Water dynamics, phytoplankton biomass and size structure of a shallow freshwater subtropical lake (Itapeva lake, south of Brazil).

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ABSTRACT: Water dynamics, phytoplankton biomass and size structure of a shallow freshwater subtropical lake (Itapeva lake, South of Brazil). Regular tools used to characterize the phytoplankton community structure are taxonomic composition, diversity of species and the classification of organisms according to their size. The main objective of this study was to characterize the phytoplankton size structure of the Itapeva lake, south of Brazil, considering the biomass (by biovolume) over an annual cycle (December 1998 to August 1999), and to establish a relationship with the physical factors (wind velocity and wind direction). Three fractions in the phytoplankton community were selected: nanoplankton, microplankton and netplankton. The netplankton fraction predominated over the other size fractions and was associated to the abundance of filamentous species, like the diatom Aulacoseira granulata, and the cyanobacteria species Anabaena circinalis and A. spiroides. The succession of phytoplankton size fractions was related directly to disturbance caused by the strong winds and long fetchs, or the lack of them.

Key-words: phytoplankton, size structure, biovolume, shallow lake, hydrodynamics, wind.

RESUMO: Dinâmica da água, da estrutura de tamanho e da biomassa fitoplanctônica em uma lagoa rasa subtropical (lagoa Itapeva, sul do Brasil). As principais ferramentas utilizadas para caracterizar a estrutura da comunidade fitoplanctônica são, além da composição taxonômica, da riqueza e da diversidade de espécies, a classificação dos organismos de acordo com o seu tamanho. Este trabalho teve como objetivo principal caracterizar a estrutura de tamanho do fitoplâncton da lagoa Itapeva, sul do Brasil, em função da biomassa (por biovolume) durante um ciclo anual (dezembro de 1998 a agosto de 1999), e estabelecer relações com os fatores físicos, velocidade e direção de vento, que atuaram diretamente na lagoa. As três frações que melhor representaram a comunidade fitoplanctônica foram: nanoplâncton, microplâncton e netplâncton. A predominância da fração netplanctônica sobre as demais se deve à abundância de espécies filamentosas, como a diatomácea Aulacoseira granulata, e as cianobactérias Anabaena circinalis e A. spiroides. As sucessões das frações de tamanho do fitoplâncton estiveram relacionadas diretamente à ação de distúrbios intensos provocados pelos fortes ventos e longo fetch, ou a falta deste.

Palavras-chave: fitoplâncton, estrutura de tamanho, biovolume, lagos rasos, hidrodinâmica, vento.

Introduction

The plankton food chain is clearly structured by the size of the organisms. The predator/prey size ratios brought about by hydrodynamic constraints results in trophic levels which act as holons with quite different time constants (Harris, 1986). The surface/volume ratio of the biomass influences the exchange of energy (light and heat) and nutrients (Lewis, 1976; Malone, 1980; Lane & Goldman, 1984; Reynolds 1984a). The diversity of phytoplankton morphology is emphasized by species which form multi-celled coenobial or colonial structures. These arrangements of individual cells often generate new shapes.

Thus, the structure decreases the area of contact between individual cells, so that surface/ volume ratio is largely preserved. In an attempt to stabilize, i.e., keep in a good physiological state, the phytoplankton responds by means of different individual morphological adaptations of species (shapes, sizes, structural organizations of the colonies and pigmentations, relating to chlorophyll and accessory photosynthetic pigments) to the environmental variability (Reynolds, 1984a).

The main tools used to characterize the structure of the phytoplankton community, besides taxonomic composition, are diversity of species and the classification of the organisms in size. The latter is a useful tool in studies on the microalgal community due to physiological and ecological implications (Torgan et al., 2000). The size classes have been used to divide the algal community given the potential of influence of the particle on the dynamics of the food chain, and also because species within the same class tend to respond similarly to environmental changes (Lane & Goldman, 1984). Assuming that an approximately uniform distribution of biomass with body size implies an approximately regular approach of the biomass distribution over a continuum of functional guilds. It is may help to explain how the empirically established ecosystem property of a continuous size distribution without gaps emerges from local interactions. Functional niches can be found together with a size gradient, due to the similarity of the different groups of plankton organisms (Gaedke, 1992b). External factors may also influence the form of biomass size distribution, and environmental fluctuations may increase the irregularity of spectra size (Gaedke, 1992a).

