Seasonal composition of the phytoplankton community in Itapeva lake (north coast of Rio Grande do Sul – Brazil) in function of hydrodynamic aspects.

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ABSTRACT: Seasonal composition of the phytoplankton community in Itapeva lake (north coast of Rio Grande do Sul – Brazil) in function of hydrodynamic aspects. The structure of the phytoplankton community in Itapeva lake was formed by 7 phyla and more than 148 phytoplankton species, in which microplankton was the predominant size class. The largest richness recorded was for the Bacillariophyta in springtime. Diatoms and cyanobacteria presented higher density and richness in the lake. The seasonal distribution revealed that during the cold seasons, mean density increased in the phytoplankton community, although a spring "peak" had been recorded. In spring, the dominance of a diatom (Aulacoseira granulata) occured at all sampling stations. The cyanobacteria (Anabaena circinalis) bloom dominated in the North sampling site during the other seasons of the year. The greatest mean diversity (H=2.21) was found during winter/98, while in autumn, the smallest diversity was observed (H= 1.07). These changes were closely related to hydrodynamic aspects of the Itapeva lake, due to the wind action on the spatial distribution of the phytoplankton community. The relationships of diatoms with hydrodynamics aspects (wind and water level) are indexes that the phytoplankton group is a good indicator of hydrodynamics in the lake.

Key-words: phytoplankton, shallow lake, hydrodynamic, fetch.

RESUMO: Composição sazonal da comunidade fitoplanctônica na lagoa Itapeva (litoral norte do Rio Grande do Sul - Brasil) em função de aspectos hidrodinâmicos. A estrutura da comunidade planctônica na lagoa Itapeva esteve formada por 7 filos e mais de 148 espécies fitoplanctônicas, e o microplâncton foi a classe de tamanho predominante. Maior riqueza foi encontrada para a divisão Bacillariophyta na primavera. As diatomáceas e as cianobactérias foram caracte-rísticas para a lagoa, tanto em densidade, quanto em riqueza. A distribuição sazonal revelou que nas estações frias do ano ocorreu um aumento de densidade média na comunidade fitoplanctônica, embora tivesse sido registrado o pico primaveril. Na prima-vera foi registrada a ocorrência de uma espécie de diatomácea dominante (Aulacoseira granulata) em todas as estações de amostragem. Excetuando o outono, quando ocorreu a floração de cianobactéria (Anabaena circinalis), somente no Norte esta espécie domi-nou nas demais estações do ano. Durante o inverno/98 ocorreu a maior diversidade média (H= 2,21), enquanto que, no outono observou-se a menor diversidade (H= 1,07). Correlações entre diatomáceas e aspectos hidrodinâmicos (vento e nível d'água) suge-rem que este grupo fitoplanctônico é significativamente afetado pela hidrodinâmica des-ta lagoa rasa.

Palavras-chave: fitoplâncton, lagoa rasa, hidrodinâmica, fetch.

Introduction

The study of phytoplankton dynamics has been analyzed in terms of the environmental physical disturbances caused by wind (George & Edwards, 1976; Harris 1986; Demers & Therriault, 1987; Padisák et al, 1988, 1990; Vörös & Padisák, 1991; Millet & Cecchi, 1992;

Carrick et al, 1993). Phytoplankton assemblages are selected according to the speed and efficiency of the biological responses. Since phytoplankton behaves as a "living transfer function" of the environment, it is useful to consider the responses of emerging properties of populations to evaluate the impact of small-scale disturbances, such as the wind, because the lack of biological "memory" beyond 1-3 days for the shallow area (Millet & Cecchi, 1992).

It is essential to determine the covariance between environmental events and the responses of the phytoplankton, to identify physiological responses, shifts in species' composition and changes in succession. The maintenance of adequate phytoplankton development results from growth rates at different degrees of stability/vertical mixing and hydrodynamic factors on the horizontal axis that depend on currents induced by the wind or by water flow (Tundisi,1990). Knowledge on the phytoplankton community in coastal lakes on the north coast of Rio Grande do Sul is still very scanty. Studies dealing with the phytoplankton community were developed in the Tramandaí and Armazém Lagoons (Callegaro et al., 1981), Pombas (Kremer, 1985), Emboaba (Vélez, 1990) and Marcelino-Pinguela lakes (Salomoni, 1997). Although the wind plays an important role in coastal lakes, specially in Rio Grande do Sul, the basic hypothesis that the wind acts as the main determinant factor of hydrodynamic was tested only for Itapeva lake (Cardoso, 2001).Thus, if the wind is so important to drive the hydrodynamic regime in Itapeva lake it is expected to be important to spatial and temporal changes of the phytoplankton community. The goal of this study was not only to increase the knowledge about the phytoplankton community in coastal lakes of Rio Grande do Sul, but also to establish correlations between phytoplankton and lake hydrodynamic aspects (wind and water level).

Material and methods

Description of site studied (Itapeva lake) as well as the sampling design were fully described in Cardoso & Motta Marques (2003). Itapeva lake is a shallow lake (maximum depth of 2.5m) with an elongated shape (30.8 km x 7.6 km) and parallel to predominant wind direction (NE-SW). A tower was installed in three sampling stations (North, Center and South) inside the lake to obtained automatically environmental data (water level, meteorological data with a Davis meteorological station, and physicochemical data with a YSI 6000 multiprobe). At the same sites phytoplankton samples were collected at surface depth, during four time intervals throughout the day (6am, 10am, 2pm and 6pm), during the three days in August and December/98, March, May and August/99.

The methods used to collect and quantify the phytoplankton samples followed established standards (Vollenweider 1974; Sournia 1978; APHA 1992; Parra & Bicudo, 1995). Samples to quantify the phytoplankton were taken using the Van Dorn (horizontal) bottle, fixed with lugol solution and counted in a Sedgwick -Rafter chamber with 400x of magnification (16x lenses and 25x objectives). A minimum of 100 individuals were counted for phytoplankton with a minimum 80% efficiency (Pappas & Stoermer, 1996).

The structure of the phytoplankton community was defined in terms of specific and relative density (APHA, 1992), size classes (Dussart, 1965), abundance and dominance (Lobo & Leighton, 1986), richness (Krebs, 1989), and Shannon- Wiener's specific diversity (Shannon & Weaver, 1949 apud Krebs, 1989).

