Development of *Anabaena* Bory (Cyanobacteria) blooms in a subtropical shallow lake, south Brazil.

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Abstract: Development of *Anabaena* Bory (Cyanobacteria) blooms in a subtropical shallow lake, south Brazil. Cyanobacteria have a number of special properties wich determine their relative importance in phytoplankton communities. Some species of cyanobacteria produce toxins and their blooms may cause the death of aquatic organisms or even of human beings. Species of cyanobacteria respond in different ways to environmental fluctuations in the habitat. The main purpose of this paper is to record the occurrence of blooms of *Anabaena circinalis* and *A. spiroides* in Itapeva Lake, as well as the factors involved in forming these blooms. *Anabaena circinalis* and *Anabaena spiroides* blooms were characterized for Itapeva Lake, during the period from December 1998 to August 1999, the first species bloom being more intense (duration and density) than the second. Blooms of both species were found independent of season of the year. The maximum values recorded for both species occurred in autumn (May/99), a period in which blooms were recorded at three different regions in the lake. It should be stressed that the density used to consider bloom was a minimum of 2,000 $cel.mL^{-1}$. This maximum bloom was preceded by an event with strong turbulence in the system, which made nutrients available and/or dispersed the spores of these cyanobacteria stored in the sediment into the water column. The remaining time of the studied period was characterized by an increasing reduction in wind velocity and longer stabilization period in the water column.
Key-Words: Cyanobacteria, *Anabaena circinalis, Anabaena spiroides*, bloom, shallow lake.

Resumo: Desenvolvimento de florações de *Anabaena* Bory (Cianobactéria) em uma lagoa rasa subtropical, sul do Brasil. Cianobactérias possuem propriedades especiais que determinam sua importância na comunidade fitoplanctônica Algumas espécies deste grupo produzem toxinas e as suas florações podem causar mortandade de organismos aquáticos ou até mesmo do próprio homem. Espécies de cianobactérias respondem de formas diferentes às flutuações ambientais dentro de cada habitat. O objetivo principal deste trabalho é registrar a ocorrência das florações das espécies de *Anabaena* (*A. circinalis* e *A. spiroides)* na lagoa Itapeva, bem como os fatores abióticos envolvidos. Florações de *Anabaena circinalis* e *Anabaena spiroides* foram caracterizadas para a Lagoa Itapeva, no período entre dezembro de 1998 a agosto de 1999, sendo a da primeira espécie mais intensa (duração e densidade) que a segunda. Os valores máximos registrados para ambas as espécies ocorreram no outono (Maio/99), um período em que a floração foi observada nas três regiões da lagoa (Norte, Centro e Sul). Deve-se enfatizar que a densidade usada considerada para uma floração foi de um mínimo de 2,000 $cel.mL^{-1}$. O pico da floração foi precedida por um evento com forte turbulência no sistema, que disponibilizou nutrientes e/ou dispersou os esporos estas espécies armazenados no sedimento na coluna da água. Os restantes do período estudados foram caracterizados por uma redução crescente na velocidade do vento e em um período mais longo da estabilização na coluna da água.
Palavras-chave: Cianobactéria, *Anabaena circinalis, Anabaena spiroides*, florações, lago raso

Introduction

The study of cyanobacteria in freshwater bodies has been intensified, especially concerning “water quality” aspects. Some species of cyanobacteria produce toxins and their blooms may cause the death of aquatic organisms or even of man himself, as occurred in the summer of 1996 in Caruaru, state of Pernambuco (Sant'Anna & Azevedo, 2000a). Blooms of toxic cyanobacteria in lakes, reservoirs and rivers are associated with enrichment by nutrients (Fergunson, 1997) or else they are due to the combination of physical factors such as intensity of thermal stratification and the ability of these organisms to regulate their cell density (Oliver, 1994). These blooms, particularly the genera *Microcystis* and *Anabaena*, have caused problems that frequently result in the deterioration of "water quality", with adverse effects on lake ecology, on livestock, water supply and recreational activities. (Sigee et al.,1999).

Genus *Anabaena* occurs in freshwater, and it is sometimes present in brackish and marine environments (Carpenter & Carmichael, 1995). This genus synthetizes most of the known toxins, both hepatotoxic (microcystins) and neurotoxic (anatoxin-a, anatoxin-a(s) and saxytoxins) (Cood, 1995; Cood et al., 1997). Toxin production by *A. circinalis* was recorded both for microcystins in France and for saxitoxins, in Australian rivers and reservoirs (Sinoven & Jones, 1999). Some cyanobacteria that present gas vacuoles (aerotope), amongst which *Anabaena*, form dense populations on the surface of lakes and reservoirs, the so-called blooms. The blooms cause serious problems due to their appearance, probability of deoxygenation, unpleasant odoriferous substances and the frequent formation of toxins (Whitton, 1992). In order to be considered a bloom the cell density in the sample varies greatly. Taking *Microcystis aeruginosa* and its toxins as a reference, a level of 2,000 cels.mL^{-1} is applied for this to be considered a harmful bloom, i.e., with risk to humans and to populations in the environment (Chorus & Bartram, 1999). For species of *Anabaena*, Jones & Korth (1995) consider that even at concentrations beneath 1,000 cels.mL^{-1}, a strong smell of geosmine is felt, what would characterize a level of bloom in the sanitary aspect.

