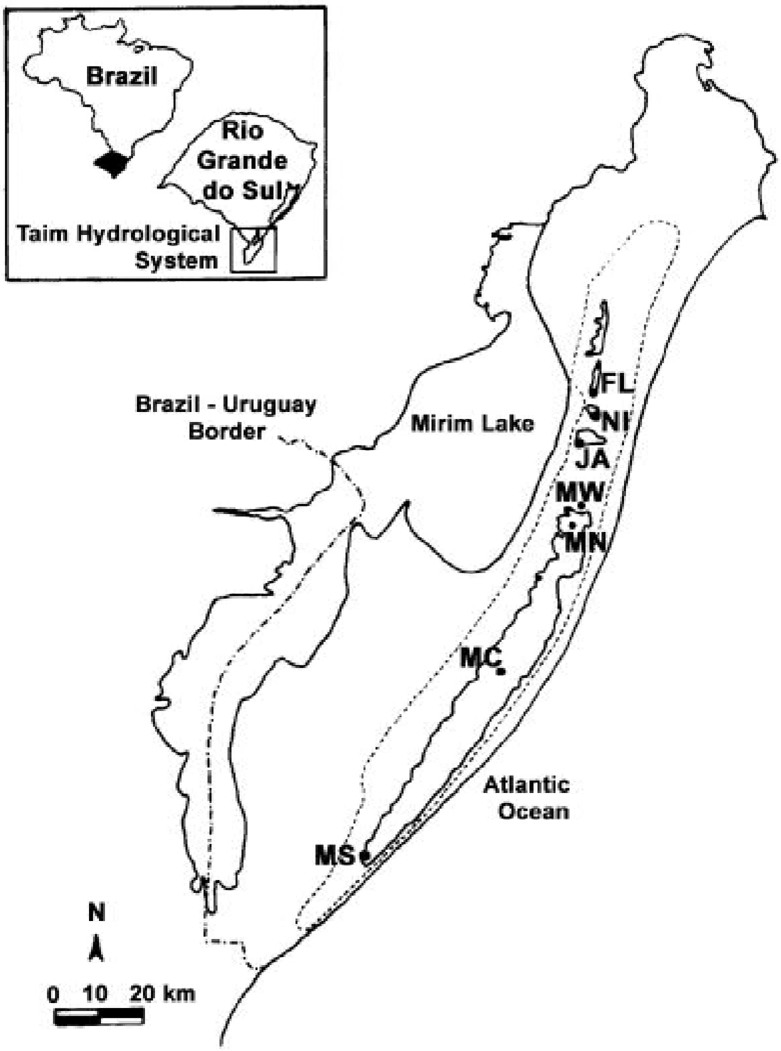

Figure 1: Taim Hydrological System (THS) and its subsystems. (FL= Flores Lake; NI= Nicola Lake; JA= Jacaré Lake; MN= North Mangueira Lake; MW= Mangueira Lake Wetlands; MC= Central Mangueira Lake; MS= South Mangueira Lake).

Abiotic characteristics

Water samples were collected from March to December 2001 (monthly collections) in the North subsystem at Flores Lake (FL), the transition subsystem at Nicola Lake (NI) and Jacaré Lake (JA), and at four sites of the South subsystem at Mangueira Lake (South - MS, Central - MC, North – MN) and wetland-lake Mangueira interface (MW) (Fig. 1).

These samples were analyzed for nutrients (total phosphorus, reactive phosphorus, total nitrogen, ammonia and nitrate) by Mackereth et al. (1989); total and volatile suspended solids, alkalinity, and CO_2 (APHA, 1992). Water temperature, pH, electric conductivity, redox potential and dissolved oxygen measures were taken at the same sampling stations using a YSI 6920 sonde. Water transparency was estimated using a Secchi disk.

Climatic data (wind direction and velocity) were continuously collected using a DAVIS GroWeather weather station. Water level was collected by an automatic gauge. Wave period and wave height were estimated from wind data (Håkanson, 1981). These data were taken in three locations regarding to each subsystems: 1. North Subsystem, 2) Wetland-Lake Mangueira interface, and 3) South Subsystem.

Biological Variables

Phytoplankton samples were obtained in the same places and times as for water samples. Samples for taxonomic identification (qualitative) were collected using a plankton net (25mm of mesh). For diatoms, the taxonomic study was performed using permanent slides that were prepared following the technique described by Kobayasi et al. (1982). The systemic arrangement of the divisions and classes of algae followed Hoeck et al. (1995). Quantification was performed using an inverted microscope (400x) following Utermöhl (1958), and density was expressed in individuals.mL^{-1}. At least one hundred individuals of most abundant taxon were counted per sample, being counting error of 20% .

No sampling was carried out at MN or MW in September 2001 due to technical problems.

Data treatment

The indices of species diversity (Shannon & Weaver, 1963) and evenness (Loyd & Ghelardi, 1964) were calculated using the program DIVERS (Krebs, 1989). Species richness was expressed in terms of total number of taxa per sample.

Data were statistically treated using descriptive (means, standard deviation, box-plot) and Principal Component Analysis (PCA). Data transformation was carried out before PCA: log (x+1) for biological data and "ranging" for abiotic data.

Results

Abiotic Variables

The water level registered the highest values in spring (max. 1.93 m), and the lowest (0.83 m) in autumn, and remaining on average at 1.5m (Tab. I, Fig. 2). Small oscillations were also registered at all system lakes. The largest water level was registered at North Subsystem (FL, NI, JA) (Tab. I). The largest wind velocities registered at the subsystems were coincident with the largest water levels at these same locations (max. 8.3 $m.s^{-1}$ and mean 4.2 $m.s^{-1}$, Tab. I, Fig. 2).

Water level seasonal fluctuations were linked with changes on water chemistry. Higher water levels observed in spring were associated with higher dissolved oxygen values (except Central Mangueira Lake in autumn), silica (at the both wetland-lakes: Flores Nicola and Jacaré), CO_2 (in Flores Lake/subsystem North, South Mangueira Lake-MS, interface Taim wetland/Mangueira Lake-MW, and the wetland-lakes Nicola-NI and Jacaré-JA), and alkalinity (in Central and South Mangueira Lake, Flores Lake, lakes Flores Nicola and Jacaré) (Fig. 3, Tab. I). During the fall reduced water levels were observed together with larger values of conductivity, silica (at spots on the Mangueira Lake) CO_2 (in North-MN and Central Mangueira-MC), and alkalinity (MN and MW) (Fig. 3, Tab. I).

Larger oscillations not following a seasonal pattern were observed for pH, Secchi depth (water transparency) and total phosphorus (Tab. I). Higher values of wave height and period, total dissolved phosphorus (TDP), ammonia and volatile suspended solids (SSV) were observed at high waters (spring and winter), whereas total suspended solids (TSS), total nitrogen (NT), reactive phosphorus (PR) and dissolved inorganic nitrogen (DIN) showed higher values only in winter (Fig. 3, Tab. I).

The Principal Component Analysis (PCA) based on twenty abiotic variables of the Taim Hydrological System subsystems explained 43.7% of the data variability. Alkalinity, conductivity, nitrate, and water temperature were the variables more correlated with axis 1 ($r > 0.65$). This axis explained 24.1% of the data variability, and may represent the general metabolism on the positive side with the highest alkalinity values over the warm months (March, April, November, and December) (Fig. 3). On the negative side of this axis, the nitrogen series were arranged (NH_4, NO_3, and NT) and the largest suspended volatile solid values corresponding to June and July samples (cold months). Axis 2 explained 19.6% of the data variability; wave height, wind velocity, water level, and dissolved oxygen were the variables with the highest correlation with this axis ($r > 0.63$). This axis represented the water turbulence and water oxygenation by turbulence. The sampled units from Flores Lake were arranged on the positive side associated to larger concentrations of total phosphate (PT) and reactive phosphorus (RP). On the opposite side higher values of average wind speed, water level, wave height, dissolved oxygen, and pH were associated with sampling units of July, August, September, and October in all subsystems, except for Flores Lake (Fig. 3). Nonetheless, the PCA showed that the THS subsystem sample units ordination was temporal, except Flores Lake.