The algae were classified acording to Round (1983). The size classes used (Dussart, 1965) were nanoplankton (‹20 ㎛), microplankton (20 to 200 ㎛), and macroplankton (›200 ㎛). The size of the species was considered based on the GALD - the largest linear dimension axis (Lewis, 1976).

The wind hydrodynamics bases and physicochemical characteristics of Itapeva lake were publish elsewhere (Cardoso & Motta Marques, 2003).

A descriptive analysis was performed on phytoplankton groups at each sampling station and season as well as correlation (r-Pearson, p ‹0.05) analyses with hydrodynamic data. The analysis of variance (ANOVA) was performed to verify significant spatial and temporal variations for the factors: sampling station, profile of water column, day and shift (in hour) in each seasonal time. Diversity was computed using program PC-ORD® version 4.0 (McCune & Mefford, 1999).

Results

The phytoplankton community of Itapeva lake was composed of 7 phyla and more than 148 species, since a few were grouped within the same genus. Species composition and size class have shown a seasonal variation (Tab. I, II, III, and IV).

Table I: Occurrence of Bacillariophyta species in Itapeva lake (winter/98= AUG/98, spring= DEC/98, summer= MAR/99, autumn= MAY/99, winter/99= AUG/99; N= North, C= Center, and S= South stations; nano= nanoplankton, micro= microplankton, macro= macroplankton).

BACILLARIOPHYTA	size class	Winter 98	Spring	Summer	Autumn	Winter 99
Aulacoseira ambigua (Grunow) Simonsen	micro	N				
Aulacoseira distans (Ehrenberg) Simonsen	nano	NCS	NCS	NCS	NCS	NCS
Aulacoseira granulata (Ehrenberg) Simonsen	micro	NCS	NCS	NCS	NCS	NCS
Aulacoseira granulata var. angustissima O. Müller	micro	CS	NCS	NCS	NCS	NCS
Aulacoseira cf. italica (Ehrenberg) Simonsen	micro	NCS	N	S	N	
Cocconeis placentula var. euglypta (Ehrenberg) Cleve	micro		NCS		NS	NCS
Cyclotella sp.	nano	CS	N			N
Cymbella tumida (Brébisson) Van Heurck	micro	NS	NCS	NS	N	NC
Eunotia camelus Ehrenberg	micro	N	NCS	C		CS
Eunotia didyma Hustedt ex Zimmermann	micro				N	
Eunotia sudetica O. Müller	micro	NS	N	CS	NC	N
Eunotia valida Hustedt	micro					C
Eunotia spp.	micro	NCS	NCS	C	NC	NCS
Fragillaria cf. javica Hustedt	nano		N			
Fragillaria cf. pinnata Ehrenberg	nano	S	NCS			NCS
Fragillaria sp1.	nano	C	C			
Fragillaria sp2.	micro	N				
Frustulia sp.	micro	S		S		
Gomphonema cf. augur Ehrenberg	micro	N	N	S	N	C
Gyrosigma sp.	micro	N	N	C	N	NC
Navicula cryptocephala Kützing	micro		NC	NCS		S
Navicula cryptotenella Lange-Bertalot	micro	CS	NCS	NCS	N	NCS
Navicula spp.	micro	NS	N	S		
Nitzschia spp.	micro	NCS	NCS	NCS	NC	S
Nitzschia acicularis (Kützing) Wm. Smith	micro	S	NCS	NCS	NC	NCS
Nitzschia amphibia Grunow	nano	S	NCS			NCS
Nitzschia cf. constricta (Kützing) Ralfs	micro			C		NS
Nitzschia frustulum (Kützing) Grunow	nano	N				
Nitzschia cf. fruticosa Hustedt	micro	NS	NCS	NCS	NS	NCS
Nitzschia gracilis Hantzsch	micro	NCS	NCS	NCS	NCS	NCS
Nitzschia cf. intermedia Hantzsch	micro		C			
Nitzschia cf. lanceolata Wm. Smith	micro		S	C		
Nitzschia linearis (Agardh) Wm. Smith	micro		NC	C		
Nitzschia palea (Kützing) Wm. Smith	micro	NCS	NCS	NCS	NCS	NCS
Nitzschia sigma Wm. Smith	micro	NS	NCS	NCS	NC	NCS
Nitzschia cf. subacicularis Hustedt	micro		NCS	NCS		NCS
Pinnularia spp.	micro	NCS	NC		N	N
Pinnularia neomajor Krammer	macro	N			N	N
Pinnularia maior var. subacuta (Ehrenberg) Cleve	micro				N	

Table I: Continuation

BACILLARIOPHYTA	size class	Winter 98	Spring	Summer	Autumn	Winter 99
Pinnularia viridis (Nitzsch) Ehrenberg	micro	S	NCS	C	NC	NC
Stauroneis cf. anceps Ehrenberg	micro		NS	C	NC	
Stauroneis sp1.	micro				N	
Stauroneis sp2.	micro	S	C	C	N	NC
Staurosira construens (Ehrenberg) Williams & Round	nano	NS	NCS	NCS	NCS	NCS
Surirella guatemalensis Ehrenberg	micro		NCS	NC	N	
Surirella ovata var. minuta (Schumann) Kirchner	micro	S	NCS	NCS	NCS	NCS
Surirella tenera Gregory	micro	N	NCS	NCS	NCS	NCS
Surirella sp1.	micro	NS	NS	NCS	NCS	NCS
Surirella sp2.	micro	NS	CS	NCS	NC	NS
Surirella sp3.	micro		NC	NC		C
Synedra ulna (Nitzsch) Ehrenberg	micro	NS	NC	NC	NCS	NCS
Synedra sp1.	micro			S	N	
Synedra sp2.	micro	S				
Synedra sp3.	micro	N				
Synedra sp4.	micro			CS		
Tryblionella levidensis Wm. Smith	nano	NCS	NCS	NCS	NCS	NCS
Tryblionella victoriae Grunow	nano	NC	NCS	NCS	N	S

Table II: Occurrence of Cyanobacteria species in Itapeva lake (winter/98= AUG/98, spring= DEC/98, summer= MAR/99, autumn= MAY/99, winter/99= AUG/99; N= North, C= Center, and S= South stations; nano= nanoplankton, micro= microplankton, macro= macroplankton).