Concrete proof of the growing importance of these plankton organism for "water quality" can be see in Administrative Ruling nr. 518 of the Ministry of Health (Brazil, 2004), which includes the analysis of cyanobacteria and their toxins (microcystins). The level of cyanobacteria concentration determined by Brazilian law (microcystin 1.0 mg.L^{-1}) is well beyond the limits mentioned previously in the bibliography of World Health Organization (WHO) (Chorus & Bartram, 1999). Following this law, cyanobacteria monitoring in source waters at the intake station is done at a monthly frequency when the number of cyanobacteria should not be higher than 10,000 cels.mL^{-1} (or 1 mm^3.L^{-1} of biovolume), and weekly, when the number of cyanobacteria surpasses 20,000 cels.mL^{-1} (or 2 mm^3.L^{-1} of biovolume) (Brazil, 2004).

Species of cyanobacteria respond in different ways to environmental fluctuations in each habitat (Whitton, 1992). Intense cyanobacteria blooms develop on the surface of stratified systems with a long residence time. However, with strong winds and a small residence time, the cyanobacteria blooms disappear, and their place is taken by diatoms (Tundisi, 1990). Sites where characteristics of stagnation predominate at some times of the year, generally suffer the isolated impact of harmful *Anabaena* species (Yunes, 1999). Lakes generally have long water retention times compared with rivers, and by their nature lakes tend to accumulate sediments and the chemicals associated with them. Sediments therefore act as sinks for important nutrients such as phosphorus. However, under changing conditions sediments may also serve as input source, delivering nutrients back into the water, where it can stimulate the growth of cianobacteria and algae (Chorus & Bartram, 1999). Recent studies highlighted the role of turbulence in algae blooms. It has been suggested that a P concentration above 10 □g.L^{-1} the development of potentially bloom forming of cyanobacteria may be described by physical factors, such as water column stability. The presence or absence of these organisms may be related to different forms of turbulence (Whitton, 1992).

The main goal of this paper is to record the occurrence of blooms of *Anabaena circinalis* Rabenhorst *ex* Bonet & Flahault and *Anabaena spiroides* Klebbahn in Itapeva Lake (Rio Grande do Sul), south of Brazil, as well as the factors involved in forming these blooms included hydrodynamic regime.

Material and methods

Itapeva Lake is a shallow subtropical lake located in the south of Brazil (Rio Grande do Sul State), characterized by an elongated shape (30.8 km x 7.6 km), a surface of »125 km^2 and maximum depth of 2.5 m. Full description of the site studied (Itapeva Lake) was included in Cardoso & Motta Marques (2002).

Three fixed sampling stations were used at Itapeva Lake: North (0615690E – 6747815N), Center (0603350E – 6732254N) and South (0597474E – 6725967N). Sampling was performed over four campaigns: December 14-20, 1998 (spring), March 1-7, 1999 (summer), May 20-26, 1999 (autumn), August 20-26, 1999 (winter).

A tower was installed in three sampling stations with the following instruments: limnimetric gauge, meteorological weather station (DAVIS, Weather Wizard III, Weather Link), installed only at the Center Station, and YSI multiprobe 6000 (Yellow Spring Instruments). The following variables were determined: (a) temperature, conductivity, dissolved oxygen, pH, ORP (oxy-reduction potential) and turbidity, through a Multiprobe YSI (readings obtained at 5-minute intervals); (b) air temperature, wind velocity and direction, through a meteorological station (readings obtained at 30-minute intervals).

The sampling of phytoplankton was performed using a 2L horizontal Van Dorn bottle (Wetzel & Likens, 2000). Samples from water surface were taken at 6 am, 10 am, 2 pm and 6 pm, for each sampling day. Phytoplankton was fixed with Lugol (Sournia, 1978).

The quantitative analysis (for individuals and cells) was performed using a Sedgwick-Rafter chamber in an optic microscope Zeiss Jenaval (400X) (APHA, 1992). A minimum of 100 individuals were counted for the phytoplankton with a minimum of 80% efficiency (Pappas & Stoermer, 1996).

Water samples with a Van Dorn-type bottle were also taken to analyze pigments (chlorophyll a and pheopigments), total nitrogen, total phosphorus, and solids (total, dissolved and suspended) (APHA, 1992).

Data were submited to descriptive statistics analysis of variance (ANOVA) and correlation analysis (Zar, 1974).

Results

Physical and chemical regime in the lake

The water temperature presented a unimodal behavior (Tab.I). The maximum values were obtained in summer, while the smallest values were recorded in the winter of the same year, together with the greatest variation. Smaller deviations were found in autumn.

Conductivity was higher during autumn, especially at the North sampling station (Tab.I). The lowest values were recorded in summer, especially in the South sampling station. The largest standard deviation (7.02) occurred at the North of Itapeva Lake during winter. During spring, the oxygen values were very high, above saturation at the South (Tab.I). During this period a constant change occurred in wind direction, which caused pulses of turbulence in the system and oxygen transfer to the mass of water (Tab.II). The smallest deviations were recorded during the autumn.