The main objective of this study was to characterize the phytoplankton size structure based in the biomass (biovolume) in Itapeva lake, over an annual cycle (December 1998 to August 1999), and establish the possible relationships with the dominant physical factor (wind).

Material and methods

Itapeva lake is a shallow subtropical lake located in the south of Brazil, characterized by an elongated shape, with a maximum depth of 3.5 m and mean depth of 2.23 m (Schwarzbold & Schäfer, 1984). The description of the site studied (Itapeva lake) as well as the sampling design (spatial and temporal frequency) has been defined in Cardoso & Motta Marques (2002) (Fig.1). Towers were installed in three sampling stations (North, Center and South regions) with the following instruments: limnimetric gauge, meteorological weather station (only at the Center Station, DAVIS, Weather Wizard III, Weather Link). Environmental data (wind speed and direction) and water level data, were recorded every 30 minutes, throughout the period.

Samples were collected during four campaigns: December 14-20, 1998 (spring), March 1-7, 1999 (summer), May 20-26, 1999 (autumn), August 20-26, 1999 (winter).

The collection was performed on the water surface, using a 2L horizontal Van Dorn bottle (Wetzel & Likens, 2000). The samples were taken at the water surface in pre-established shifts (6 a.m., 10 a.m., 2 p.m. and 6 p.m.) for each. No collection occurred at the Center Station in spring on Dec 17/98 at 2 p.m. and 6 p.m., due to strong winds.

The material was fixed with Lugol - neutral solution (Sournia, 1978). The quantitative analysis was performed using a Sedgwick-Rafter chamber (APHA, 1992), an optic microscope Zeiss Jenaval (400X), considering the number of individuals and cells of organisms with chromoplasts. The algal biovolume was calculated using formulae for geometric shapes (Edler, 1979; Hillenbrand et al., 1999; Wetzel & Likens, 2000). For the size fractions, the determination of the Greatest Axial Linear Dimension (GALD) was used (Lewis, 1976). The organisms size classification was done according to program ALGAMICA classes (Gosselain & Hamilton, 2000; Gosselain et al. 2000), which makes it easier to determine the fractionation by GALD. The classes considered in this program are: picoplankton (0-2.0 mm), u-ultraplankton (2.1-5.0 mm), ultraplankton (5.1-10.0 mm), nanoplankton (10.1-22.0 mm), microplankton (22.1-64.0 mm) and netplankton (>64.1 mm).

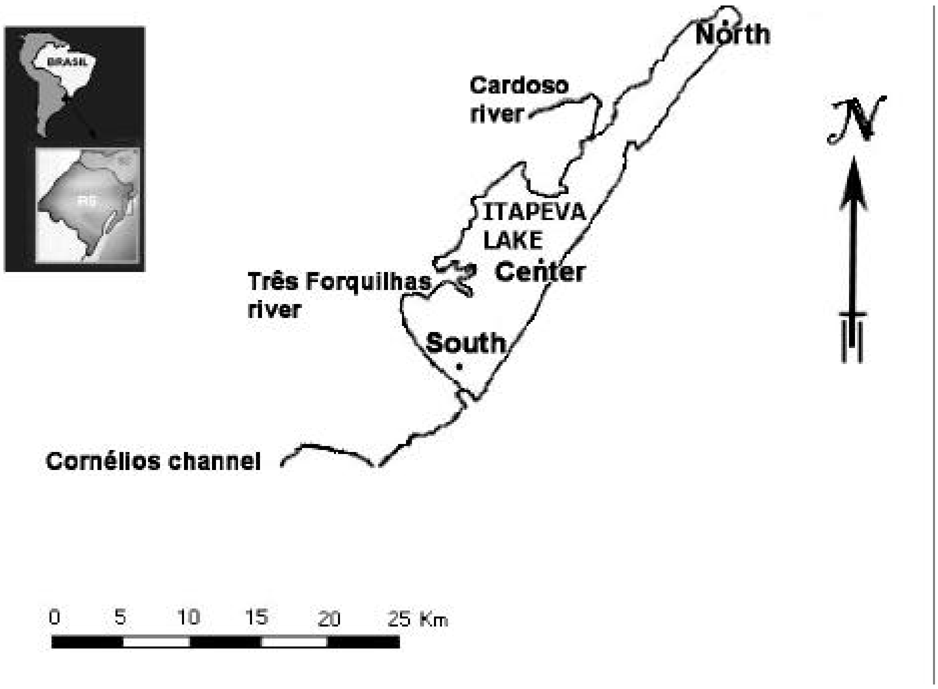

Figure 1: Location of the sampling area, Itapeva lake, South of Brazil. Source: Cardoso & Motta Marques (2002)

Pearson correlation (p<0.05) analyses were performed using the variables wind speed and water level, and the size categories based on biomass (nanoplankton, microplankton and netplankton), for each sampling station (north, center and south).