Table I: Values (minimum, maximum, mean, and standard-deviation) of the principal abiotic variables in the THS subsystems in the period between March and December of 2001 (n=10). (FL= Flores Lake; NI= Nicola Lake; JA= Jacaré Lake; MN= North Mangueira Lake; MW= Mangueira Lake Wetlands; MC= Central Mangueira Lake; MS= South Mangueira Lake).

Abiotic variables	**FL**	**NI**	**JA**	**MN**	**MW**	**MC**
Water temperature (°C)	13.6 - 24.4 (19.7 ± 4.1)	13.3 - 24.0 (19.3 ± 3.7)	13.5 - 24.2 (19.0 ± 3.7)	11.8 - 23.1 (18.3 ± 4.2)	11.0 - 22.8 (18.2 ± 4.3)	13.6 - 23.5 (18.2 ± 3.5)
Secchi depth (cm)	0.3 - 30 (8.5 ± 13.3)	0.3 - 32.0 (9.6 ± 14.5)	0.2 - 90.0 (18.4 ± 31.8)	0.4 - 124.0 (40.9 ± 60.3)	0.4 - 168.0 (45.4 ± 70.8)	0.5 - 95.5 (25.0 ± 39.5)
Conductivity ($\mu S.cm^{-1}$)	57.0 - 100.0 (75.5 ± 13.1)	110.0 - 379.0 (234.0 ± 73.5)	241.0 - 387.0 (306.0 ± 48.0)	275.0 - 401.0 (333.1 ± 43.0)	266 – 402 (327.1 ± 37.8)	268.0 - 380.0 (321.0 ± 35.6)
Dissolved Oxygen ($mg.L^{-1}$)	8.4 - 11.5 (9.5 ± 1.0)	6.9 - 12.6 (9.4 ± 1.9)	5.8 - 13.7 (8.6 ± 2.3)	7.8 - 13.4 (10.1 ± 1.7)	6.9 - 12.0 (9.3 ± 1.7)	8.5 - 13.7 (10.6 ± 1.7)
Oxygen Saturation (%)	90.7 - 127.8 (104.0 ± 9.7)	77.6 - 138.0 (101.4 ± 17.8)	60.2 - 145.7 (92.0 ± 23.6)	89.9 - 141.0 (106.0 ± 14.4)	77.1 -124.5 (97.2 ± 13.1)	94.0 -136.0 (111.0 ± 14.5)
pH	6.6 - 8.1 (7.5 ± 0.4)	6.8 - 8.2 (7.6 ± 0.3)	6.9 - 8.0 (7.6 ± 0.3)	7.7 - 8.4 (8.1 ± 0.2)	7.2 - 8.1 (7.8 ± 0.2)	7.8 - 8.6 (8.3 ± 0.2)
VSS ($mg.L^{-1}$)	5.0 - 35.0 (19.9 ± 10.0)	1.5 - 35.0 (17.4 ± 9.4)	5.0 - 34.9 (17.3 ± 11.3)	5.50 - 33.0 (19.1 ± 9.1)	0.0- 29.0 (16.3 ± 9.6)	6.5 - 59.0 (25.5 ± 17.2)
TSS ($mg.L^{-1}$)	14.5 - 121.0 (41.6 ± 32.2)	7.0 - 107.0 (38.7 ± 28.4)	11.5 - 95.5 (43.0 ± 30.2)	18.6 - 60.0 (30.8 ± 15.4)	10.5 - 134.3 (38.5 ± 38.23)	18.0 - 141.8 (47.0 ± 38.5)
CO_2 ($mg.L^{-1}$)	0.2 - 7.2 (3.8 ± 2.6)	0.2 - 15.3 (4.4 ± 4.2)	0.3 - 10.9 (5.4 ± 3.3)	0.2 - 5.04 (2.5 ± 1.4)	0.1 - 8.8 (3.9 ± 2.7)	0.01- 3.02 (1.7 ± 0.9)
Si ($mg.L^{-1}$)	0.1 - 8.0 (2.3 ± 2.4)	0.2 - 0.4 (2.3 ± 1.0)	0.3 - 4.8 (3.1 ± 1.3)	0.2 - 4.9 (2.3 ± 1.5)	0.1 - 5.1 (2.4 ± 1.6)	0.1- 4. (2.3 ± 1.4)
TN ($mg.L^{-1}$)	0.00 - 0.52 (0.18 ± 0.17)	0.01- 0.36 (0.11 ± 0.13)	0.0 - 0.85 (0.17 ± 0.27)	0.0- 0.32 (0.10 ± 0.12)	0.01- 0.68 (0.15 ± 0.23)	0.0 - 0.79 (0.17 ± 0.25)
TP ($mg.L^{-1}$)	0.02 - 0.22 (0.09 ± 0.07)	0.01 - 0.11 (0.05 ± 0.03)	0.01 - 0.07 (0.03 ± 0.02)	0.0 - 0.06 (0.03 ± 0.02)	0.0 - 0.11 (0.05 ± 0.04)	0.0 - 0.05 (0.03 ± 0.02)
RP ($mg.L^{-1}$)	0.0 - 0.19 (0.06 ± 0.06)	0.0 - 0.11 (0.04 ± 0.03)	0.0 - 0.11 (0.03 ± 0.03)	0.0 - 0.03 (0.01 ± 0.01)	0.0 - 0.04 (0.01 ± 0.01)	0.0 - 0.02 (0.01 ± 0.01)
NO_3^- ($mg.L^{-1}$)	0.0 - 1.11 (0.27 ± 0.34)	0.0 - 1.25 (0.17 ± 0.38)	0.0 - 0.86 (0.19 ± 0.31)	0.0 - 0.86 (0.21 ± 0.29)	0.0 - 0.57 (0.16 ± 0.22)	0.0 - 0.86 (0.10 ± 0.27)
NH_4^+ ($mg.L^{-1}$)	0.0 -0.11 (0.04 ± 0.04)	0.0 - 0.04 (0.01 ± 0.01)	0.0 - 0.08 (0.02 ± 0.02)	0.0 - 0.04 (0.02 ± 0.02)	0.0 - 0.09 (0.04 ± 0.03)	0.0 - 0.06 (0.02 ± 0.02)
TDP ($mg.L^{-1}$)	0.012 - 0.158 (0.06 ± 0.05)	0.013- 0.072 (0.03 ± 0.02)	0.009 - 0.059 (0.02 ± 0.02)	0.002 - 0.210 (0.03 ± 0.07)	0.007 - 0.023 (0.01 ± 0.01)	0.01 - 0.021 (0.01 ± 0.01)
Alcalinity ($mg.L^{-1}$)	0.0 - 108.8 (28.0 ± 30.4)	4.0 - 112.1 (60.4 ± 33.4)	6.1 - 98.4 (73.4 ± 31.9)	6.2 - 121.7 (76.7 ± 35.5)	5.9 - 98.3 (71.5 ± 32.1)	5.9 - 114.0 (79.5 ± 24.6)
Wind velocity ($m.s^{-1}$)	1.8 - 8.3 (4.3 ± 1.9)	0.9 - 8.3 (3.8 ± 2.4)	1.8 - 8.3 (4.3 ± 1.9)	1.8 - 8.3 (4.3 ± 2.02)	1.8 - 8.3 (4.3 ± 2.0)	0.9 - 8.3 (3.8 ± 2.4)
Wave height (m)	0.01 – 0.19 (0.07 ± 0.05)	0.01- 0.18 (0.06 ± 0.05)	0.01 - 0.14 (0.07 ± 0.04)	0.04 - 0.30 (0.14 ± 0.10)	0.05 - 0.45 (0.14 ± 0.14)	0.01 - 0.36 (0.17 ± 0.13)
Wave period (h)	0.43 - 1.41 (0.83 ± 0.27)	0.38 - 1.36 (0.76 ± 0.31)	0.45 - 1.13 (0.81 ± 0.25)	0.54 - 1.96 (1.27 ± 0.49)	0.82 - 2.63 (1.30 ± 0.59)	0.38 - 2.52 (1.55 ± 0.74)
Water level (m)	0.84 - 1.93 (1.53 ± 0.42)	0.84 - 1.93 (1.53 ± 0.42)	0.84 - 1.93 (1.53 ± 0.42)	0.92 - 1.83 (1.52 ± 0.35)	0.92 - 1.83 (1.52 ± 0.35)	0.92 - 1.86 (1.55 ± 0.35)