CYANOBACTERIA	size class	Winter 98	Spring	Summer	Autumn	Winter 99
Anabaena crassa (Lemm.) Kom.-Legn & Cronb	macro	NC	NCS	NCS	NCS	S
Anabaena sp2.	micro			NC	NCS	
Anabaena circinalis Rabenhorst ex Bonet & Flahault	micro	NCS	NCS	NCS	NCS	NCS
Anabaena spiroides Klebahn	micro	C	NCS	NCS	NCS	NCS
cf. Aphanizomenon sp1.	micro	NCS	N			
cf. Aphanizomenon sp2.	micro	NS		N		
Aphanizomenon sp.	micro	S	CS	C		NCS
Aphanocapsa sp.	micro	N				
Aphanocapsa delicatissima W. & G.S. West	micro	NCS	NCS	NCS	NCS	NCS
Aphanocapsa nubilum Komárek & Cronberg	micro	NCS	C	NS		
Aphanocapsa roeseana Bary	micro		NS	S		
Aphanothece sp.	nano	NS	N			
Chroococcus cf. limneticus Lemmermann	micro		NCS	NCS	NCS	N
Chroococcus minor (Kützing) Nägeli	nano	NC	NCS	CS		CS
Chroococcus minutus (Keissler) Lemmermann	nano		CS	CS	NC	
Coelosphaerium sp.	nano	S	NS			
Coelosphaerium kuetzingianum Nägeli	micro	N				
Cyanodiction imperfectum Cromberg & Weibull	micro	NCS	NCS	NCS	NCS	NCS
Cyanodiction reticulatum (Lemmermann) Geitler	micro	NS	N	S		NCS
Gloeocapsa cf. kuetzingiana Nägeli	micro	NC	NCS	NCS	NCS	NCS
cf. Gloeocapsa	nano	NC		C		

Table II: Continuation

CYANOBACTERIA	size class	Winter 98	Spring	Summer	Autumn	Winter 99
Gomphosphaeria sp.	micro		N		N	
Lyngbya sp.	micro	C				
Merismopedia tenuissima Lemmermann	nano	NCS	NCS	S	NCS	CS
Microcystis aeruginosa (Kützing) Kützing	micro		NCS		N	
Microcystis cf. minutissima W. West	micro	S	NCS	NCS	NCS	S
Oscillatoria sp.	micro	N	S			
Planktolyngbya contorta (Lemmermann) Anagnostidis & Komárek	micro	S				
Planktolyngbya limnetica (Lemmermann) Komárkova-Legnerová & Cronberg	micro	NCS	NCS	NCS	NCS	NCS
cf. Pseudoanabaena	micro	S				S
no identified	micro	S				

Table III: Occurrence of Chlorophyta species in Itapeva lake (winter/98= AUG/98, spring= DEC/98, summer= MAR/99, autumn= MAY/99, winter/99= AUG/99; N= North, C= Center, and S= South stations; nano= nanoplankton, micro= microplankton).

CHLOROPHYTA	size class	Winter 98	Spring	Summer	Autumn	Winter 99
Ankistrodesmus sp.	micro				N	
Closteriopsis acicularis (G.M. Smith) Belcher & Swale	micro			CS		NS
Closterium acutum var. variabile (Lemmermann) W. Krieg	micro	CS	NCS	NCS		CS
Closterium parvulum Nägeli	micro	NCS	NCS	CS		
Crucigeniella apiculata (Lemmermann) Komárek	nano		NC	NS		
Crucigeniella crucifera (Wolle) Komárek	nano		N	NCS		
Golenkinia radiata Chodat	nano		C			
Kirchneriella arcuata G.M. Smith	nano	S	C			
Kirchneriella cf. contorta var. elegans (Playfard) Komárek	nano	C	C	C		CS
Kirchneriella incurvata Belcher & Swale	nano	N				
Kirchneriella irregularis (G.M. Smith) Korschikov	nano	S	S			
Kirchneriella obesa (W. West) Schmidle	nano	NCS	NCS	NCS		CS
Lagerheimia ciliata (Lagerheim) Chodat	nano	N	NCS	NCS	NCS	NC
Monoraphidium arcuatum (Korsikov) Hindák	micro	NCS	NCS	NCS	NC	CS
Monoraphidium contortum (Thuret) Komárková-Legnerova	nano	NCS	NCS	NCS	N	CS
Monoraphidium griffithi (Berkeley) Komárková-Legnerova	micro	S	NS			N
Monoraphidium irregulare (G.M.Smith) Komárková-Legnerova	micro	C		S		
Monoraphidium minutum (Nägeli) Komárková-Legnerova	nano	NCS	CS			S
Monoraphidium tortile (W. & G.S. West) Komárková-Legnerova	micro	S	NC	NCS		NCS
Mougeotia sp.	micro			S		
Pediastrum duplex var. duplex Meyen	micro	N	NCS	NCS	NC	NS
Pediastrum simplex Meyen	micro		S			NS
Oocystis lacustris Chodat	nano	NC	NCS	NCS	NCS	S
Scenedesmus spp.	nano	NCS	CS			

Table III: Continuation

CHLOROPHYTA	size class	Winter 98	Spring	Summer	Autumn	Winter 99
Scenedesmus acuminatus var. acuminatus (Lagerhein) Chodat	micro		S			
Scenedesmus acuminatus var. minor G.M. Smith	nano	S	NCS	NCS	NCS	C
Scenedesmus communis Hegewald	nano	S	NCS	NCS	C	N
Scenedesmus ecornis (Ehrenberg) Chodat	nano	S	NCS	NCS	NCS	NCS
Scenedesmus intermedius Chodat	nano		N			
Scenedesmus cf. ovalternus Chodat	nano	NCS		N	S	CS
Scenedesmus quadricauda (Turpin) Brébisson	nano	S	NCS	NCS	NCS	C
Scenedesmus quadricauda var. parvus G.S.Smith	nano					C
Schroederia setigera (Schröder) Lemmermann	nano	NCS	NCS	NCS		C
Sphaerocystis planctonica (Korsikov) Bourrelly	micro			N		
Spirogyra sp.	micro			S		
Tetraedron trigonum (Nägeli) Hansgirg	nano	NCS	NCS	NCS	NC	NCS
Tetrastrum elegans Playfair	nano				N	
Tetrastrum glabrum (Roll) Ahlstrom & Tiffany	nano	NCS	NCS	NCS	S	CS
Tetrastrum triacanthum Korsikov	nano	N	N	C		
Tetrastrum triangulare (Chodat) Komárek	nano	NS	NCS	NCS	NCS	C
no identified sp1.	nano	NC				
no identified sp2.	nano	NS	NS			

Table IV: Occurrence of Cryptophyta, Dinophyta, Euglenophyta and Chrysophyta species in Itapeva lake (winter/98= AUG/98, spring= DEC/98, summer= MAR/99, autumn= MAY/99, winter/99= AUG/99; N= North, C= Center, and S= South stations; nano= nanoplankton, micro= microplankton).