Analysis of variance (one-way ANOVA) was also carried out, applying the Tukey test, using the sampling stations, day and season of the year as factors.

Results

Itapeva lake wind pattern

The Itapena Lake did show a seasonal pattern considering the wind quadrants (Tab.I). The greatest range of wind direction variation occurred over Spring (highest standard deviation). In contrast of the Spring quadrants, NE and WSW was the characteristic for winter. Summer was characterised as the most stable season of the year, due to the lowest wind speed values, as well as the smallest direction deviations (quadrants N and E). Winds were frequent between quadrants SW and W in the autumn.

In this lake the greatest range of wind speed variation and windless periods, recorded both in autumn and in winter, was related to the arrival of cold fronts in the region (Cardoso & Motta Marques, 2003).

Seasonal changes on biomass and size structure of phytoplankton

Three fractions in the phytoplankton community were selected: nanoplankton, microplankton and netplankton (Fig.2). The relative contribution of the three most representative fractions of size in Itapeva lake, resulted in a higher percentage of netplankton (66%), followed by microplankton (30%), and nanoplankton fractions (4%) (Fig.2). The u-ultraplankton and ultraplankton fractions were present at several moments of the study, however, were irrelevant for the statistical analyses due to very low biomass values.

Table I: Wind direction and speed ($m.s^{-1}$), during the seasonal study, at Itapeva lake, south of Brazil.

Season	Date / Hour	Wind speed mean	Wind speed max	Wind direction
spring	12/15/98 06 a.m.	8.5	10.7	NNE
	12/15/98 10 a.m.	3.6	5.8	SSW
	12/15/98 02 p.m.	3.6	6.3	SSE
	12/15/98 06 p.m.	2.7	4.0	SE
	12/17/98 06 a.m.	4.5	10.7	N
	12/17/98 10 a.m.	7.6	17.9	WNW
	12/17/98 02 p.m.	12.1	17.9	WNW
	12/17/98 06 p.m.	10,3	16.5	W
summer	03/02/99 06 a.m.	4.5	5.8	NE
	03/02/99 10 a.m.	3.1	4.5	NNE
	03/02/99 02 p.m.	3.1	4.9	E
	03/02/99 06 p.m.	5.8	8	ENE
	03/04/99 06 a.m.	6.3	9.4	NNE
	03/04/99 10 a.m.	5.8	7.2	NE
	03/04/99 02 p.m.	8	11.2	ENE
	03/04/99 06 p.m.	6.7	10.7	ENE
autumn	05/21/99 06 a.m.	5.4	8.5	WSW
	05/21/99 10 a.m.	7.6	11.6	W
	05/21/99 02 p.m.	5.4	8.0	SW
	05/21/99 06 p.m.	4.9	9.4	WSW
	05/23/99 06 a.m.	0.4	1.3	ESE
	05/23/99 10 a.m.	4.0	4.9	NE
	05/23/99 02 p.m.	3.6	4.9	NE
	05/23/99 06 p.m.	0.4	2.7	E
winter	08/16/99 06 a.m.	3.1	4.5	W
	08/16/99 10 a.m.	2.2	4.0	WSW
	08/16/99 02 p.m.	4.9	7.6	ESE
	08/16/99 06 p.m.	0.0	.0.	0
	08/18/99 06 a.m.	3.6	5.8	NE
	08/18/99 10 a.m.	5.8	7.2	NE
	08/18/99 02 p.m.	8.5	10.7	ENE
	08/18/99 06 p.m.	6.7	8.9	NE

The netplankton and microplankton were the dominant fractions, alternating the dominance from spring to winter (Fig.3). Different fractions produced more or less biomass in each season showing a dynamic size structure throughout the season. In spring the netplankton fraction was higher (61.6%) than the microplankton (26.2%) and nanoplankton (12.2%) fractions (Fig.3). In summer, the largest biomass corresponded to microplankton (48.5%), followed by the netplankton (40.2%) and nanoplankton (11.3%). The netplankton was the dominant fraction in autumn with most of the biomass of the phytoplankton community (98.0%), followed by microplankton (1.9%) and nanoplankton (0.1%). In winter, the highest percentage of biomass came from the microplankton (80.2%), followed by netplankton (19.3%) and nanoplankton (0.5%) (Fig.3).