VSS - volatile suspended solids, TSS - total suspended solids, TN - total nitrogen, TP - total phosphorus, RP- reactive phosphorus, TDP - total dissolved phosphorus.

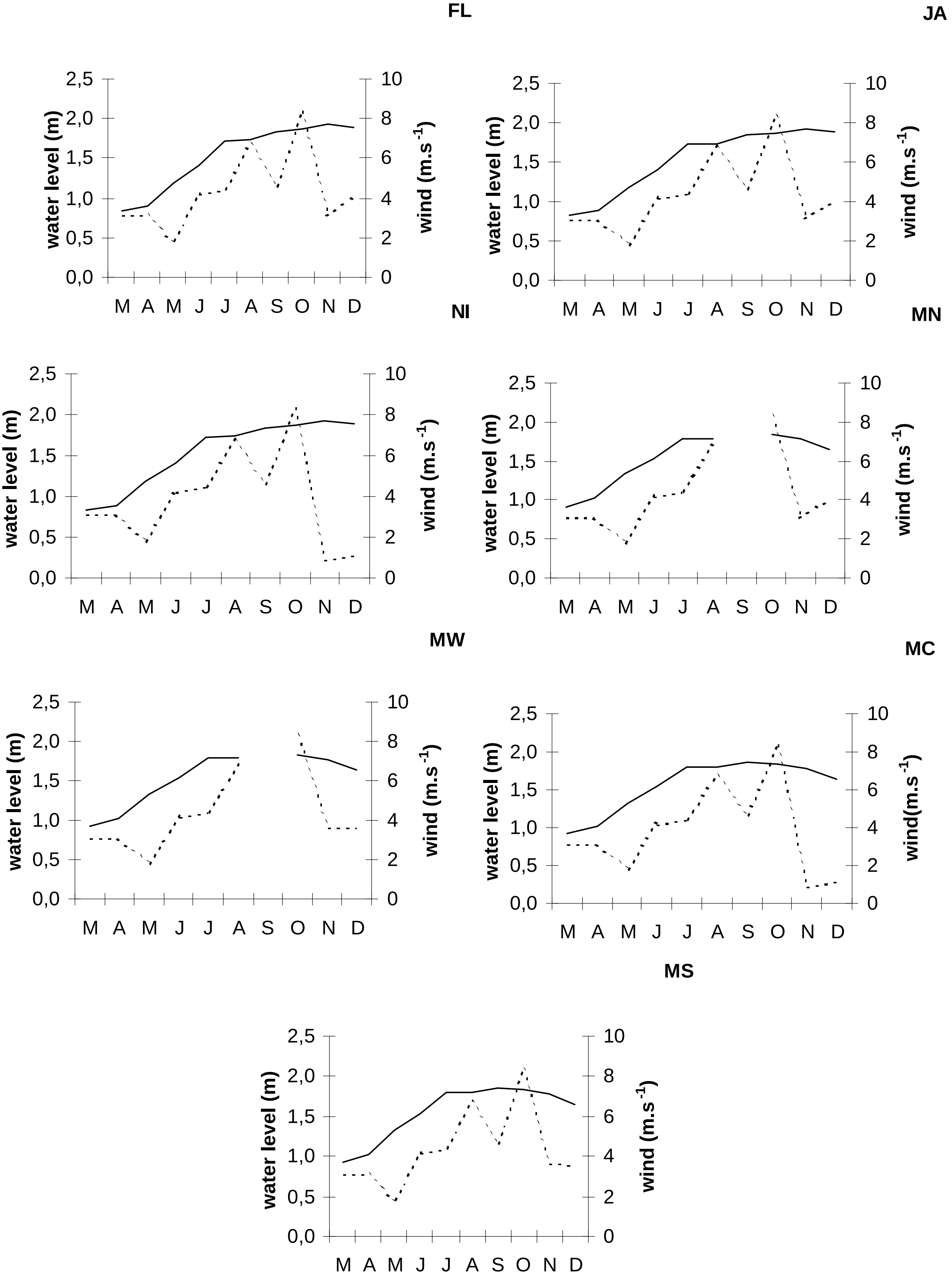

Figure 2: Water level (full line) and wind velocity (dotted line), registered in the THS subsystems, during the period between March and December of 2001. (FL= Flores Lake; NI= Nicola Lake; JA= Jacaré Lake; MN= North Mangueira Lake; MW= Mangueira Lake Wetlands; MC= Central Mangueira Lake; MS= South Mangueira Lake).