Phyla	Species	size class	Winter 98	Spring	Summer	Autumn	Winter 99
CRYPTOPHYTA	Chroomonas acuta Utermöhl	nano			S		S
	Cryptomonas erosa Ehrenberg	micro	NCS	NCS	NCS	C	NCS
	Cryptomonas marsonii Skuja	nano	N	NS			N
	Cryptomonas pyrenoidifera Geitler	nano	S				
	no identified	micro	S				
DINOPHYTA	Gymnodinium sp.	nano	S		C		
	Peridinium volzii Lemmermann	micro	NS				
	Peridinium sp.	nano		N			
	no identified	nano		N	CS		
EUGLENOPHYTA	Euglena sp.	nano		S			
	Trachelomonas sp.	nano	NC	NC	NC		C
	Trachelomonas volvocina Ehrenberg	nano	NS	C	NC	N	NCS
	Strombomonas sp.	nano				N	
CHRYSOPHYTA	Dinobryon sertularia Ehrenberg	nano		C		NC	
	Mallomonas sp.	nano			S		
	Salpingoeca sp.	nano		N			

The richness of phytoplankton in Itapeva lake increased during spring (106 taxons) and decreased in autumn (69 taxons), due to an Anabaena circinalis bloom. The spatial variation of the richness indicated a higher percentage of species at the North of the lake in spring and autumn, at the Center during summer and winter /99 and at the South during winter /98. There was a greater similarity in phytoplankton richness between the sampling sites over the winter of 1999.

The highest mean density in the phytoplankton community (2,288 $ind.mL^{-1}$) was observed in autumn, although the peak was recorded for spring (7,029 $ind.mL^{-1}$). At the Center and South of the lake, the highest density mean occurred clearly during the autumn, while at the North, the mean density during winter (Aug/99) was slightly higher than the one in autumn (Fig. 1). The phytoplankton density in Itapeva lake was observed to increase in the coldest seasons (autumn and winter/99). The highest mean density from summer to winter/99 was recorded for cyanobacteria (760, 2,047 and 922 $ind.mL^{-1}$ respectively). In spring, the diatoms were more abundant (729 $ind.mL^{-1}$). In winter/98 both groups presented similar mean densities (229 $ind.mL^{-1}$ and 227 $ind.mL^{-1}$, diatoms and cyanobacteria, respectively).

Diatoms and cyanobacterias were the predominant phytoplankton groups in Itapeva lake, both in terms of density (Fig. 1) and richness (Tab. I to IV). Only diatoms density was significantly correlated to wind velocity in summer (r=0.52, p‹0.05) and chlorophyts in winter/99 (r=-0.35, p‹0.05). Diatoms was correlated to wind direction (r=0.41, p‹0.05) in winter/99 and to water level in autumn (r=0.71, p‹0.05) and in winter/99 (r=0.62, p‹0.05). However, Cyanobacteria was inversely correlated to water level (r=-0.38, p‹0.05) in summer.

Filamentous species of Aulacoseira were resident (Tab. 1) and abundant in Itapeva lake. Cyanobacteria were more abundant during autumn in Itapeva lake, when a Anabaena circinalis bloom occurred (Cardoso, 2001; Becker et al., 2004). Since the five other phyla presented low density (Fig. 1), they were considered as a single group. The highest density occurred during spring in North (449 $ind.mL^{-1}$), in Center (399 $ind.mL^{-1}$), and in South (169 $ind.mL^{-1}$), although maximum value for the South site was recorded in summer (242 $ind.mL^{-1}$).

The analysis of variance (ANOVA) showed seasonal significant spatial and temporal variations (p‹0.01) for density considering the sampling site, day and sampling shift, but not in autumn (p›0.05). During spring and summer, these factors were significant (p‹0.01), showing that the variation of densities between sampling shifts (short term) was characteristic for these seasons. A significant variability on density occurred, since a spatial and temporal interactions between sampling station and shift and station-day-shift (both p‹0.01) was observed in autumn. Indeed, the cyanobacteria bloom peaks occurred at different moments in each sampling point (Fig. 1). In winter, the density variance was not significant (p›0.05) between shifts, but it was significant (p‹0.01) for the interactions between sites and days.

In winter/98 there was no dominant species, although the abundant species of diatom was different for each sampling station (Aulacoseira granulata in North, A. cf. italica in Center, and A. distans in South). Three species of cyanobacteria were abundant in winter. Aphanocapsa delicatissima was abundant at all sites, Cyanodiction imperfectum for the North and South sampling stations, and Anabaena circinalis at the Center. Only in the North, the two abundant cyanobacteria species contribute to a relative density higher than 50%. The rainy winter/98 was characterized by high water level which was directly correlated with A. distans (r=0.75, p‹0.05) and inversely with C. imperfectum (r=-0.59, p‹0.05).