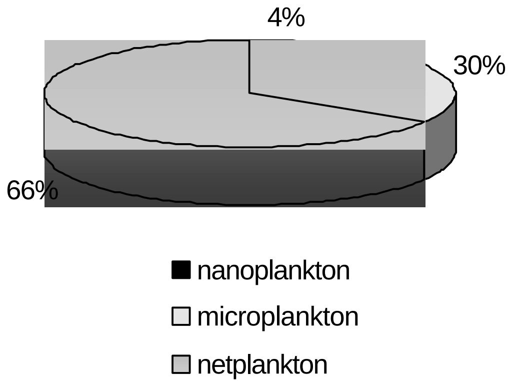

Figure 2: Relative biomass (%)of the size categories in the phytoplankton community at Itapeva lake, south of Brazil

The seasonal variation of the phytoplankton community size fractions was significant. The microplankton fraction presented significant seasonal variations ($p<0.001$), between winter and spring ($p=0.004$) and autumn ($p=0.001$). Seasonal variation was also found for the netplankton fraction, being the contribution in autumn significantly different from the other seasons ($p<0.001$). The nanoplankton fraction did not present a significant seasonal variation.

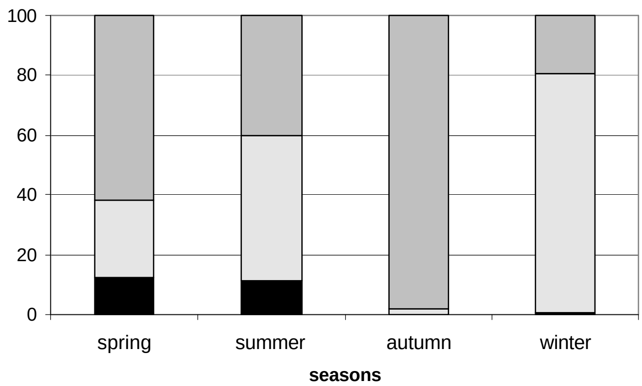

Figure 3: Relative biomass (%) of the nanoplankton (■), microplankton (□) and netplankton (▒) fractions (seasonal campaigns) at Itapeva lake, south of Brazil. (spring= Dec/98, summer= Mar/99, autumn=May/99, winter= Aug/99).

Spatial variation of size structure

A spatial pattern of biomass size structure was also observed in Lake Itapeva. This pattern recorded as a biomass gradient in the main lake axis (Fig.4).

The nanoplankton presented the largest average values of biomass in the South sampling station, during the spring (Dec/98) and the summer (Mar/99), in the Center sampling station in the autumn (May/99), and the North sampling station in the winter (Aug/99) (Fig.4). In the spring, this fraction presented a rising values in the North-South (N®S) direction.

The biomass of the netplankton, in the spring, also decreased from the North to South (Fig.4). This fraction was dominant throughout the autumn (May/99), due to an Anabaena circinalis bloom, which covered all the Itapeva lake surface. The higher biomass (70.75 $mg.L^{-1}$) was found in the South sampling station (Fig.4).