The pH did not fluctuate much (7.2 to 8.4), throughout the period, and was slightly alkaline (Tab.I). The smallest deviations occurred during the autumn-winter period, while the highest occurred during spring-summer, which might be related to higher primary production (Cardoso, 2001).

The oxi-reduction potential showed that the North usually behaves as a reducing environment, due to the constant negative values, in contrast with the two other sampling stations, which behave as an oxidizing environment (Tab.I). Extreme values (maximum values in each sampling period) were recorded during the winter for the North (negative values) and Center (positive values) sampling stations. The shape of the lake, associated with the circulation pattern, should influence this behavior. Water circulation is restricted in the northern region of the Lake Itapeva (Lopardo, 2002).

Table I: Values of the data obtained by high frequency monitoring at each sampling station in Itapeva Lake, south of Brazil. (N=North, C= Center, S= South)

Variables	**Descriptive**	**SPRING**			**SUMMER**			**AUTUMN**			**WINTER**		
	analysis	N	C	S	N	C	S	N	C	S	N	C	S
	Minimum	21,3	20,5	21,0	26,8	25,9	26,0	13,4	14,1	14,4	10,2	10,7	11,7
Temperature	Mean	23,8	22,9	22,9	29,1	28,4	28,3	15,7	15,6	15,4	12,8	13,0	13,1
(^{o}C)	Maximum	25,4	24,5	24,9	31,6	31,0	31,6	16,8	17,1	16,6	16,1	15,7	15,4
	Stand. Deviation	1,1	1,1	1,1	1,2	1,3	1,5	0,9	0,7	0,6	1,5	1,3	1,0
	Minimum	51,0	46,8	48,0	46,8	—	40,4	110,9	110,0	105,0	138,7	—	109,4
Conductivity	Mean	55,3	52,2	53,2	50,1	—	42,1	122,8	116,5	108,1	126,0	—	103,2
(S.cm^{-1})	Maximum	60,0	57,4	57,0	53,7	—	45,4	129,5	121,9	111,0	156,9	—	117,0
	Stand. Deviation	2,1	2,4	2,0	1,4	—	1,1	3,7	2,9	1,6	7,0	—	3,8
	Minimum	72,5	109,7	142,7	100,8	94,4	97,6	107,5	73,2	96,2	89,8	100,6	100,8
DO	Mean	90,2	117,3	157,2	108,9	99,4	102,1	110,3	76,3	98,5	113,6	116,8	103,7
(%)	Maximum	98,6	124,6	164,6	118,7	105,4	111,8	113,6	79,3	101,9	134,0	130,0	105,8
	Stand. Deviation	6,2	4,5	5,0	4,3	3,1	3,1	1,4	1,4	1,4	11,2	10,8	1,3
	Minimum	6,2	9,2	11,8	6,5	7,6	6,6	10,7	7,4	9,6	9,2	10,0	9,7
DO	Mean	7,6	9,8	13,5	7,1	8,4	6,9	11,0	7,6	9,8	11,6	11,9	10,3
(mg.L^{-1})	Maximum	8,2	10,4	14,1	7,7	9,4	7,3	11,6	8,1	10,1	12,8	13,3	10,7
	Stand. Deviation	0,5	0,4	0,5	0,3	0,6	0,2	0,2	0,1	0,1	1,0	1,1	0,3
	Minimum	7,3	7,6	7,2	7,5	7,8	7,6	7,3	8,0	7,5	7,4	8,0	7,3
pH	Mean	7,5	7,7	7,4	7,8	8,0	7,8	7,4	8,1	7,6	7,6	8,1	7,4
	Maximum	7,8	8,0	7,6	8,2	8,2	8,3	7,5	8,4	7,8	7,6	8,2	7,5
	Stand. Deviation	0,11	0,09	0,10	0,14	0,11	0,15	0,05	0,07	0,07	0,04	0,06	0,03
	Minimum	-60,7	208,3	91,6	-143,9	288,3	149,2	-161,9	273,7	232,3	-222,9	317,8	242,6
ORP	Mean	-29,6	274,5	188,4	-133,8	361,3	216,1	-139,2	346,1	274,6	-166,2	380,4	301,9
(mV)	Maximum	-0,1	302,8	284,4	-121,6	400,3	263,7	-118,3	368,8	308,1	-123,1	405,6	339,6
	Stand. Deviation	17,0	22,1	74,1	6,3	29,9	30,2	10,4	20,0	21,5	42,0	21,2	32,0
	Minimum	48,4	65,9		41,4	44,0	56,7	143,2	61,2	74,0	162,1	102,5	109,7
Turbidity	Mean	99,2	208,2		55,4	83,9	103,1	221,5	115,2	138,3	276,6	206,4	207,7
(NTU)	Maximum	197,7	520,8		86,6	132,2	148,4	528,1	229,8	231,5	525,5	490,7	327,3
	Stand. Deviation	40,7	127,1		11,7	23,2	22,9	76,0	38,4	35,0	95,9	91,1	47,3