A dominant diatom (Aulacoseira granulata) was registered for all sites in spring. In the North, together with the diatom a cyanobacteria (Anabaena circinalis) predominated. In the Center, this diatom was also the only abundant species in other seasons. In the South of the lake, the two abundant species, registered in the winter 98, were abundant again in the spring.
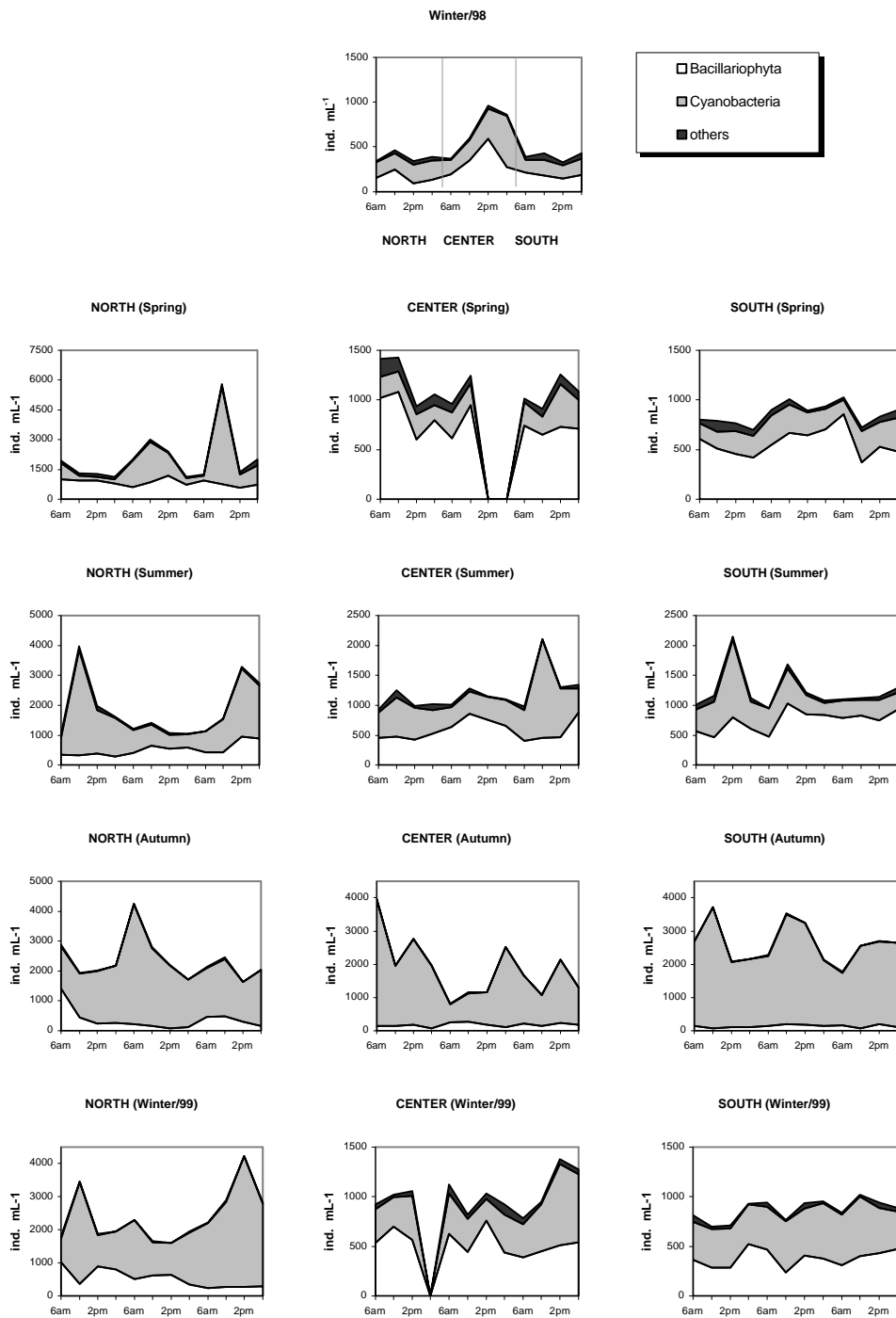
Figure 1: Phytoplankton groups density (ind.mL^{-1}) for each sampling site and station in Itapeva lake (others = Cryptophyta, Dinophyta, Euglenophyta and Chrysophyta).

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In summer, A. circinalis was the dominant species in the North and the Center sites, and abundant in the South of the lake. The dominant diatom species (Aulacoseira granulata) during the previous season was now abundant only in the North and the Center sites. A. granulata and Surirella tenera were two diatoms correlated with wind velocity (r=0.54 and r=0.42, p‹0.05, respectively). Density of A. distans was increased from North to South, in the same wind direction (NE) and Anabaena species (A. circinalis and A. spiroides) were diminished in this direction. Thus, the water level was directly correlated with diatom species (r=0.56, p‹0.05) and inversely correlated with the cyanobacteria species (r=-0.39 and r=−0.54, p‹0.05, respectively).

In autumn, a bloom of the cyanobacteria A. circinalis was found at all sites and during most of the shifts, and their relative density remained higher than 50%. None significant relation to hydrodynamics was registered with this species. In winter/99, the North was the only site where the presence of the dominant species (A. circinalis) was recorded.

In relation to the phytoplankton size structure of each season, a dominance of microphytoplankton in the community was recorded at all lake sites, since that all the dominant and abundant species are included in this size category. An exception is Aulacoseira distans, a nanoplanktonic species.

The highest and lowest mean diversity (H=2.21 and H=1.07) was observed in winter/98 and autumn (Fig. 2). In winter/98, the density of species among the abundant groups (Cyanobacteria and Bacillariophyta) was quite equivalent, thus increasing the diversity. On the other hand, the presence of cyanobacteria blooms in autumn reduced the diversity. The mean values of taxonomic richness were also higher in winter/98 (32 species) and lower in autumn (15 species).

The greatest diversity and richness occurred both in the South of the Itapeva lake in winter/98 (Fig. 2), since similar densities among the phytoplankton groups were recorded (179 ind.mL^1 for Bacillariophyta and 174 ind.mL^1 for Cyanobacteria). High precipitation associated with higher water inflow (W boarder of lake) by the Três Forquilhas river, in combination with the direction of water movement (NE®S) in the lake, may have induced this kind of phytoplankton spatial distribution on diversity and richness. The higher or lower diversities were not always associated with greater or smaller richness at each sampling station (Fig. 2). However, both diversity and richness were significantly correlated (p‹0.05) during all period (r=0.62 in Dec/98; r=0.71 in May/99; r=0.75 in May/99, and r=0.79 in Aug/99). The greater diversity in spring was recorded both in the North (H=2.3) and in the South (H=2.25) lake areas, although in the South a maximum increase in richness (35 species) was detected. For the same period, diversity was inversely correlated to cyanobacteria density (r=-0.42, p‹0.05) and directly correlated to chlorophyts density (r=0.36 p‹0.05), while richness was correlated to diatoms (r=0.46 p‹0.05) and chlorophyts (r=0.56 p‹0.05) density.