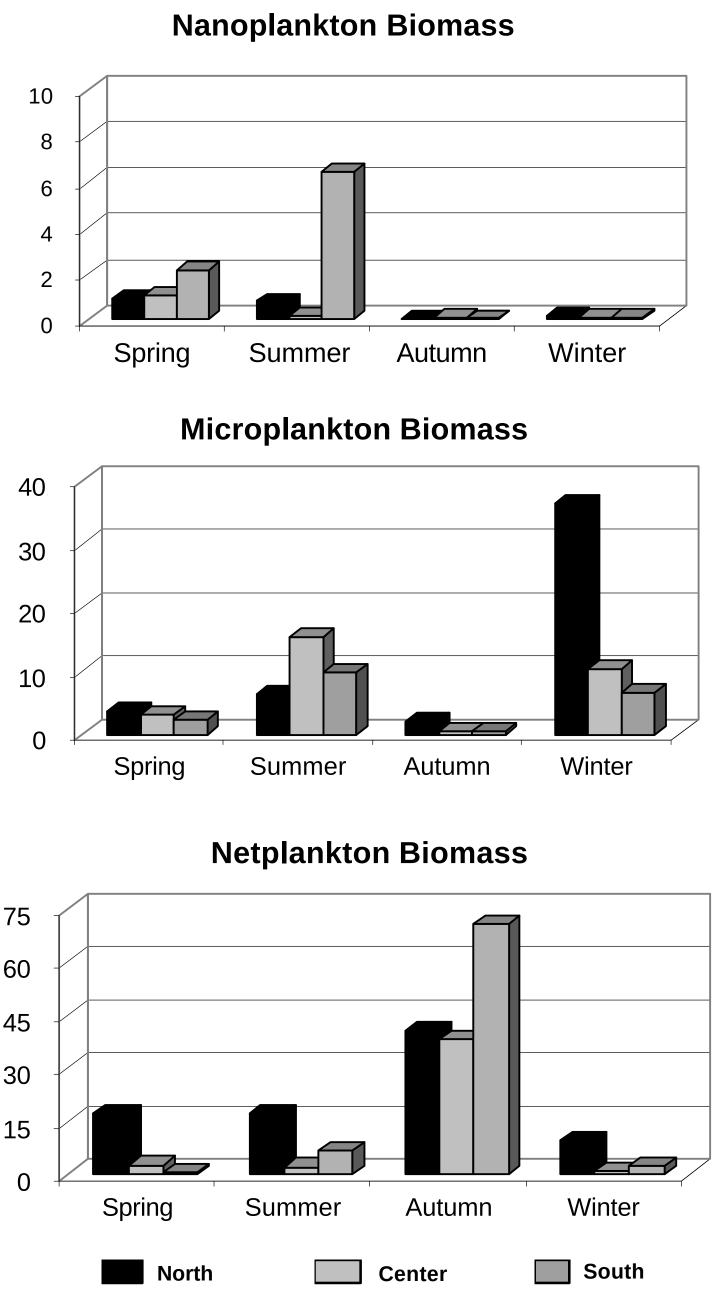

Figure 4: Biomass ($mg.L^{-1}$) of the nanoplankton, microplankton and netplankton fractions in the sampling stations at Itapeva lake, south of Brazil. (spring= Dec/98, summer= Mar/99, autumn=May/99, winter= Aug/99).

Wind effect on biomass and size structure daily changes

Fast wind quadrant shifts were associated with changes on the dominant size fraction. During the spring, on the first sampling day (for 10 a.m., 2 p.m. and 6 p.m. shifts) the wind direction fluctuated between SSW-SSE (Tab.I) due to the longest fetch at the North station. In this, very turbulence site, the dominant organisms were those belonging to the microplankton fraction, such as the Aulacoseira granulata (Fig.5). In the South less turbulent sampling station, the smaller organisms (nanoplankton) remain on the water surface. On the second sampling day, at 6 a.m., the N quadrant wind (mean speed of 4.5 $m.s^{-1}$) produced a higher effective fetch at the Center and South sampling stations. Conversely to North sampling station, the less turbulent water allowed the buoyancy of cyanobacteria presenting aerotopes, such as Anabaena circinalis, A. spiroides and Microcystis aeruginosa, the dominant species. The highest biomass was recorded at 6 a.m., specially due to the large colonies presented by these species of netplankton (Fig.5).

When the southern portion of the Itapeva lake became a more turbulent environment, the microplankton fraction was the outstanding biomass fraction. At 10 a.m. of the same day (17 Dec/98), the mean wind speed rose to 7.6 $m.s^{-1}$ and wind direction changed to WNW (Tab.I), leading to a decrease of community´s biomass in the North station. The combination of the outflow of Três Forquilhas River into the lake and the wind action raised the water level at the Center sampling station. The biomass of netplankton decreased in the North, while the nanoplankton biomass once again increased in the South (Fig.5).