Higher turbidity values were recorded at the North station during autumn-winter/99, coinciding with the arrival of a cold front in the region (Tab.I). In these cold seasons, a period of predominant winds from the W-SW quadrant was characteristic (Cardoso & Motta Marques, 2003; Cardoso et al., 2003), and their effect was felt more intensely at this sampling station due to the effective fetch effect (Cardoso, 2001). At the same station, in the summer, the turbidity was lower for the same reason, with predominant winds from the NE-E quadrant (Cardoso & Motta Marques, 2003; Cardoso et al., 2003) during the period, and no turbulence was caused at this location. Thus, turbidity was the most appropriate response variable for the effect of hydrodynamics controlled by the wind at Itapeva Lake.

The air temperature values presented the same unimodal behavior as regards water temperature, i.e., higher in summer and lower in winter (Tab.II). However, the greatest deviations were found in winter and the smallest in summer, as the opposite.

As to wind velocity, the highest mean values (V_{med} e V_{max}) were very close, both in spring and in winter (Tab.II). The highest maximum values as well as the largest deviations were obtained in autumn. This fact was related to the arrival of a severe cold front, from quadrants SW-W. The summer was characterized as the most stable season of the year, due to the lowest values, as well as the smallest deviations.

Precipitation was heaviest during the winter, as is characteristic of this region, but in summer the maximum recorded occurred due to passing storms.

Spring was the season during which the greatest range of variation occurred (highest standard deviation), winds from the NNE and W quadrants being the most frequent (Tab.II).

However, in summer the winds were characteristics of the coast, fluctuating only between the N and E quadrants, the smallest range of variation being observed between the campaigns.

Table II: Maximum (T_{Max}) and minimum (T_{Min}) temperatures (in ^oC), mean (V_{med}) and maximun (V_{max}) wind velocity (in $m.s^{-1}$), wind direction (Dir) and precipitation (P in mm) in Itapeva Lake, south of Brazil during the study period.

Seasons	descriptive analysis	T max (°C)	T min (°C)	V med ($m.s^{-1}$)	V max ($m.s^{-1}$)	Dir *	P (mm)
Spring	Mean	23.0	22.3	5.7	8.7	155.0	0.0
	Minimum	18.8	18.3	0.4	1.8	0.0	0.0
	Maximum	33.5	29.2	12.5	17.9	315.0	2.8
	Stand. Deviation	2.2	2.0	2.4	3.7	104.9	0.2
Summer	Mean	27.0	26.3	5.2	7.0	44.0	0.0
	Minimum	22.4	21.7	0.9	1.8	0.0	0.0
	Maximum	32.6	31.9	8.5	12.1	90.0	5.2
	Stand. Deviation	2.0	1.9	1.7	2.2	24.8	0.3
Autumn	Mean	15.7	15.1	4.9	7.3	187.0	0.1
	Minimum	11.6	11.0	0.0	0.0	0.0	0.0
	Maximum	24.9	20.7	15.6	23.2	315.0	3.6
	Stand. Deviation	2.1	1.9	3.4	5.0	90.0	0.4
Winter	Mean	12.8	12.3	5.9	8.5	163.8	0.1
	Minimum	8.6	8.1	0.0	0.0	22.5	0.0
	Maximum	19.6	19.1	11.6	17.4	315.0	2.6
	Stand. Deviation	2.5	2.4	3.0	4.2	98.8	0.3

Anabaena species densities

The density of *Anabaena circinalis*, both at the level of $cel.mL^{-1}$ and $ind.mL^{-1}$, was higher when compared to *A. spiroides*, for the whole period (Fig.1). However, the ratio between the number of cells and number of individuals (cel:ind) was always higher for *A. spiroides*, showing that the filaments of this species were larger. For *A. circinalis*, the highest values in the ratio cel:ind were found at the Center sampling station during the autumn.

Blooms of both species were found independent by the season of the year. The maximum values recorded for both species occurred in autumn, a period in which blooms developed in the 3 regions of the lake (Fig. 1). The density used to define a bloom was a minimum of 2,000 $cel.mL^{-1}$ (Chorus & Bartram, 1999). During spring and winter blooms of *Anabaena circinalis* e *A. spiroides* were recorded only at the North.

In autumn it was found that the mean values of *A. circinalis* were higher in the Center (8,0401 $cel.mL^{-1}$; 1,397 $ind.mL^{-1}$) and in the South (65,804 $cel.mL^{-1}$; 2,586 $ind.mL^{-1}$), while for *A. spiroides*, they were higher in the North (10,062 $cel.mL^{-1}$; 110 $ind.mL^{-1}$) and in the South (7,447 $cel.mL^{-1}$; 290 $ind.mL^{-1}$). However, the maximum peaks as compared with the number of cells often occurred in the North for both species, while in the South the maximum peaks occurred for number of individuals. This shows the tendency to a spatial gradient in terms of density; in the South there were more individuals/filaments, but smaller in size (number of cells), the opposite occurring towards the North. The ratio that exists between number of cells per number of individuals (cel:ind.) were almost always higher in the Center, showing that at this place the filaments were larger as compared to the other lake regions for both species. However, for *A. spiroides* the North was much closer to the Center regarding distribution .