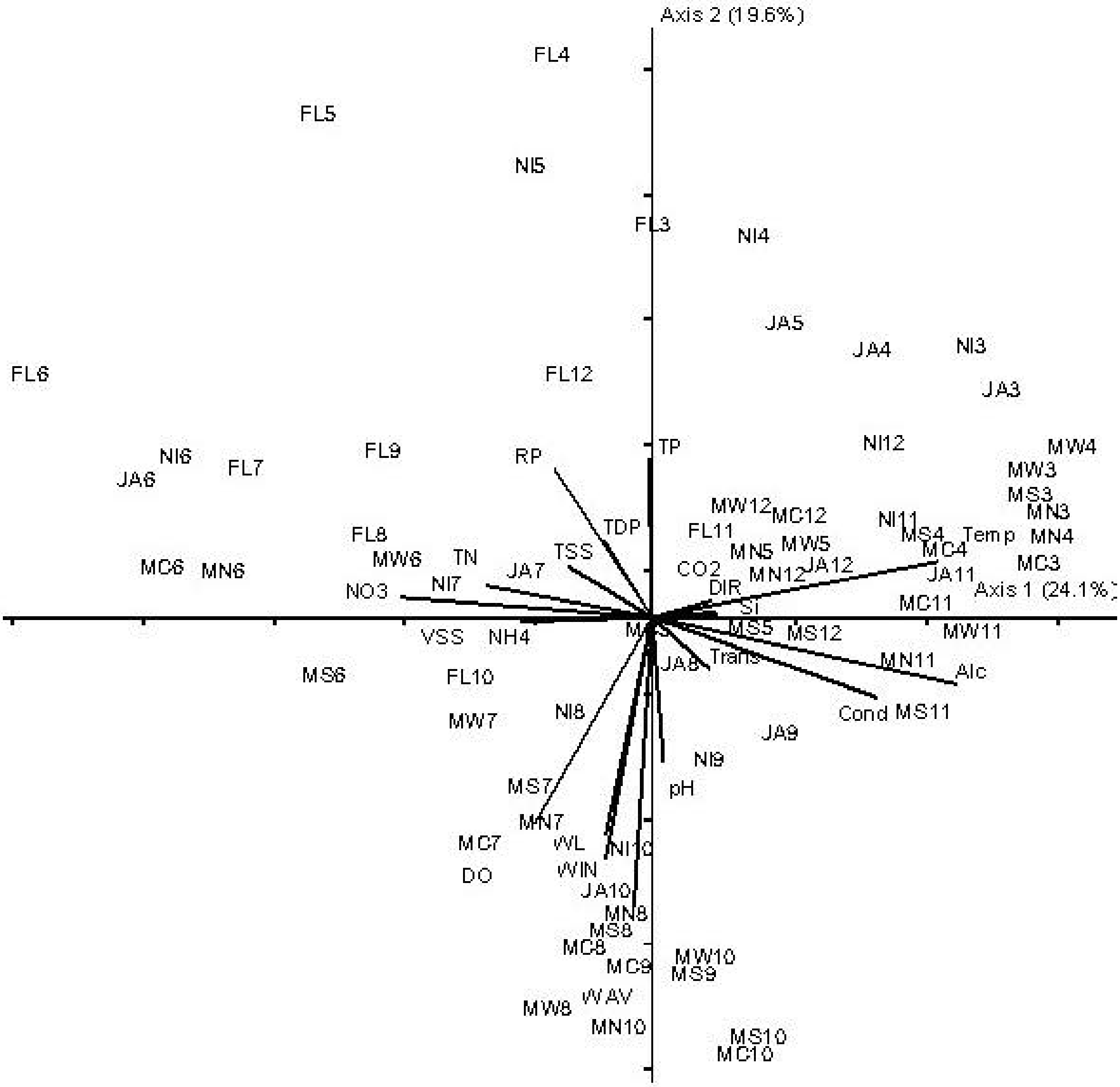

Figure 3: Principal Component Analysis (PCA) Biplot environmental variables in the THS subsystems, during the period between March and December of 2001. (FL= Flores Lake; NI= Nicola Lake; JA= Jacaré Lake; MN= North Mangueira Lake; MW= Mangueira Lake Wetlands; MC= Central Mangueira Lake; MS= South Mangueira Lake; Temp= water temperature; Cond= conductivity; DO= dissolved oxygen; VSS= volatile solid suspense; TSS= total solid suspense; TN= total nitrogen; TP= total phosphorus; RP= reactive phosphorus; TDP= total dissolved phosphorus; Alc= alkalinity; WL= water level; Trans= Secchi transparency; Dir= wind direction; Wind= wind velocity; Wave= wave height).

Biological Characteristics

Diversity and richness

Three hundred thirty-three species were distributed within nine algal classes. The largest values of specific richness were observed in Mangueira Lake subsystem (Fig. 4). In this subsystem high diversity values and low evenness values were observed as the result of dominance shown by some cyanobacterial species. However, the largest recorded diversities occurred in Nicola-NI and Jacaré-JA lakes (wetland-lakes, Central subsystem), that together with Flores Lake-FL (subsystem North) present elevated evenness values and lower specific richness values.

Phytoplankton biomass and density

The chlorophyll values fluctuations in the surveyed subsystems were not associated with the registered water levels (Fig. 4). Flores (North subsystem, Nicola, and

Jacaré (wetland-lakes, Central subsystem) presented the lowest phytoplankton densities, while the Mangueira Lake subsystem (MW, MN, MC, MS) presented the highest ones (Fig. 4). Density variations were registered in FL and JA lakes with the contribution of several algae classes, while cyanobacteria were responsible for the density increment in NI lake, especially during the low-level water period (Fig. 5) In North of Mangueira Lake-MN and Taim wetland/Mangueira Lake-MW interface the largest values of density were coincident with the lowest observed water levels. The Central and southern part of Mangueira Lake (MC and MS) also showed high values during the low water level period and reduced wind velocities although with some density fluctuations. In all these subsystems cyanobacteria contributed more to the total phytoplankton density, followed by the diatoms, in MN and MW, and green algae, in MC and MS (Fig. 5).

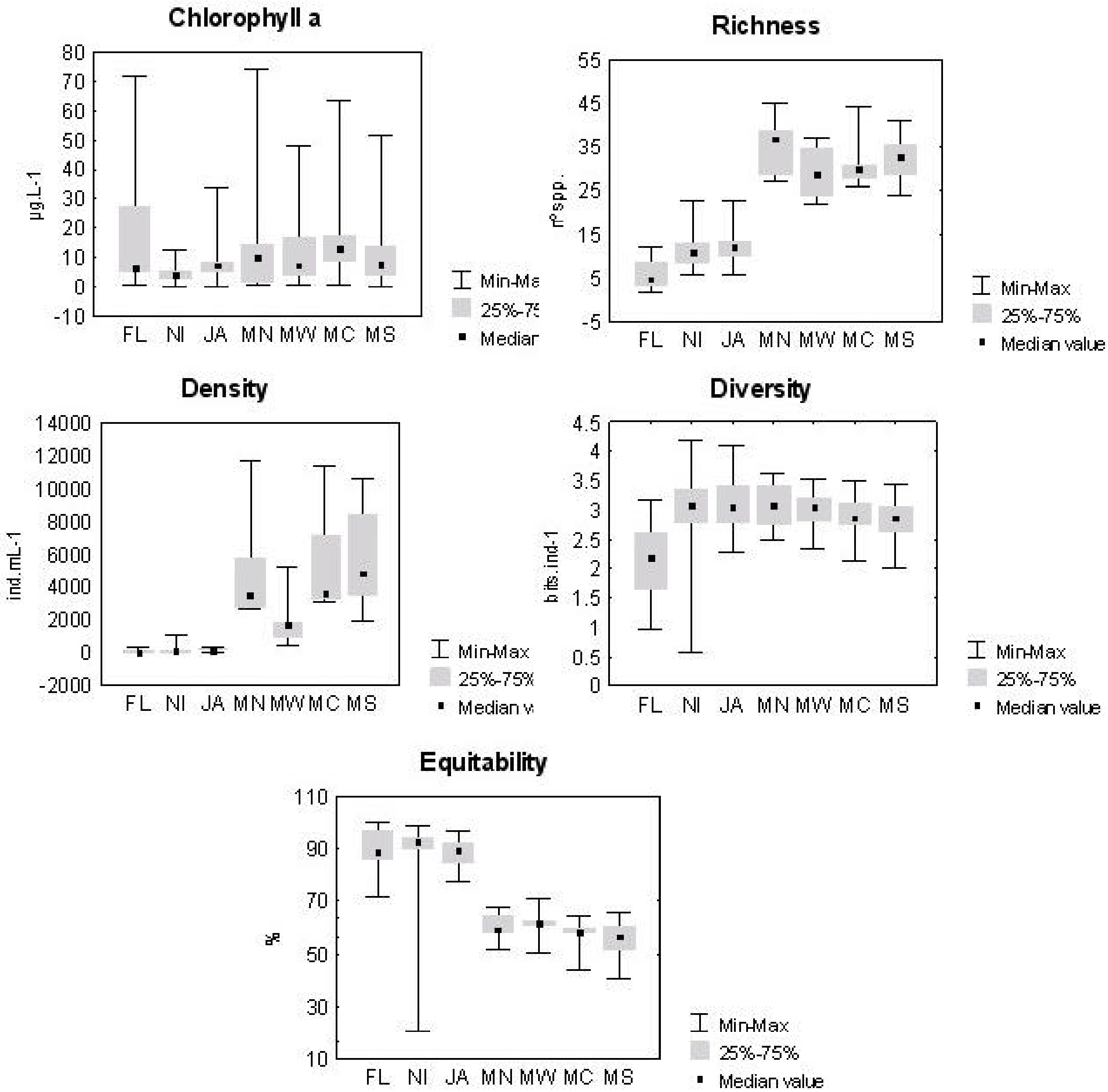

Figure 4: Taim Hydrologic System subsystems in the biotic variable boxplot during the period between March and December of 2001. (FL= Flores Lake; NI= Nicola Lake; JA= Jacaré Lake; MN= North Mangueira Lake; MW= Mangueira Lake Wetlands; MC= Central Mangueira Lake; MS= South Mangueira Lake).