In summer, there was a decreasing temporal gradient of diversity and richness in the lake central area. However, the data of North and South sites were completely different, i.e., when diversity/richness increased in one shift in the North station, it decreased in the South station (Fig. 2). This fact is probably related to the fetch effect from NE (12.4 km) at this time of the year (Cardoso, 2001; Cardoso et al., 2002). The persistent direction of the wind (Fig. 3) induced greater displacement of the communities from North to South areas of the lake. It was shown especially by the temporal gradient exhibited at the Center station (Fig. 2) and standard deviation of diversity was greatest at the North site and smallest at the South (Fig. 3). However, diversity was correlated only to water velocity (r=0.35, p‹0.05). In this time, diversity was inversely correlated to cyanobacteria density (r=-0.67 p‹0.05), while richness was correlated only to chlorophyts (r=0.49 p‹0.05) density.

The arrival of cold fronts in the region (autumn and winter/99) with winds from quadrants SW and WSW, respectively, promoted long fetches from S®N 19.8 and 14 km, respectively (Cardoso, 2001; Cardoso et al, 2002). The "peaks" of diversity and richness
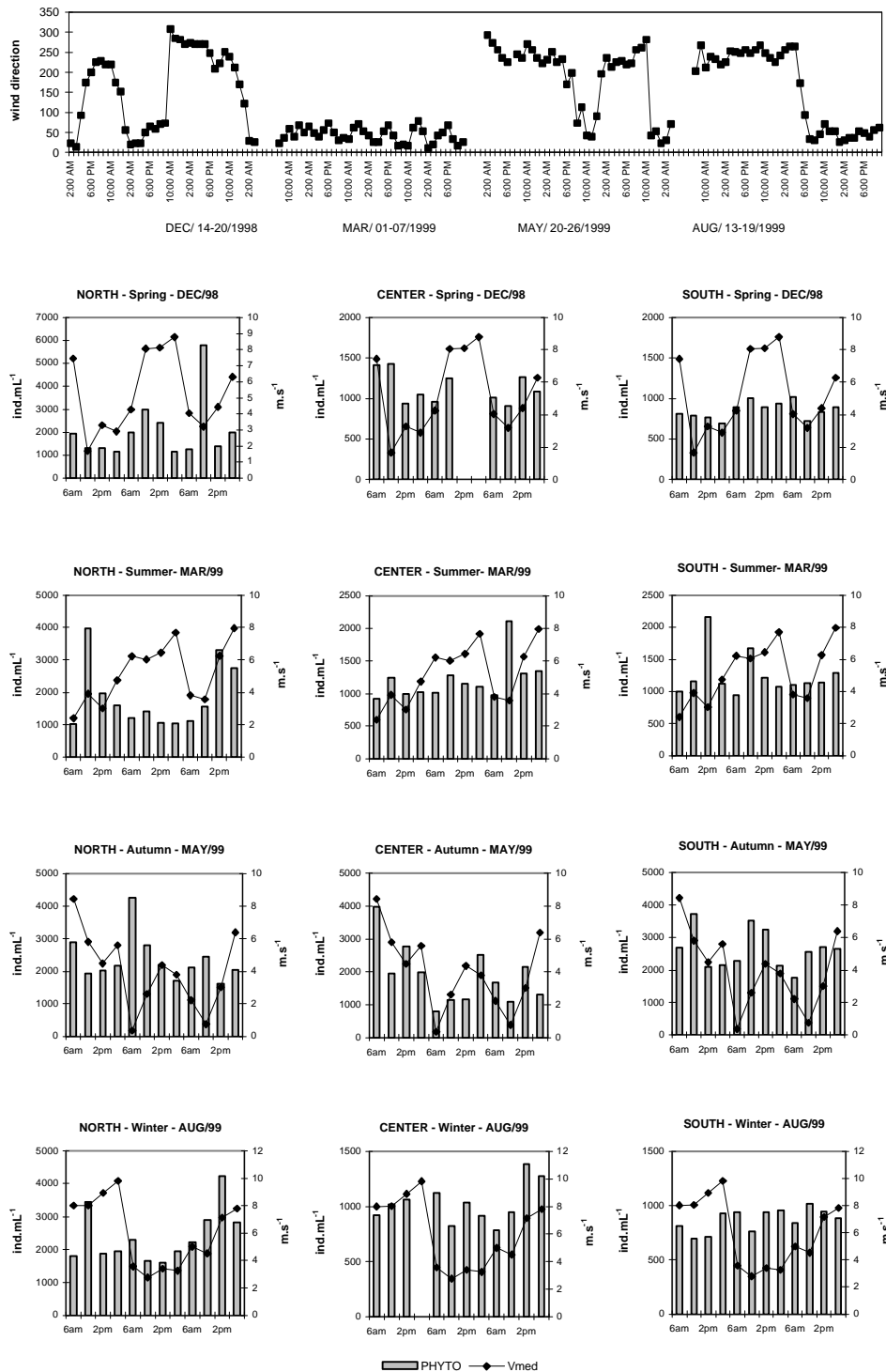
Figure 2: Phytoplankton total density (PHYTO ind.mL^{-1}) in relation to wind mean velocity (m.s^{-1}) and direction ($^\circ$) for each sampling site and station in Itapeva lake. (values of wind direction, where: N= 0, NE= 45, E= 90, SE= 135, S= 180, SW= 225, W= 270, NW= 315).
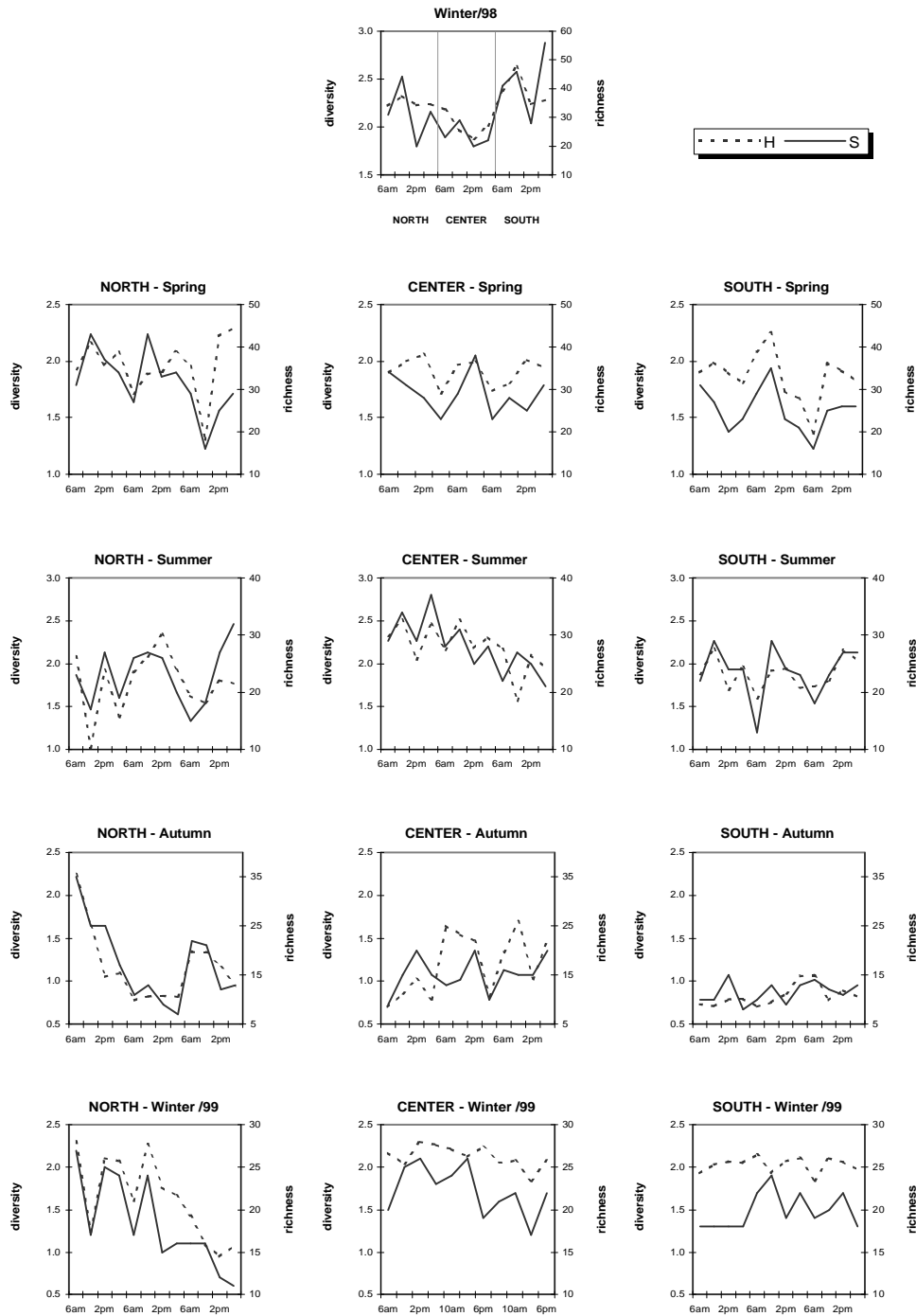
Figure 3: Shannon-Wiener diversity (H) and richness (S) of phytoplankton for each sampling site and station in Itapeva lake.