Both species presented a clear seasonal behavior regarding size of the filament, these being larger in summer and autumn. During these seasons, the bloom was also more homogeneous spatially and temporally in Itapeva Lake.

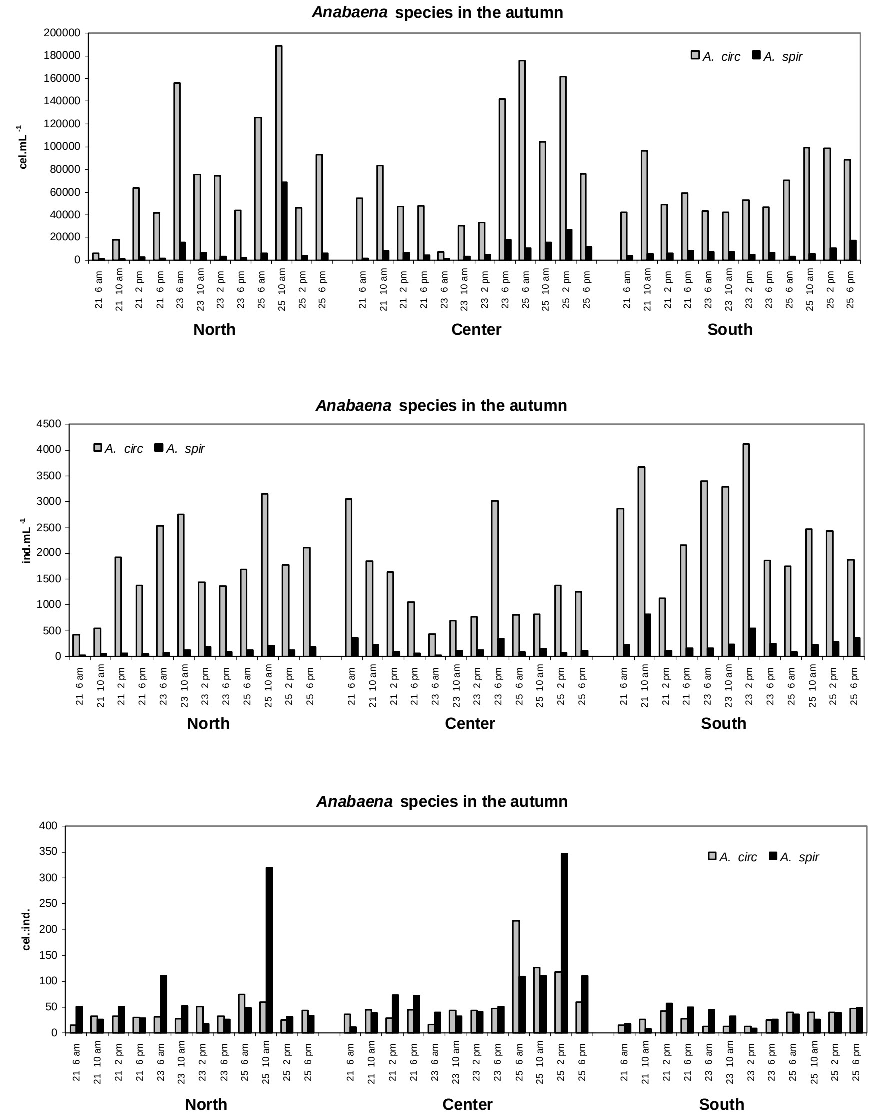

Figure 1: Daily variation of the density of *A. circinalis* (*A. circ*) and *A. spiroides* (*A. spir*) at the sampling stations in Itapeva Lake during the autumn (May/1999).

Anabaena **species and the wind**

The correlation matrix for the autumn data showed significant and positive relations between both species (*Anabaena circinalis* e *A. spiroides*), both at a level of the number of cells and as to individuals. These same relations, but more intense and slightly superior, were also clear in the general data from the campaigns.

Comparing the density curves of *Anabaena circinalis* to the wind curves (Fig.2), it is found that the bloom peaks were more intense at the North, coinciding with the decrease of wind velocity. This effect of wind reduction had an immediate response, since the wind direction in the SW-WSW quadrant clearly disturbed the North region, with an effective fetch of almost 20 km (Cardoso, 2001). Thus, under strong pressure due to hydrodynamics, driven by wind action, the phytoplankton community, and, in particular *Anabaena* species responded immediately. The density pulses at the Center preceded and proceeded the 2nd peak in the North, precisely at the time when wind direction changed to opposite quadrants (NE-SW-NE) (Fig.2). The phytoplanktonic community, and in particular *Anabaena* species, responded immediately to lake hydrodynamic driven by wind action (Fig.2).

The density pulses at the Center preceded and proceeded the 2nd peak in the North, precisely at the times when wind direction changed to opposite quadrants (NE-SW-NE). This fact highlights that although the Center is not located at a geographically central position in the lake, this sampling station acts as the central axis in the hydrodynamics of this lake based on predominant winds. Small fluctuations occurred at the South, showing that here the bloom was more homogeneous. For *A. spiroides* the density pulses taking the wind into account were also the same exhibited by *A. circinalis*, but on a smaller scale (Fig.2).