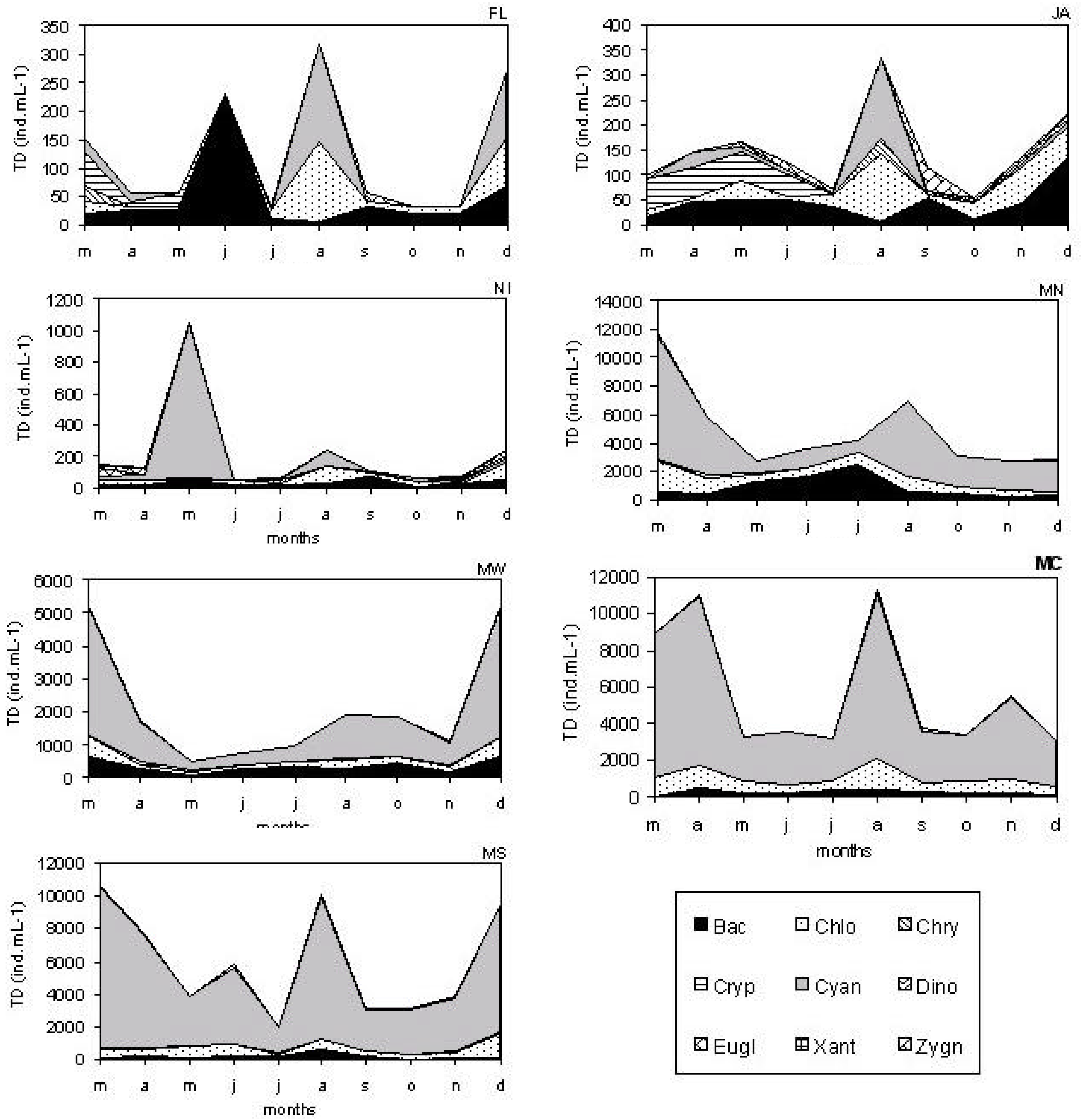

Figure 5: Total class density (ind.mL-1) in the THS subsystems, during the period between March and December of 2001. (FL= Flores Lake; NI= Nicola Lake; JA= Jacaré Lake; MN= North Mangueira Lake; MW= Mangueira Lake Wetlands; MC= Central Mangueira Lake; MS= South Mangueira Lake).

Compartment indicator species

In at least one of the studied subsystems Aulacoseira granulata (Ehrenberg) Simonsen, Synedra acus Kützing, Aphanocapsa delicatissima West et G.S. West, Cylindrospermopsis raciborskii (Woloszynska) Seenayya et Subba Raju, and Planktolyngbya contorta (Lemmermann) Komárkova-Legnerová et Cronberg were biological describers, contributing with 5% or more to the total phytoplankton density. Ecological data for the periods when these species contributed the most are summarized in Tab. II. These species present the highest densities and contributed with 65% to the total phytoplankton density in the subsystem Mangueira Lake (Fig. 6). In the others subsystems, the contribution of these species was lower.

The species Aulacoseira granulata and Synedra acus presented higher densities in the Mangueira Lake subsystem, decreasing from the North to

South (Fig. 6) in relation with the highest water levels (Fig 2).

Table II: Values (minimum and maximum) of the abiotic variables registered in the THS subsystems, when the descriptor species were more abundant (Temp= water temperature; TSS= total solid suspense; RP= reactive phosphorus; WIN= wind velocity; WL= water level).

Descriptor species		Temp	TSS	RP	NO3	WIN	WL
Synedra acus	min	11,8	23,0	0,0248	0,25	1,80	1,33
	max	15,9	60,0	0,0299	0,86	4,42	1,79
Aulacoseira granulata	min	11,8	18,2	0,0050	0,00	1,80	1,33
	max	17,6	54,7	0,0518	1,25	8,30	1,83
Cylindrospermopsis raciborskii	min	15,4	12,5	0,0000	0,00	0,87	0,92
	max	23,1	33,5	0,0158	0,10	6,75	1,79
Planktolyngbya contorta	min	14,1	20,5	0,0017	0,00	3,10	0,92
	max	23,5	38,7	0,0244	0,55	4,19	1,54
Aphanocapsa delicatissima	min	15,4	12,5	0,0000	0,00	3,10	0,92
	max	23,5	32,0	0,0249	0,13	6,75	1,79

