Development of Anabaena Bory ex Bornet & Flahault (Cyanobacteria) blooms in a shallow, subtropical lake in southern Brazil.

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ABSTRACT: Development of Anabaena Bory ex Bornet & Flahault (Cyanobacteria) blooms in a shallow, subtropical lake in southern Brazil. Cyanobacteria have a number of special properties that states their relative importance in phytoplankton communities. Some species of cyanobacteria produce toxins and their blooms can cause the death of aquatic organisms and even humans. Species of cyanobacteria respond differently to environmental fluctuations in each habitat. The main goal of this paper was to record the occurrence of Anabaena circinalis and A. spiroides blooms in Itapeva Lake, as well as some factors involved in forming these blooms. Anabaena circinalis and Anabaena spiroides blooms were identified at Itapeva Lake during the period from December 1998 to August 1999, the former species blooming more intensely (duration and density) than the latter. Blooms of both species were found independent of the season of the year. Maximum density values recorded for both species occurred in autumn (May/99), a period in which blooms were recorded at three different regions of the lake. It should be stressed that the density used to consider the bloom was a minimum of 2,000 cel.mL^{-1}. The maximum bloom was preceded by an event of strong turbulence in the system, which made nutrients available and the cyanobacteria spores stored in the sediment were dispersed into the water column. The remaining time of the study period was characterized by a progressive 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 ex Bornet & Flahault (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 foi registrar a ocorrência de florações das espécies de Anabaena (A. circinalis e A. spiroides) na lagoa Itapeva, bem como alguns dos 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 de densidades 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 para considerar uma floração foi de um mínimo de 2,000 cel.mL^{-1}. O pico da floração foi precedido por um evento com forte turbulência no sistema, que eventualmente disponibilizou nutrientes e/ou dispersou os esporos destas espécies armazenados no sedimento para a coluna da água. Os restantes do período estudado 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 intensified, especially concerning "water quality" aspects. Some species of cyanobacteria produce toxins and their blooms can cause the death of aquatic organisms or even humans, 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 are due to a combination of physical factors such as the intensity of thermal stratification and the ability of these organisms to regulate their cell density (Oliver, 1994). Such blooms, particularly from the genera Microcystis and Anabaena, have caused problems that frequently result in the deterioration of "water quality", with adverse effects on lake ecology, livestock, water supply and recreational activities. (Sigee et al., 1999).

The genus Anabaena occurs in freshwater, and 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). Anabaena is among a number of cyanobacteria that present gas vacuoles (aerotope) and form dense populations on the surface of lakes and reservoirs, the so-called blooms. The blooms cause serious problems due to their appearance, the probability of deoxygenation, unpleasant odoriferous substances and the frequent formation of toxins (Whitton, 1992). When considering what constitutes a bloom, 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 it to be considered a harmful bloom, i.e., a risk to humans and populations in the environment (Chorus & Bartram, 1999). For the Anabaena species, Jones & Korth (1995) consider that even at concentrations below 1,000 $cels.mL^{1}$, a strong smell of geosmine is emitted, which would characterize a level of bloom in the sanitary aspect.

Concrete proof of the growing importance of these plankton organisms in "water quality" can be seen in the Administrative Ruling no. 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 $mg.L^{1}$) goes well beyond the limits mentioned in the bibliography of World Health Organization (WHO) (Chorus & Bartram, 1999). In accordance with this law, cyanobacteria monitoring in source waters at the intake station is done at a monthly frequency, when the number of cyanobacteria is no 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 short residence time, the cyanobacteria blooms disappear and are replaced with diatoms (Tundisi, 1990). Sites where stagnation characteristics predominate at times during the year generally suffer the isolated impact of the harmful Anabaena species (Yunes, 1999). Lakes generally have longer water retention times in comparison to rivers and, by their nature, tend to accumulate sediments along with the chemicals associated to them. Therefore, sediments act as sinks for important nutrients such as phosphorus. However, under changing conditions, sediments may also serve as an input source, delivering nutrients back into the water, where they stimulate the growth of cianobacteria and algae (Chorus & Bartram, 1999). Recent studies have highlighted the role of turbulence in algae blooms. It has been suggested that with a P concentration above 10 $mg.L^{1}$, the development of potentially bloom-forming cyanobacteria is 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 was to record the occurrence of Anabaena circinalis Rabenhorst ex Bonet & Flahault and Anabaena spiroides Klebbahn blooms at Itapeva Lake (Rio Grande do Sul) in southern Brazil, as well as the some factors involved in forming these blooms, including the hydrodynamic regime.