were recorded for the North area at this time (Fig. 2 and 3). This was linked, over autumn, to persistent small diversity and richness in the South site and the permanent blooms of Anabaena circinalis (Fig. 1 and 2). The wind velocity was correlated to richness of phytoplankton (r=0.35, p‹0.05). However, water level was correlated with both richness (r=0.65, p‹0.05) and diversity (r=0.48, p‹0.05). The two "peaks" of diversity and richness in the North area (Fig. 2) were a direct result of a long fetch (Fig. 3) when diatoms density increased simultaneously (Fig. 1). Bacillariophyta density was directly correlated to diversity (r=0.72, p‹0.05) and richness (r=0.77, p‹0.05), whereas Cyanobacteria density was inversely correlated (r=-0.70 and r=−0.41, respectively, p‹0.05).

In winter/99, a decreasing temporal gradient of diversity and richness over short periods was observed in the North station (Fig. 2), possibly related to the change of wind direction from the WSW to NE quadrants (Fig. 3). This induced the development of A. circinalis blooms, especially on the last day of the survey, due to greater stability of the water column (Fig. 1). The wind direction and water level were correlated to richness (r=0.42 and r=0.60, respectively, p‹0.05) and diversity (r=0.37 and r=0.49, respectively, p‹0.05) of phytoplankton. Bacillariophyta density was directly correlated to diversity (r=0.48, p‹0.05) and richness (r=0.63, p‹0.05), whereas Cyanobacteria density was inversely correlated (r=-0.91 and r=−0.62, respectively, p‹0.05).

Discussion

Itapeva lake is not a eutrophic system (Cardoso, 2001; Cardoso & Motta Marques, 2003), although the greatest phytoplankton density was associated to Cyanobacteria.

The phytoplankton density, increased in the cold seasons, was probably induced by wind, alternating between periods of intense velocity and total calm, which promoted high mixing of water column, followed by a more stable environment for cell development. However, correlation between cyanobacteria density and water level was significant (r=-0.38, p‹0.05) only in summer. There was no significant correlation with wind velocity and direction. During this time, the persistent wind direction (NE) promoted an increase in water level in the lake Southern region while at the same time, cyanobacteria blooms occured in the calmer Northern region. Diatoms density increased significantly as an instantaneous response to hydrodynamic and not indirectly as for cyanobacteria.

Aulacoseira species are meroplanktonic organisms that enter in the water column when mixing conditions are such that they can be resuspended from the bottom sediments and maintained in suspension. Furthermore, Aulacoseira species appear to have rather high nutrient requirements. This is to be expected because they thrive in the nutrient-rich hypo- or metalimnetic waters that are mixed throughout the water column after the stratification. They also occur in many shallow eutrophic waters. When filaments sink to the sediments their protoplasmic contents often contract into a condensed resting form. In this form, the cells are not affected by the absence of light or oxygen, and may remain viable for months or years. Turbulent mixing then resuspends resting filaments to provide an inoculum for new populations of Aulacoseira (Kilham, 1990).