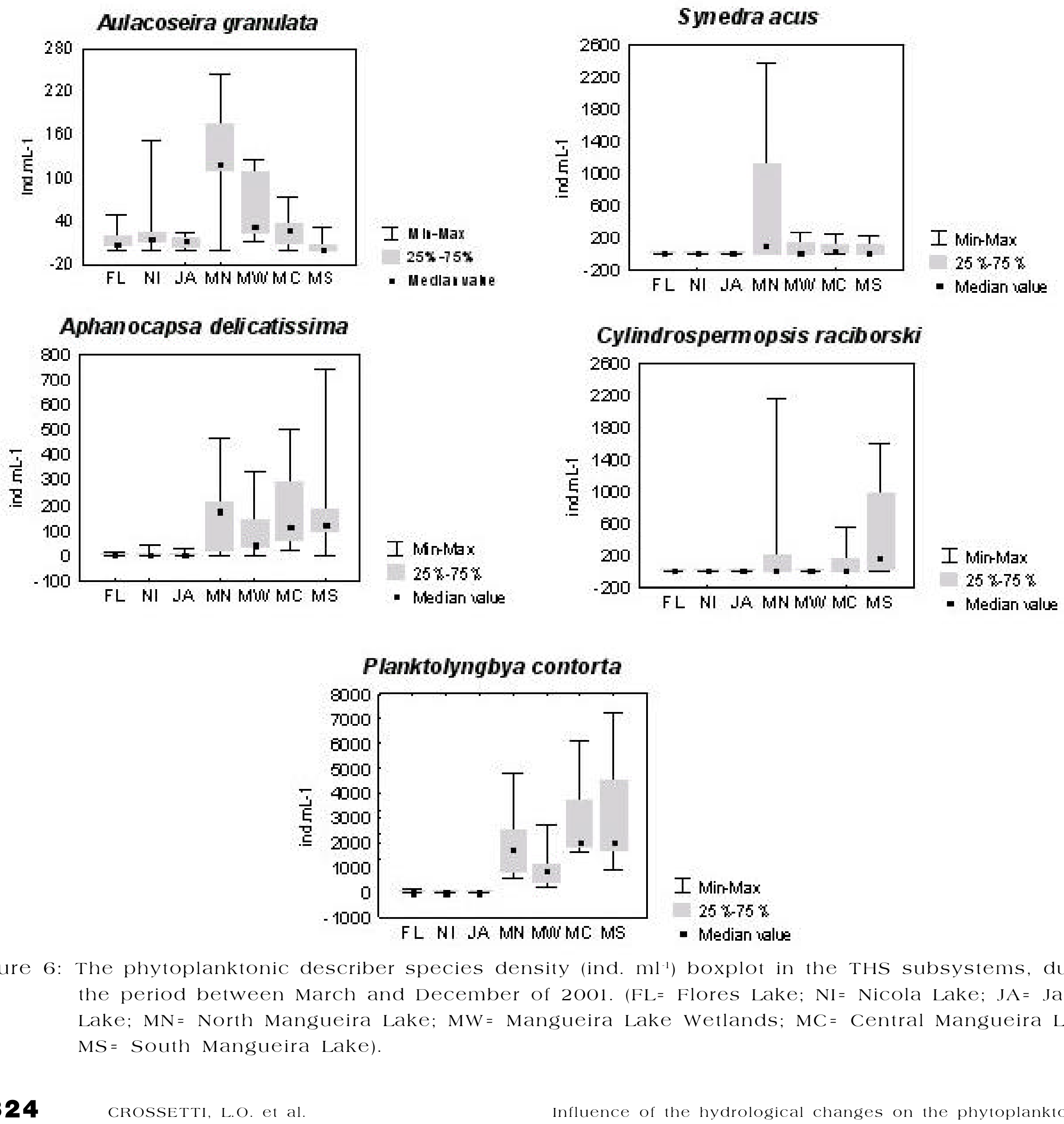

Figure 6: The phytoplanktonic describer species density (ind. ml^{-1}) boxplot in the THS subsystems, during the period between March and December of 2001. (FL= Flores Lake; NI= Nicola Lake; JA= Jacaré Lake; MN= North Mangueira Lake; MW= Mangueira Lake Wetlands; MC= Central Mangueira Lake; MS= South Mangueira Lake).

This is the first time Cylindrospermopsis raciborskii is registered in the Taim Hydrological System-THS. Its presence was observed for the study period in the Mangueira Lake subsystem with the largest densities in the warmest months, in all sampling stations (Fig. 6). The cyanobacteria Aphanocapsa delicatissima presented greater densities in Central and southern parts (MC and MS) of Mangueira Lake associated with low water level (Fig. 6). Planktolyngbya contorta also showed higher densities during the lower water level period (Fig. 6), especially in Mangueira Lake.

The Pearson correlation between total phytoplankton density and water level was not significant ($p>0.05$). But, a significant correlation between the total density and the wave height and wave period was recorded ($r= 0.31$ and $r= 0.40$, $p<0.05$, respectively). The water level presented an inverse correlation with C. raciborskii ($r= -0.34$, $p<0.05$), with Cryptophyceae ($r= -0.41$, $p<0.05$), and Dinophyceae ($r= -0.27$, $p<0.05$). Wave height and period were directly correlated with richness ($r= 0.38$ and 0.47, respectively, $p<0.05$), and inversely correlated with evenness ($r= -0.34$ and -0.40, respectively, $p<0.05$). Wave height and period were also correlationed with Planktolyngbya contorta ($r= 0.28$ and 0.37, respectively, $p<0.05$), and with the majority of the classes (Chlorophyceae, Cyanobacteria, Xanthophyceae, and Zygnemophyceae ($r= 0.28$ and 0.42, respectively, $p<0.05$).

The diversity did not present a significant correlation ($p>0.05$) with the, abiotic and biotic variables, although the richness was directly correlated with most of the describer species ($r= 0.32$ to 0.69, $p<0.05$) and classes ($r=0.25$ to 0.75, $p<0.05$). Evenness showed a negative correlation with these biotic variables ($r= -0.27$ to -0.63, $p<0.05$).

Discussion

The Taim Hydrological System hydroperiod pattern, during the studied period, was similar to that observed in an earlier study (Motta Marques & Villanueva, 2001). The amplitude of the water level variation followed the same pattern, showing high water level in spring and low in fall.

In the THS species system Synedra acus and Aulacoseira granulata showed density peaks when total suspended solids, nitrate and wind velocity presented high values (Tab. II). According to Reynolds et al. (2002), Synedra acus inhabits turbid, enriched environments and is tolerant to mixture. The same authors state that Aulacoseira granulata is tolerant to moderate light levels and sensitive to stratification.

In relation to the cyanobacteria, in the THS system, their greater abundance was registered under temperature and reactive phosphorous higher amplitude (Tab. II).

Aphanocapsa delicatissima is a typical species of shallow nutrient rich environments, being sensitive to deep mixture (Reynolds et al., 2002). The THS subsystems are shallow which justifies the presence of this species. Nõges et al. (2003) recorded higher values of biomass for one species of Planktolyngbya, under conditions of low water level in a temperate shallow lake. Such a fact was also observed for P. contorta, as it was mentioned in the results section.

Cylindrospermopsis raciborskii is a subtropical species common in eutrophic environments (Pádisak & Reynolds, 1998), which has a high capacity to form blooms and produce toxins (Tucci & Sant'Anna, 2003), is tolerant to environments with little light and N deficiency, and is sensitive to perturbations (Reynolds et al., 2002). In the THS, this species was one of the descriptors and the only one with significant correlation and inverse relation with water level, presenting the highest densities registered for Mangueira Lake during the hottest months. Indeed its higher contribution was verified under wide wind velocity amplitude (Tab. II).