During the largest bloom period (autumn), few significant correlations were found between the *Anabaena* species and the environmental variables. The density expressed as number of cells of *A. circinalis* was negatively correlated with the mean wind velocity (*r*= -0.34) and total solids (*r*= -0.36), positively with chlorophyll *a* (*r*= 0.34). The values of *A. circinalis* ratios in cel.ind.$^{-1}$ were correlated with dissolved oxygen (*r*= -0.38) and pH (*r*=

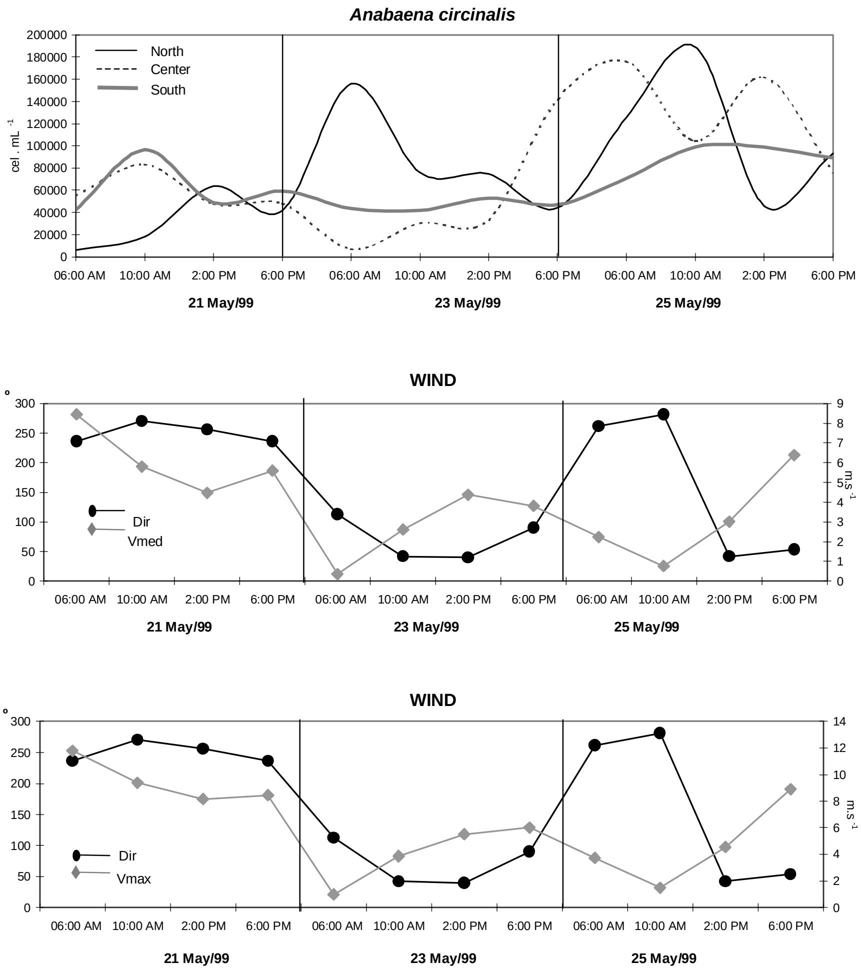

Figure 2: Density of *A. circinalis* at the sampling stations in Itapeva Lake during the autumn, and their relationships with the wind.

0.36). For *A. spiroides* the density in number of cells only presented positive correlation with chlorophyll *a* (*r*= 0.48). The values of *A. spiroides* ratios in cel.ind.$^{-1}$ were correlated with dissolved solids (*r*= 0.48).

The analysis of variance (ANOVA) "three-way" (repeated measures for the sampling stations and seasons) was carried out in order to identify the spatial and temporal variability.

Horizontal spatial variation, for factor time (day, shift, and seasonal sampling), of *Anabaena circinalis,* was significant for density in cels.mL^{-1}($p < 0.05$) and ind.mL^{-1} ($p < 0.01$). A significant ($p < 0.01$) spatial variation was observed for the ratio cels:ind^{-1} in a temporal scale (day and month). For *Anabaena spiroides,* the horizontal spatial variation was always extremely significant ($p < 0.001$) expressed in cel.mL^{-1}; ind.mL^{-1} and cel:ind^{-1}, for all time scales tested. The seasonal temporal variation was extremely significant ($p < 0.001$) for both *Anabaena circinalis* and *Anabaena spiroides* for any density parameter (cel.mL^{-1}; ind.mL^{-1} and cel:ind^{-1}).

For both *Anabaena* species, the horizontal variation was significant ($p < 0.05$) for density and ratio cel:ind^{-1} under an intense bloom (autumn), showing a spatial variability. Temporal variation between sampling days was significant ($p < 0.01$) for *A. circinalis* (cel.mL^{-1} and ratio cel:ind^{-1}), showing the bloom cycle (start, climax, and decline) in Lake Itapeva.