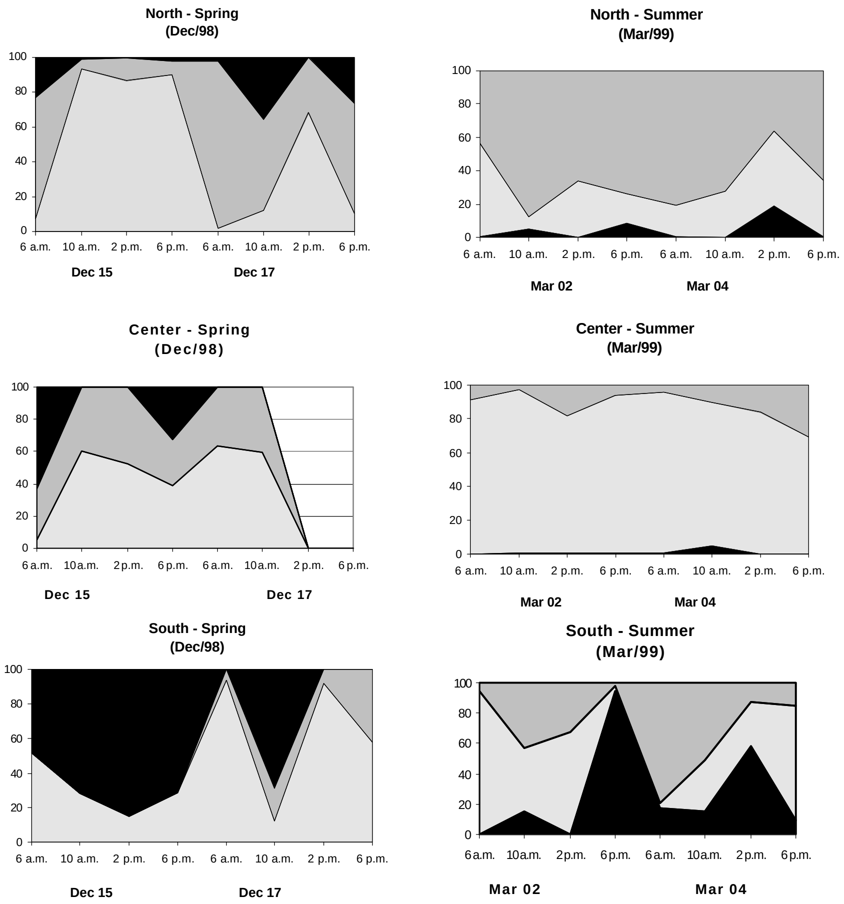

Figure 5: Spatial and temporal variations of the relative biomass (%) of nanoplankton ( ), microplankton ( ) and netplankton ( ) in the spring and summer at three sampling stations of Itapeva lake, south of Brazil.

Over the Summer, the netplankton dominated the biomass in the North sampling station, while at the Center the dominance was related to the microplankton fraction (Fig.5). The wind direction presented low variation when compared with the seasonal campaigns. A small oscillation between the NNE-ENE quadrants, was found and, a higher velocity was recorded at the end of the day (Tab.I).

Daily changes on both biomass and density were observed in winter (Fig.6). On the first sampling day, the wind fluctuated between W-WSW quadrants during the morning shift (Tab.I), causing a greater disturbance at the North region, due to a long effective fetch. At the South sampling station the netplankton fraction was dominant (Fig.6), as already mentioned previously, due to an Anabaena circinalis bloom. On the second sampling day, the winds changed to a NE-ENE predominant quadrants (Tab.I), producing a more intense effect from the Center station towards the South, increasing the dominance of the microplankton fraction (Fig.6).