Material and methods

Itapeva Lake is a shallow, subtropical lake located in southern 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 a maximum depth of 2.5 m. A 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), and August 20-26, 1999 (winter).

A tower was installed in the 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 on 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 from 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 submitted 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). Maximum values were obtained in summer, whereas 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 in 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. In spring, oxygen values were very high, above saturation at the South station (Tab.I). During this period, a constant change in wind direction occurred, causing pulses of turbulence in the system and oxygen transfer to the mass of water (Tab. II). The smallest deviations were recorded in autumn.

The pH fluctuated little (7.2 to 8.4) throughout the period and was slightly alkaline (Tab. I). The smallest deviations occurred during the autumn-winter period, whereas the highest occurred during spring-summer. This could be related to higher primary production (Cardoso, 2001).

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

Variables	Descriptive analysis	SPRING N	SPRING C	SPRING S	SUMMER N	SUMMER C	SUMMER S	AUTUMN N	AUTUMN C	AUTUMN S	WINTER N	WINTER C	WINTER S
Temperature (^oC)	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
	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
	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
Conductivity ($mS.cm^{-1}$)	Minimum	51.0	46.8	48.0	46.8	—	40.4	110.9	110.0	105.0	138.7	—	109.4
	Mean	55.3	52.2	53.2	50.1	—	42.1	122.8	116.5	108.1	126.0	—	103.2
	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
DO (%)	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
	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
DO ($mg.L^{-1}$)	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
	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
	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
pH	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
	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
ORP (mV)	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
	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
	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
Turbidity (NTU)	Minimum	48.4	65.9		41.4	44.0	56.7	143.2	61.2	74.0	162.1	102.5	109.7
	Mean	99.2	208.2		55.4	83.9	103.1	221.5	115.2	138.3	276.6	206.4	207.7
	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

The oxi-reduction potential showed that the North usually behaves as a reducing environment due to the constant negative values. In contrast, the two other sampling stations behave as oxidizing environments (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, may influence this behavior. Water circulation is restricted in the northern region of the Itapeva Lake (Lopardo, 2002).

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 the colder seasons, a period of predominant winds from the W-SW quadrant was characteristic (Cardoso & Motta Marques, 2003; Cardoso et al., 2003), and these winds were felt more intensely at this sampling station due to the fetch effect (Cardoso, 2001). At the same station, turbidity was lower in the summer for the same reason, with predominant winds from the NE-E quadrant (Cardoso & Motta Marques, 2003; Cardoso et al., 2003) throughout 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 the 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 to wind velocity, the highest mean values (V_{med} and V_{max}) were very close in both spring and winter (Tab. II). The highest maximum values, along with the largest deviations, were obtained in autumn. This fact was related to the arrival of a severe cold front from quadrants SW-W. Due to both the lowest values and the smallest deviations, summer was characterized as the most stable season of the year.

Precipitation was heaviest in winter, as is characteristic of this region, but the maximum recorded precipitation occurred in summer 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, the winds in summer were characteristics of the coast, fluctuating only between the N and E quadrants, the smallest range of variation observed between the campaigns.

Table II: Maximum (T_{Max}) and minimum (T_{Min}) temperatures (in °C), mean (V_{med}) and maximum (V_{max}) wind velocity (in $m.s^{-1}$), wind direction (Dir) and precipitation (P in mm) in Itapeva Lake, southern Brazil throughout 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

* N=0°, NE=45°, E=90°, SE=135°, S=180°, SW=225°, W=270°, NW=315°, other intermediate values calculated from these values.