Discussion

Although changes in the cell mass and vertical migration have been well documented in many plankton cyanobacteria that form blooms, the additional influence of rapid changes in the size of the biomass unit is much less well documented (Brookes et al., 1999). Smith & Gilbert (1995) observed seasonal changes in the length of the filament of *Anabaena*; although it has not been documented quantitatively. According to the results on the relationship of nr. of cells/nr. of individuals, both species presented a clear seasonal behavior as regards size of the filament, these being larger in summer and autumn. During these seasons, the bloom was also more homogeneous spatially and temporally (day and time of sampling) in Itapeva Lake. The constant wind direction during summer, together with the low velocity, and increasing reduction of velocity during autumn were factors that explained the spatial and temporal homogeneity.

Larger filaments of *A. circinalis* at the Center appear to be related to changes in wind direction. This was due to change from quadrants SW and NE and create a greater disturbance at the North and South, respectively, due to the fetch effect. With the wind direction, the Center functions as the axis of inclination of the lake water level and is disturbed on a smaller scale and presents a smaller fetch (Cardoso, 2001)

In spring and in winter the fluctuations of mean and maximum wind velocities were rather similar (Cardoso & Motta Marques, 2003; Cardoso et al., 2003). In summer, small fluctuations occurred in the daily cycle (7 m.s^{-1}). However, a peak was recorded in autumn, one day before the sampling of the physicochemical and biological parameters began. Probably winds of this magnitude promote a strong resuspension of the bottom sediment into the water column (Håkanson, 1981). Later, a period of decline in wind velocity was observed (Cardoso & Motta Marques, 2003; Cardoso et al., 2003) may have provided favorable conditions for the development of *Anabaena* blooms.

Comparing the mean values in autumn to the whole study period at Itapeva Lake, it was found that more than 70% of the density of both species of *Anabaena* was recorded during the bloom. Conductivity, oxi-reduction potential, turbidity and solid matter increased to increasing density of *Anabaena*. On the other hand, temperature and wind velocity were lower. The bloom was established when temperatures were low, wind velocity had been reduced and conductivity was higher (íons and dissolved solids). The largest standard deviation of pH (7.02) occurred at the North (Tab.I) during winter, and was related to the *A. circinalis* blooms, only at this station and period. The high turbidity occurred due to the greater amount of suspended algae. During the period of the arrival of the cold fronts, wind pulses cause a resuspension of sediments that affect the turbidity (Cardoso & Motta Marques, 2003; Cardoso et al., 2003).

Foam lines expected to be equally spaced at a distance equal to twice the depth of the water column (Kjerfve & Magill, 1989). Signs of this type of convection were observed in Itapeva Lake when the winds had a constant direction and velocities for a given shift of the day (Cardoso, 2001).

The direct relationship to chlorophyll a and inverse relationship to the mean wind velocity and total solids were extremely significant. Both species (*Anabaena circinalis* e *A. spiroides*), were negatively related to wind and positively related to conductivity, dissolved oxygen, solids, N:P ratio, pigments. Relative abundance of cyanobacteria in Itapeva was positively related to temperature, pH, and TP; and negatively associated to light, mixture, nitrate and TN:TP ratio.

During the intense bloom period (May/99) for both species of *Anabaena,* the horizontal variation was significant, except for density expressed in number of cells. Thus the bloom was quite spatially homogeneous, in Itapeva Lake during the autumn.

The *Anabaena* species are closely related and occur commonly in Brazilian freshwaters environments (Torgan, 1989; Sant'Anna & Azevedo, 2000a, 2000b). *A. circinalis* blooms occur commonly by in some lakes on the Rio Grande do Sul State coast (Kleerekper, 1990) and were recorded for the Tramandaí and Armazém Lagoons, in the spring of 1976 and 1997; for Patos Lagoon in the winter of 1985, and Zoo Park in spring and summer 1988; while blooms of *A. spiroides* var. *crassa* were recorded for the Caí River, in the summer of 1987, for Ernestina Dam in the winter 1984, and for the Guaíba Lake in the summer of 1983 (Torgan, 1989). The development of blooms of the two *Anabaena* species in Itapeva Lake, especially during the autumn, is the recorded for the first time, both for this body of water and for this season of the year in the state of Rio Grande do Sul.

Beside the effect of wind velocity, wind direction interferes in bloom development. Oderbrecht et al. (1987) found high spatial and temporal variations in the concentration of chlorophyll a in the northern area of the Patos Lagoon, during the summer 1986. The variations are a consequence of Langmuir-type convection cells, with cyanobacteria concentration, especially *Microcystis*, on the surface of long strips parallel to the wind direction. In the strips, a concentration of chlorophyll a up to 1,976 $mg.L^{-1}$ was found. The duration of events caused by wind action interfere in the water column mixing and, are an important factor for the growth and seasonal variations of *Microcystis* in Patos Lagoon.