Cyanobacteria species were the major contributors for phytoplanktonic density in most of the THS subsystems. This may be related with the group large adaptive capacity which gives them an ecological advantage under particular situations. Several of their prokaryotic properties, such as gas-vesicles, low CO_2 /high pH optimum, and nitrogen-fixation, bear special ecological significance (Dokulil & Teubner, 2000). Filamentous cyanobacteria can tolerate lower light levels and also create higher turbidity at lower phosphorous concentrations than other algae (Scheffer, 1998).

It seems clear that the resident communities in this system have adapted not only to fluctuations in water level, but principally to the set of abiotic variables that comprise the principal force functions of the THS (Fig. 3). The high frequency of cyanobacteria and microplanktonic diatoms (50-200 mm) describe the system as a whole. Diatoms are dependent on water mixture and capable to tolerate constant turbulence induced by wind. These factors and biological capabilities can create important patterns by leading to alterations in the local biological communities. Wind driven hydrodynamic can impose changes on the planktonic community of other shallow lake in Rio Grande do Sul, Brazil (Cardoso, 2001; Cardoso & Motta Marques, 2003, 2004). The disturbances produced by wind, or lack of it (making a stable environment), resulted in Anabaena circinalis blooms (Becker, 2002; Becker et al., 2004) in shallow lake of Rio Grande do Sul.

The shortage of light associated with turbidity and wind promoted turbulence in the THS seem to be an important species selection factors. In the PCA the inverse relation between the transparency factors and suspended total solids was clear. These suspended solids were also related to nutrients, showing the effect of sediment stock ressuspension back into the water column, and as a potential selection factor.

Phytoplankton communities of smaller lakes or protected lakes inside a wetland suffer less pressure from this factor. Shallow regions hold more favorable conditions for algal growth, since light penetration in the water column is efficient and the productivity in these areas may be more effective, probably by bentonic community. On the THS wetland it was measures a reduction of 90% in the surface water incident PAR (Finkler Ferreira, 2005) with an associated reduction on the estimated phytoplankton biomass (Fragoso Jr., 2005). At the interface wetland-lake (MW) the variation of the phytoplanktonic density was also low during the studied period, presenting a tendency to increase during the summer, which may show a constant trade of nutrients between the subsystems Central and South.

A pattern found in shallow lakes is a constant wind action promoting high turbidity due to sediment particles resuspension. As expected the plankton may respond to wind generated hydrodynamics with changes in the community structure (Demers et al., 1987; Padisák et al., 1990; Millet & Cecchi, 1992; Carrick et al., 1993; MacIntyre, 1993; Cristofor et al., 1994; Dokulil, 1994; Dokulil & Padisák, 1994; Padisák & Dokulil, 1994; Lacroix & Lescher- Moutoué, 1995; Gervais et al., 1997; Zagarese et al., 1998). However the Taim Hydrological System-THS wind patterns did not present a direct relation with the phytoplankton, but it was a power factor that pushed other physical and chemical factors in the system to act more directly on the community.

The Taim Hydrological System subsystems components (Flores Lake/North subsystem, Nicola and Jacaré Lakes-wetland-lakes/Central subsystem, Mangueira Lake/South subsystem) were considered different among themselves, presenting abiotic characteristics varying temporarily during the study period.

A spatial variation in the richness and density of individuals was reported within the studied subsystems with group formation, where Mangueira Lake (South subsystem) and the Flores Lake and Jacare Lake stood out. Recording the descriptor species, Mangueira Lake exhibited a distinct behavior in relation to the other three subsystems.

Cyanophyceae and Bacillariophyceae were the algal classes that stood out in the THS subsystems. The indicator species, during the studied period were Aulacoseira granulata, Synedra acus, Aphanocapsa delicatissima, Cylindrospermopsis raciborskii, and Planktolyngbya contorta . These species are representative of the Taim Hydrological System because they can benefit from turbulent and turbid environments.

THS hydroperiod seems not to have had a direct influence on the total phytoplankton density recorded for 2001. However, species composition of the subsystem better described the determinant abiotic patterns.

Local hydrodynamics is subjected to the influence of other factors, such as wind, that determine local patterns. It is believed that wind action (fetch) is the real force function in the structure and dynamics of the phytoplankton community. Therefore, the evaluation of this agent as a force function in the system will be the object of future studies. The study of the particular aspects of each lake is also needed not only for a better comprehension of ecological patterns in the Taim Hydrological System, but also to the contribution to the better knowledge of local biodiversity and its conservation.

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References

Alves-da-Silva, S.M. 1988. Euglenaceae pigmentadas (Euglenophyta) da Estação Ecológica do Taim, Rio Grande do Sul, Brasil. Iheringia Ser. Bot., (38):109-126.

American Public Health Association – APHA. 1992. Standard methods for examination of water and waste water. 18th ed. Byrd Prepress Springfield, Washington. 1268p.

Becker, V. 2002. Variação da estrutura e da biomassa fitoplanctônica na Lagoa Itapeva (Litoral Norte do Rio Grande do Sul) em função da hidrodinâmica. Porto Alegre, UFRGS, 119p (Master Thesis).

Becker, V., Cardoso, L.S. & Motta Marques, D. 2004. Development of Anabaena Bory ex Bornet & Flahault (Cyanobacteria) blooms in a shallow, subtropical lake in southern Brazil. Acta Limnol. Bras., 16(4):306-317.

Callegaro, V.L.M. & Salomoni, S.E. 1988. Diatomáceas das lagoas do Jacaré, do Nicola e Mangueira, Estação Ecológica do Taim: novas ocorrências para o Rio Grande do Sul. Iheringia Ser. Bot., (32):127-148.

Cardoso, L.S. 2001. Variações da estrutura planctônica da Lagoa Itapeva (Sistema lagunar Costeiro do Rio Grande do Sul) em função da hidrodinâmica. Porto Alegre, UFRGS, 466p (PhD Thesis).

Cardoso, L.S. & Motta Marques, D. 2003. Rate of change of the phytoplankton community at Itapeva Lake (North Coast of Rio Grande do Sul, Brazil), based on the wind driven hydrodynamic regime. Hydrobiologia, 497:1-12.

Cardoso, L.S. & Motta Marques, D. 2004. Seasonal composition of the phytoplankton community in Itapeva Lake (north coast of Rio Grande do Sul - Brazil) in function of hydrodynamic aspects. Acta Limnol. Bras., 16(4):401-416.

Carrick, H.L., Aldridge, F.J. & Schelske, C.L. 1993. Wind influences phytoplankton biomass ans composition in a shallow, productive lake. Limnol. Oceanogr., 38:1179-1192.

Cristofor, S., Vadineanu, A., Ignat, G. & Ciubuc, C. 1994. Factors affecting light penetration in shallow lakes. Hydrobiologia, 275/276:493-498.

Demers, S., Therriault, J.C., Bourget, E. & Bah, A. 1987. Resuspension in the shallow sublittoral zone of a macrotidal estuarine environment: wind influence. Limnol. Oceanogr., 32:327-339.

Dokulil, M. 1994. Environmental control of phytoplankton productivity in turbulent turbid systems. Hydrobiologia, 289:65-72.

Dokulil, M. & Padisák, J. 1994. Long-term compositional response of phytoplankton in a shallow, turbid environment, Neusiedlersee (Austria/Hungary). Hydrobiologia, 275/276:125-137.

Dokulil, M.T. & Teubner, K. 2000. Cyanobacterial dominance in lakes. Hydrobiologia, 438:1-12.

Finkler Ferreira, T. 2005. Ecologia e aplicabilidade de métodos para avaliação da produção primária de Zizaniopsis bonariensis: uma macrófita aquática emergente, no sistema hidrológico do Taim, RS. Porto Alegre, UFRGS, 150 p (Master Thesis).