Densities of Anabaena species

The density of Anabaena circinalis, both at the level of $cel.mL^{-1}$ and $ind.mL^{-1}$, was higher in comparison to A. spiroides throughout the entire 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 accounted for in autumn at the Center sampling station.

Blooms of both species were found independent of 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 and A. spiroides were only recorded at the North station.

In autumn the mean values of A. circinalis were higher in the Center (80,401 $cel.mL^{-1}$; 1,397 $ind.mL^{-1}$) and in the South (65,804 $cel.mL^{-1}$; 2,586 $ind.mL^{-1}$) regions. For A. spiroides, mean values were higher in the North (10,062 $cel.mL^{-1}$; 110 $ind.mL^{-1}$) and in the South (7,447 $cel.mL^{-1}$; 290 $ind.mL^{-1}$) regions. However, maximum peaks comparing the number of cells often occurred in the North sampling station for both species, while in the South the maximum peaks occurred for number of individuals. This shows the tendency toward a spatial gradient in terms of density; there were more individuals/filaments in the South, but smaller in size (number of cells), with the opposite occurring in the North. The ratio between the number of cells by the number of individuals (cel:ind.) was generally higher in the Center, showing that the filaments were larger in this region of the lake in comparison to the other regions for both species. However, with A. spiroides, the North was much more similar to the Center in regards to distribution.