The occurrence of *A. spiroides* was recorded for the estuary of the Patos Lagoon between January and May, 1998, reaching up to $32.5.L^{-1}$ filaments in April (Ferreira et al., 1999). The bloom of this species recorded in Itapeva Lake was much larger (820 $ind.mL^{-1}$). *A. circinalis* was recorded in the summer months in Pinguela Lake, with 109 and 70 $ind.mL^{-1}$ (Salomoni, 1997). All these lakes belong to the North Tramandaí Lagoonal Subsystem. However, in Itapeva Lake, the bloom presented higher cells densities (mean of 1,915 and mL^{-1} and maximum of 4,116 $ind.mL^{-1}$).

At Juturnaíba (Huszar et al., 2000) the maximum biomass during the autumn was of *Cylindrospermopsis philippinensis* (Taylor) Komárek and *Anabaena spiroides* Klebahn with 46 and 4% of the total biomass, respectively. In Itapeva Lake, *Anabaena circinalis* presented higher values of biomass (by biovolume) between 13 $mg.L^{-1}$ and 51 $mg.L^{-1}$ (Becker, 2002). In autumn of 1999, the densities and the biomass of the phytoplanktonic community in the sampling stations were positively correlated and was due to a spatial homogeneity of the *A. circinalis* blooms, enclosing all lake extension (Becker, 2002).

High correlations were found between heterocytic cyanobacteria and TN (r= 0.66), reactive soluble silica (r= 0.47), pH (r= 0.25), temperature (r= 0.24), TP (r= 0.24) and nitrate (r= -0.28) (Huszar et al., 2000). Except for the pH and mixing factors (wind and total solids), the other correlations recorded did not agree with the present study. In Huszar et al. (2000), all species of heterocytic cyanobacteria of the 8 environments studied, were grouped together (density data percentage wise), to then show the correlations with the environmental variables. The dominance of nitrogen-fixing cyanobacteria is supposed to be favored among other factors, for their ability to develop in nitrogen-deficient systems (Huszar et al., 2000). This factor is probably important in Itapeva Lake, an environment characterized by a total nitrogen concentration between 0.28 and 3.36 $mg.L^{-1}$ (Cardoso, 2001).

Reynolds & Petersen (2000) showed a positive correlation between the appearance of cyanobacteria blooms and the lakes trophic gradient. The trophic state may be seen simply as a function of the availability of phosphorus. This relationship was not found in this study, since the available phosphorus values (available phosphate) was mostly not detectable. The fast uptake by phytoplankton probably induces non-linear relation between algae density and TP. Itapeva Lake is considered an eutrophic lake due to TP concentration (mean 0.28 mg.L^{-1}, in autumn; 0.66 mg.L^{-1}, in spring). However, no significant relation was observed between TP and algae density. In some systems other factors may be at play, such as wind driven hydrodynamics under shallow conditions leading to nutrients resuspention.

The main factors inducing cyanobacteria growth of are: rainfall by the entry of nutrients via runoff and percolation in the drainage basin; water circulation that favor the resurgence of nutrients and the transport of littoral algae to open water; senescence of algae (especially *Chlorococcales* and *Zygnemaphyceae*) which increase nutrient availability in the water column; and high concentrations of nutrients during the driest season (Beyruth, 2000). Usually, algal blooms are found in association with increased nutrient load, enrichment from agriculture, industry and urban stormwater runoff, both in freshwater environments and in marine waters (Kneale & Howard, 1997). In Itapeva Lake, the increased nutrient concentration was probably related to the high wind velocity recorded one day before the autumn bloom due to a strong resuspension of the bottom material due to the shallow water column, increasing turbidity and total solids, especially in the North region, under the strong effect of the fetch from the SW (Cardoso et al., 2003; Cardoso & Motta Marques, 2003).

Cyanobacteria often become dominant at the end of autumn in eutrophic shallow lakes. This phenomenon was not been recorded for Itapeva Lake and, consequently, the growth of plankton populations apparently does not depend on the simultaneous amount of nutrient and its proportions in the lake water. Instead it is determined by nutrients status in the sediment and the physical conditions that affected germination (Padisák & Dokulil, 1994). However, Itapeva Lake is not an eutrophic environment and it is characterized as a shallow lake in which the essential nutrients for phytoplankton growth are probably also stored in the sediment. This may explain the absence of correlation between water nutrients content and algae density under bloom conditions.

The occurrence of a high density of Cyanobacteria is related to stable environments (Talling, 1986). However, the highest concentration of cyanobacteria recorded in Brazilian environments was in Lago de Fora, an environment highly turbulent. Turbulence did not limiting to the development of cyanobacteria, and for the probably other environmental variable, such as wastewater organic matter, may be a key factor. The short time of residence, in Lago de Fora, may be limits the development of organisms with a larger cellular volume, favoring those with the smallest biomass and shortest duplication time. This is probably reason why the bloom in Lago de Fora was formed by the small Chroococales-cyanobacteria *Synecocystis aquatilis* (Domingos, 1991).

The available information about the influence of environmental variables (e.g. nutrients, wind), on the development of cyanobacteria blooms, should not be generalized too early, but requires full investigations of the species and systems system involved. Since cyanobacteria species may have different physiological characteristics this will probably be another factor contributing to variations observed in bloom development.

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