Flôres, T.L., Moreira-Filho, H. & Ludwig, T.A.V. 1999. Contribuição ao inventário florístico das diatomáceas (Bacillariophyta) do banhado do Taim, Rio Grande do Sul, Brasil: I-Epithemia Brebisson ex Kutzing, Rhopalodia O. Muller e Surirella Turpin. Insula, 28:149-166.

Fragoso Jr., C.R. 2005. Simulações da dinâmica de fitoplâncton no Sistema Hidrológico do Taim (RS). Porto Alegre, UFRGS, 137p (Master Thesis).

García de Emiliani, M.O. 1997. Effects of water level fluctuation in a river-floodplain lake system (Paraná River, Argentina). Hydrobiologia, 357:1-15.

Gervais, F., Opitz, D. & Behrendt, H. 1997. Influence of small-scale turbulence and large-scale mixing on phytoplankton primary production. Hydrobiologia, 342/343:95-105.

Håkanson, L. 1981. A manual of lake morphometry. Springer-Verlag, Berlin. 78p.

Huszar, V.L.M. & Reynolds, C.S. 1997. Phytoplankton periodicity and sequences dominance in na Amazonian flood-plain lake (Lago Batata, Pará, Brazil): response to gradual environmental change. Hydrobiologia, 346:169-181.

Huszar, V.L.M. 2000. Fitoplâncton. In: Bozelli, R.L., Esteves, F.A. & Roland, F. (eds.) Lago Batata: impacto e recuperação de um ecossistema amazônico. IB-UFRJ/SBL, Rio de Janeiro. p.91-104.

Izaguirre, I., O' Farrell, I., Unrein, F. & Sinistro, R. 2004. Algal assemblages across a wetland from a shallow lake to relictual oxbow lakes (Lower Paraná River, South America). Hydrobiologia, 511:25-36.

Kobayasi, H. & Mayama, S. 1982. Most pollution tolerant diatoms of severely polluted rivers in the vicinity of Tokyo. Jpn. J. Phycol., 30:188-196.

Krebs, C.P. 1989. Ecological methodology. Harper & Row Publish, New York. 645p.

Lacroix, G. & Lescher-Moutoue, F. 1995. Spatial patterns of planktonic microcrustaceans in a small shallow lake. Hydrobiologia, 300/301:205-217.

Legendre, L. & Demers, S. 1984. Towards dynamic biological oceanography and limnology. Can. J. Fish. Aquat. Sci., 41:2-19.

Lobo, E.A., Callegaro, V.L.M., Ferraz, G.C. & Alves-da-Silva, S.M. 1992. Análise da estrutura da biocenose de diatomáceas em lagoas da Estação Ecológica do Taim, Rio Grande do Sul, Brasil. Acta Limnol Bras., 4:277-290.

Lloyd, M. & Ghelardi, R.J. 1964. A table for calculating the equitability component of species diversity. J. Anim. Ecol., 33:421-425.

Ludwig, T.A., Flores, T.L., Moreira Filho, H. & Veiga, L.A.S. 2004. Inventário florístico das diatomáceas (Ochrophyta) de lagoas do Sistema Hidrológico do Taim, Rio Grande do Sul, Brasil: Coscinodiscophyceae. Iheringia Ser. Bot., 59:97-106.

MacIntyre, S. 1993. Vertical mixing in a shallow, eutrophic lake: possible consequences for the light climate of phytoplankton. Limnol. Oceanogr., 38:798-817.

Mackeret, F.J.H., Heron, J. & Talling, J.F. 1989. Water analysis: some revised methods for limnologists. Freshwater Biological Association Scientific Publication, Ambleside. 117p. (Scientific Publication, 36).

Melo, S. & Huszar, V.L.M. 2000. Phytoplankton in an Amazonian floodplain lake (Lago Batata, Brasil): diel variation and species strategies. J. Plankton Res., 22:63-79.

Millet, B. & Cecchi, P. 1992. Wind-induced hydrodynamic control of the phytoplankton biomass in a lagoon ecosystem. Limnol. Oceanogr., 37:140-146.

Motta Marques, D. & Villanueva, A.O.N. 2001. Regime hidrológico de banhados e sua conservação. Cad. Pesqui. Ser. Biol., 13:63-79.

Nõges, T., Nõges, P. & Laugaste, R. 2003. Water level as a mediator between acclimate change and phytoplankton composition in a large shallow temperate lake. Hydrobiologia, 506-509:257-263.

O'Farrell, I., Sinistro, R., Izaguirre, I. & Unrein, F. 2003. Do steady state assemblages occur in shallow lentic environments from wetlands? Hydrobiologia, 502:197-209.

Padisák, J., Tóth, L.G. & Rajczy, M. 1990. Stir-up effect of wind on a more-or-less stratified shallow lake phytoplankton community, Lake Balanton, Hungary. Hydrobiologia, 191:249-254.

Padisák, J. & Dokulil, M. 1994. Meroplankton dynamics in a saline, turbulent, turbid shallow lake (Neusiedlersee, Austria and Hungary). Hydrobiologia, 289:23-42.

Padisák, J. & Reynolds, C.S. 1998. Selection of phytoplankton associations in Lake Balaton, Hungary, in response to eutrophication and restoration measures, with special reference to the cyanoprokariotes. Hydrobiologia, 384:41-53.

Paz, A.R. 2003. Análise dos principais fatores intervenientes no comportamento hidrodinâmico do Banhado do Taim. Porto Alegre, UFRGS, 179p (Master Thesis).

Reynolds, C.S., Huszar, V.L.M., Kruk, C., Naselli-Flores, L. & Melo, S. 2002. Towards a functional classification of the freshwater pytoplankton. J. Plankton Res., 24:417-428.

Rosa, Z.M. & Miranda-Kiesslich, A.L. 1988. O gênero Pediastrum Meyern (Chlorococcales - Hydrodictyaceae) do sistema lagunar da região litoral do Rio Grande do Sul, Brasil. Iheringia Ser. Bot. (38):149-169.

Rosa, Z.M. & Miranda-Kiesslich, A.L. 1989. Chlorococcales (Chlorophyta) da Estação Ecológica do Taim, Rio Grande do Sul, Brasil. Insula, (19):215-228.

Scheffer, M. 1998. Ecology of shallow lakes. Chapman and Hall, London. 357p.

Shannon, C.E. & Weaver, W. 1963. The mathematical theory of communication. University of Illinois Press, Urbana. 173p.
Tucci, A. & Sant´Anna, C.L. 2003. Cylindrospermopsis raciborskii (Woloszynska) Seenayya & Subba Raju (Cyanobacteria): variação semanal e relações com fatores ambientais em um reservatório eutrófico, São Paulo, Brasil. Rev. Bras. Bot., 26:97-112.
Utermhöl, H. 1958. Zur vervollkommung der quantitativew phytoplankton metodik. Mitt. Int. Ver. Theor. Angew. Limnol., 9:1-38.
Van Den Hoeck, C., Mann, D.G. & Jahns, H.M. 1995. Algae: an introduction to phycology. Cambridge University, Cambridge. 627p.
Werner, V.R. & Rosa, Z.M. 1992. Cyanophyceae da Estação Ecológica do Taim, Rio Grande do Sul, Brasil. Rev. Bras. Biol., 52:481-502.
Wetzel, R.G. 1993. Limnology. W. B. Sauders Company, Toronto. 919p.
Zagarese, H.E., Cravero, W., Gonzalez, P. & Pedrozo, F. 1998. Copepod mortality induced by fluctuating levels of natural ultraviolet radiation simulating vertical water mixing. Limnol. Oceanogr., 43:169-174.

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