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

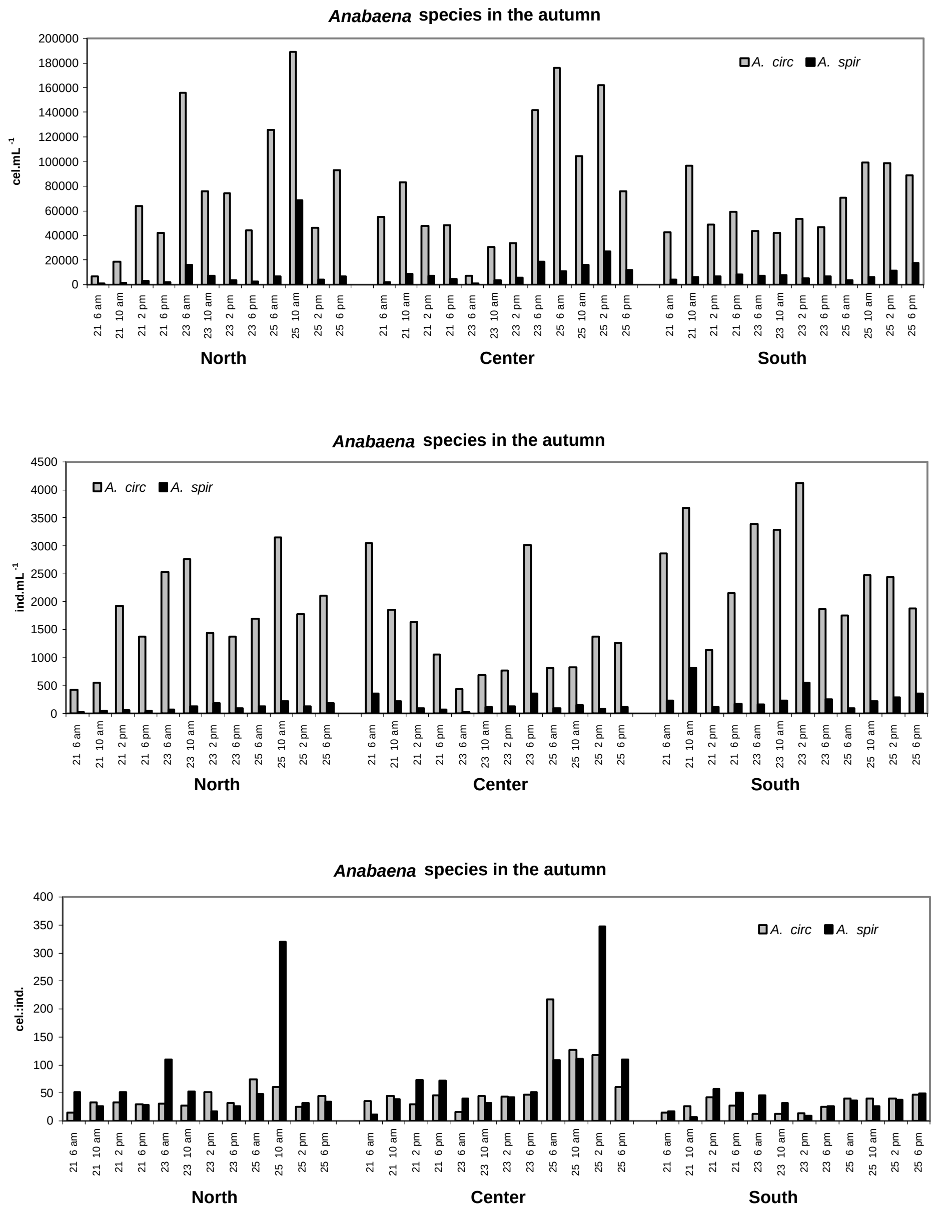

Figure 1: Daily variation of the density of A. circinalis (A. circ) and A. spiroides (A. spir) at Itapeva Lake sampling stations in autumn (May/1999).

Anabaena species and the wind

The correlation matrix for the autumn data showed significant and positive relations between the species (Anabaena circinalis and A. spiroides) both in regards to the number of cells and the number of individuals. These same relations were also evident in the general data from all the campaigns, though more intense and slightly higher.

Comparing the density curves of Anabaena circinalis to the wind curves (Fig.2), it was seen that the bloom peaks were more intense in the North region, coinciding with the decrease in wind velocity. This effect of reduced wind had an immediate response, as 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, particularly the Anabaena species, responded almost immediately. The density pulses at the Center station preceded the 2nd peak in the North, precisely at the time when wind direction changed to opposite quadrants (NE-SW-NE) (Fig.2). This highlights the fact that although the Center sampling station is not located at a geographically central position in the lake, this sampling station acts as the central fulcrum in the hydrodynamics of this lake based on predominant winds. Small fluctuations occurred at the South station, showing that here the bloom was more homogeneous. For A. spiroides, the density pulses taking the wind into account were the same as those exhibited by A. circinalis, though on a smaller scale (Fig.2).