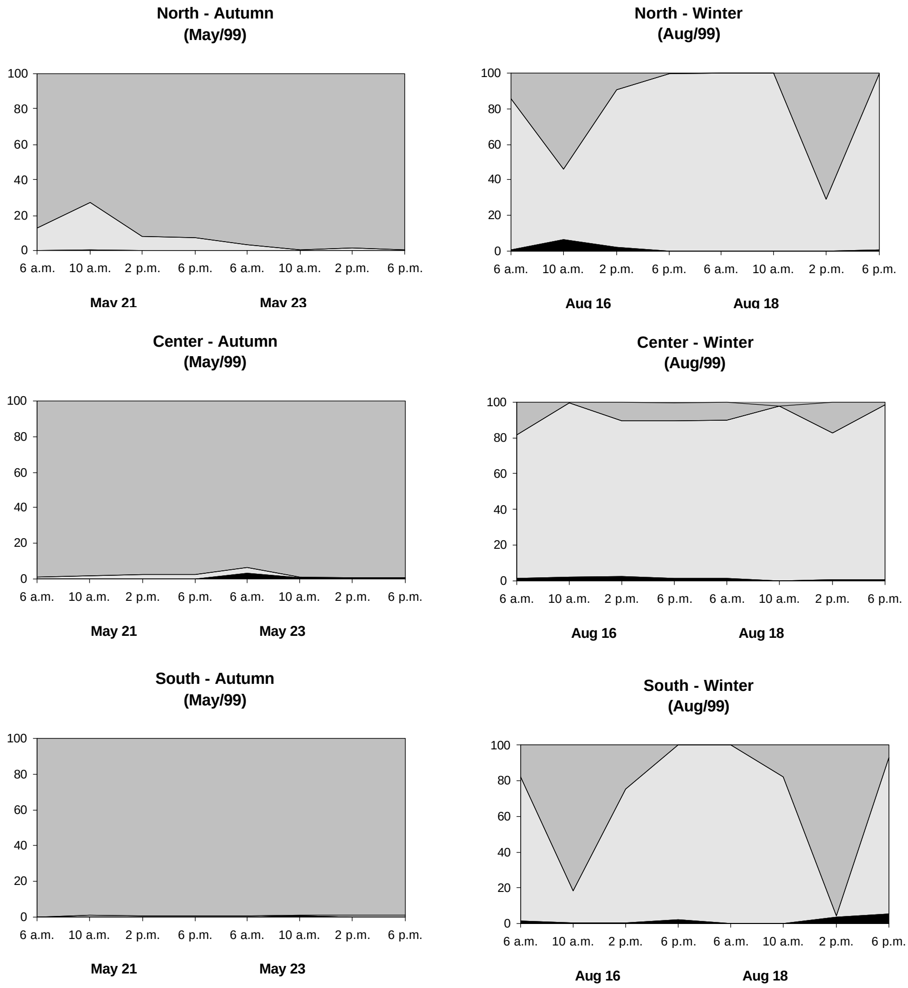

Figure 6: Spatial and temporal variations of the relative biomass (%) of nanoplankton (■), microplankton (▢) and netplankton (▢) in the autumn and winter at three sampling stations of Itapeva lake, south of Brazil.

Relationships ($p<0.05$) were found between phytoplankton community size fractions and the dominant physical factor (or derivatives) acting at the sampling stations of Itapeva lake. The nanoplankton at the North and Center presented a negative correlation with the water level, at the North, ($r= -0.36$); at the Center ($r=-0.87$), while at the South a positive correlation was found ($r=0.41$). The microplankton and netplankton at the Center presented a significant correlation ($p<0.05$) to the water level of the North sampling station ($r=-0.66$ and $r=0.54$, respectively). The netplankton of the South presented a positive correlation to the water level, measured at the same sampling station ($r=0.54$).

Discussion

Wind induced biomass and size structure changes

The observed relation between size fractions and water level, might be due to intense disturbances caused by the strong winds and long fetch at the sampling stations. The lack of disturbances, creating a stable environment, affected also the size fractions of the phytoplankton community. These factors (wind direction and speed) favored the netplankton blooms. However, the cause-effect relationship of the wind on the phytoplankton biomass of Itapeva lake may be indirect, due to the release of nutrients from the sediment surface layer and to biomass recruitment, specially in case of the cyanobacteria.

Phosphorus transport from sediment to overlying water includes processes as diffusion, wind-induced turbulence, perturbation, attached algae/cyanobacteria and rooted aquatic plants. In windy periods, the water column may interact immediately with the sediment surface layer specially in a shallow lake, resuspended materials. Currents, induced by winds, can resuspend sediment particles and release phosphorus to the overlying water (Wetzel, 2001). The high wind, inducing water turbulence in Itapeva lake, is apparently the single most important mechanism to transport phosphorus from sediment to water.

Itapeva lake sediment is mostly sandy and low in organic matter in the Centrer and South regions. In the North area, the bottom presents an organic sediment. The overlying water has a high oxygen concentration (near saturation, 103%), pH above 6.5 (mean value = 7.6) and high turbidity (mean = 247 NTU) at all the year (Cardoso, 2001). The inorganic turbidity (redish particles) is derived from sandstone and basalt of the watershed. Reactive phosphorus is most of the times < 5 ppb and the mean value of total phosphorus is $0.6 mg.L^{-1}$ (Cardoso, 2001). Under these conditions, most of the phosphate is associated with clay, aluminium, Ferric Hydroxide (Danen-Louverse et al., 1993), and $CaCO_3$ or in the Ferric Phosphate form. As the sorption capacities of Fe (III) oxide is decreased when pH is above 6.5 (Stumm & Morgan, 1995), some of the reactive phosphate in the Itapeva lake may be explained by these mechanisms. Changes in the phytoplankton biomass are not clear according to Carrick et al.(1993). They may be associated to pulse releasing nutrients from the sediment to the upper water layers, during periodic resuspensions or the direct inoculation of algae from the bottom of the lake, or due to both factors (Carrick et al., 1993). Dominant species were cyanobacteria and blooms were observed to occur. Part of these algae blooms was probably resuspensed from sediment as the result of the turnover water dynamics caused by wind. Factors associated with man impacts seem not to be the cause of the biomass changes. Nostocalean blue-green such as Anabaena and Aphanizomenon produce akinetes wich can survive on sediments of water bodies for overwintering or even longer periods (Livingstone & Jaworki, 1980). Cyanobacteria blooms were observed to occur already in Itapeva lake by the 1940's (Kleerekoper, 1990), when the region was almost empty from human settlements. Apparently changes on Itapeva lake biomass, mainly cyanobacteria blooms are related with natural physical factors. In the Itapeva lake, the higher values of biomass (by biovolume) was attributed to Anabanea circinalis, mainly in the autumn of 1999, due to the bloom in all the lake extension (Becker, 2002).