Wind can influence the standing stock of Aulacoseira italica in a reservoir (Lima et al., 1983; Marins, 1983). The wind stirred up settled cells and nutrients to water column, despite the persistent presence at Lobo's Reservoir. The ecological behavior of Aulacoseira species was similar at Itapeva Lake, when the wind drove the spatial distribution of the diatoms.

Generally, a decreasing density gradient from N®S was registred in Itapeva lake, but not in autumn (cyanobacteria blooms in all lake) and winter/98, when the Center area appears to have been enriched, probably due to a greater inflow of nutrients brought by the rain from the outflow of Três Forquilhas River. Lake shape, wind regime and river rush inflow may have induced a spatial response of the phytoplankton community as a function of the water dynamics in Itapeva lake.

"Peaks" of abundance during the cold season were also a major characteristic of algal seasonality in Lake Neusiedlersee-Hungary, a shallow, turbid and brackish lake

(Padisák & Dokulil, 1994). The dynamics of phytoplankton was characterized by periodical resuspensions over a short term, or even seasonally, while oscillations in the water level and salinity were factors that affected changes over a long term in the phytoplankton community (Padisák & Dokulil, 1994). Although Itapeva lake is not a brackish environment, the lake hydrodynamics was driven in the same way.

Cyanobacteria are characteristically tolerant of broad ranges of environmental gradient and pollution. Cyanobacteria had a capacity to regulate oscillation, binding atmospheric nitrogen, and low nutrient value for the zooplankton. They present rapid sedimentation, and are limited by nitrogen and herbivory, respectively (Domingos, 1991; Lewis, 1976). A same observation was detected in Itapeva lake where nitrogen concentrations were low (Cardoso, 2001; Cardoso & Motta Marques, 2003).

The sedimentation rate of phytoplankton varied according to the physiological status of the cells in a dependence of the concentrations of nutrients in the external environment. If there is an environmental deficiency the cells die and sink. Those that remain alive can be resuspended during a storm that causes a complete mixture in the lake. This complex phenomenon was represented by a threshold function to calculate the sedimentation rate: the population reaches senescence when a state of deficiency persists beyond a certain threshold time. In this case, when the sedimentation rate is at maximum, the diatoms are deposited in the sediment where they slowly die. The survivors will seed the system by the surface sediment layers resuspension promoted by an environmental event. Furthermore, after the mineralization of the deposited organic matter, these mineral elements become available in the water in a dissolved form, favoring the development and reproduction of remaining species (Salençon & Thebault, 1996). In Itapeva lake, diatoms answered rapidly to resuspension with a density increased with a long fetch, whereas cyanobacteria answer had a lag time dependent on calm periods.

Describing the seasonal dynamics of the phytoplankton in shallow lakes it is not a easy task. Unexpected "peaks" in the population abundance of dominant and rare species are frequently observed in a temporal scale or are superimposed on "regular" seasonal models. The irregularities on the phytoplankton dynamics are due to different sources (Padisák & Dokulil, 1994). Same pattern are rarely observed within the same season of the year, not even in subsequent years. Thus, the seasonal occurrence of the species depends on characteristic environmental events and, especially, on the range of response when changes occur. The persistent direction of the NE wind, together with the more uniform environmental conditions (on a time scale), during the summer, enabled a clear spatial distribution of the phytoplankton composition between the lake extremes (Cardoso, 2001). Persistent winds sometimes from quadrant WSW, and others from NE during winter/99, probably led to ressuspension of the algae and/or their spores from the bottom. In this condition, two abundant species of diatoms together with a cyanobacteria were found at the lake Center area.

Diversity is high or increases when species replacement rates are fast, such as in warm waters. Diversity is promoted when algae of rapid growth (usually of small size) are abundant. On the other hand, diversity is reduced in advanced successions wherever a large biomass is dominated by a single species of algae of large size (>200 μm). In strongly selective environments, such as systems or lakes characterized by high turbidity (Reynolds et al., 1993), diversity is low. The relationship between diversity and disturbance, inferred by Hardin (1960 apud Reynolds, 1993) is based on the principle of competitive exclusion, where diversity of species is suppressed when ecological balance is achieved (climax). In phytoplankton community, bloom is a climax situation. In the case of Itapeva lake, the effect of disturbance due to fetch, in situations of strong winds, promoted an immediate increase in the phytoplankton diversity. Although wind velocity was not significantly correlated to phytoplankton diversity, wind direction was correlated to phytoplankton diversity in winter/99, when wind directions changed sharply from WSW (1st day) to NE (3rd day).

In Rio de Janeiro (Brazil), many of the lagoons, natural or transformed into by artificial opening canals, present different degrees of salinity. Furthermore, the impact of anthropic

action is much greater than in the Rio Grande do Sul State coastal lake system. Exceptions are Marcelino lake at Osório (Salomoni, 1997), and Tramandaí Lagoon at Tramandai (Callegaro et al., 1981). However, in both coastal systems, the water bodies are shallow environments exposed to wind action. Thus, some responses of the plankton communities are expected to be similar. For instance, Saquarema lagoon (Domingos, 1991) was also dominated by Cyanobacteria, with a density gradient directly related to the salinity. Moreover, Cyanobacteria were nanoplankton forms (‹20■m) which presented a high surface/volume ratio. However, cyanobacteria was also related to some extent to stress and instability of water column, since there was an average 2 to 3x of magnitude in increase of population density after wind events. For Urussanga lagoon (Domingos, 1991), the faster responses and greater growth were observed in Chrysophyta and Cyanobacteria. Both population density and biomass increased towards less salinity. For the same region three other lagoons with different characteristics (Imboassica, Cabiunas and Comprida lagoons), Cyanobacteria were also abundant, developing sometimes blooms (Melo & Suzuki, 1998).

The wind is a driving force of water dynamics with a direct action on the phytoplankton community in Itapeva lake by resuspending species of the bottom (diatoms and cyanobacteria spores). Since the phytoplankton was characterized by the dominance of cyanobacteria, the resuspension of epipelic diatoms provided greater balance to the relative densities of the community, increasing diversity and/or richness. Thus, diatoms were more efficient in indicator water dynamics in the shallow Itapeva lake because appeared immediately after wind effect in water column.

Acknowledgments

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