The study of the size structure of the phytoplankton community at Patos Lagoon (southern Brazil) has been estimated the biomass by chlorophyll-a (Bergesch, 1990; Bergesch & Odebrecht, 1995; Bergesch & Odebrecht, 1997; Odebrecht et al. 1998; Torgan et al., 2000). However, this method has been considered limited, since the amount of chlorophyll does not present a significant linear correlation with the cell size, affecting the evaluation when the microplankton is included. Moreover the chlorophyll as a biomass index is invaluable to evaluate picoplankton organisms (‹2 mm) (Bergesch, 1990). At the same lagoon (Patos Lagoon), using the biovolume as index of biomass and GALD the predominance of microplankton over the other size categories was related (Torgan, 1997). The classification of the size of phytoplankton in Patos Lagoon, considered by Torgan (1997), was based on Dussart (1965), in which the microplankton ranged from 20 to 200 mm. Using this classification for Itapeva lake, the microplankton would be dominant. For the Amazon (Brazil) environments (Lake Batata, Lake Mussurá and Trombetas River), the nanoplankton (GALD 2,5-20 mm) was the dominant fraction and corresponded to 62% of phytoplankton (Huszar, 1994). The dominance of a size fraction over the others may be the consequence of the sedimentation rate of phytoplankton in the euphotic zone (Malone, 1980). The size, shape and surface/volume ratio of phytoplankton affect the sedimentation rate in the water column (Lewis, 1976). Sedimentation is one of the most important loss processes for the phytoplankton community. Different strategies were developed by various species of plankton algae, aiming to reduce the sedimentation rate, being the microscopic size possibly the most widely disseminated adaptation in this community. The sedimentation of larger algae is decreased by increasing resistance, for instance in the form of an elongated body, the presence of processes, thorns, protuberances, etc. (Reynolds, 1984b). In Itapeva lake, netplankton predominated over the other fractions, since the organisms that account for the high biomass were mainly the filamentous species, Aulacoseira granulata, Anabaena circinalis and A spiroides. The genus Aulacoseira, and specially A. granulata are organisms exposed to low grazing pressure, due to the morphological organization of the cells, as filamentous colonies and by the presence of long thorns (Reynolds, 1987). Furthermore, the filamentous organisms may represent a barrier to most of the zooplankton species, and are obstructing the filtration apparatus of Cladocera and Copepoda (Infante & Riehl, 1984). In fact, the subtropical lake zooplankton has been inefficient as controlling factor of algal biomass (Crisman & Beaver, 1990). Besides their capacity for buoyancy, regulation and nitrogen binding, cyanobacteria probably present a low nutritional value for the zooplankton (Lewis, 1976), and cause deleterious effects on these organisms (Sivonen & Jones, 1999). Thus, high biomass values were obtained in the netplankton fraction due to Anabaena circinalis blooms in Itapeva Lake.

Succession of size fractions and water dynamics

Cyanobacteria often become dominant at the end of autumn in eutrophic shallow lakes. A succession of size fractions was found at Itapeva lake. Seasonal fluctuations were more significant than daily fluctuations. In spring and autumn, the greatest biomass contribution was due the netplankton presence (in autumn, it represented about 98% of the total biomass). In summer and winter, the highest percentage of biomass was due the microplankton presence. However, the microplankton presented a spatial variation in summer, autumn and winter.

The succession of phytoplankton size fractions were related to intense disturbances, caused by strong winds and long fetch at the sampling stations, or stable environmental conditions for the cyanobacteria. The wind affecting water level, plays an important role on the size structure, it can promote the release of small amounts of nutrients from the surface layer of sediment, that are immediately taken by algae, due to limited concentrations in the water and by biomass displacement.

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