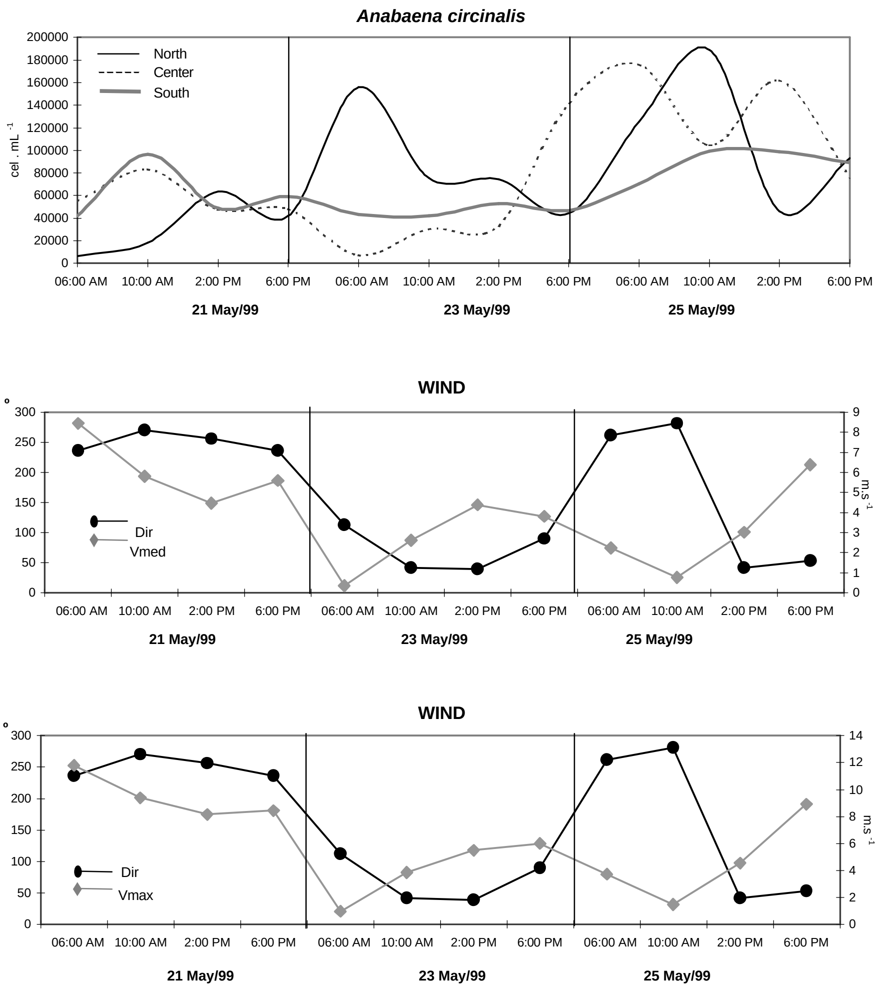

Figure 2: Density of A. circinalis at the sampling stations in Itapeva Lake during the autumn, and their relationships with the wind.

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 ($r= -0.36$), and positively correlated with chlorophyll a ($r= 0.34$). The values of A. circinalis ratio cel.ind.$^{-1}$ were correlated with dissolved oxygen ($r= -0.38$) and pH ($r= 0.36$). For A. spiroides, the density in number of cells only presented positive correlation with chlorophyll a ($r= 0.48$). The A. spiroides ratio cel.ind.$^{-1}$ values were correlated with dissolved solids ($r= 0.48$).

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 also significant ($p< 0.001$) for the density parameters of both Anabaena circinalis and Anabaena spiroides (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 Itapeva Lake.

Discussion

Although changes in cell mass and vertical migration have been well documented for many plankton cyanobacteria that form blooms, the additional influence of rapid changes in the size of the biomass unit is much less documented (Brookes et al., 1999). Smith & Gilbert (1995) observed seasonal changes in the length of the filament of Anabaena, but it has not yet been documented quantitatively. In this study, taking in account the results on the relationship of No. of cells/No. of individuals, both species presented a clear seasonal behavior in regards to filament size, which was larger in summer and autumn. During these seasons, the bloom was also more spatially and temporally homogeneous (day and time of sampling) in Itapeva Lake. The constant wind direction in summer, together with the low velocity and progressive reduction in velocity throughout autumn, explain such spatial and temporal homogeneity.

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

Fluctuations of mean and maximum wind velocities were rather similar in spring and winter (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 procedure of the sampling activity. It is likely that winds of this magnitude promote a strong re-suspension of the bottom sediment into the water column (Håkanson, 1981). Later, the period of decline in wind velocity observed (Cardoso & Motta Marques, 2003; Cardoso et al., 2003) may have provided favorable conditions for the development of the 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 are related to density of Anabaena. However, temperature and wind velocity were lower. The bloom was established when temperatures were low, wind velocity was reduced and conductivity was higher (ions and dissolved solids). The largest standard deviation pH (7.02) occurred at the North station (Tab. I) during winter, and was related to the

A. circinalis blooms only at this station and during this period. High turbidity occurred due to the greater amount of suspended matter. During the period of the arrival of cold fronts, wind pulses cause a re-suspension of sediments that affect turbidity (Cardoso & Motta Marques, 2003; Cardoso et al., 2003).

Foam lines are 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 during 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 and A. spiroides) were negatively related to wind and positively related to conductivity, dissolved oxygen, solids, N:P ratio, and pigments. Relative abundance of cyanobacteria in Itapeva Lake 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. This shows the bloom was quite spatially homogeneous at Itapeva Lake in autumn.

The Anabaena species are closely related and occur commonly in Brazilian freshwater environments (Torgan, 1989; Sant'Anna & Azevedo, 2000a, 2000b). Anabaena circinalis and A. spiroides have already been cited for Itapeva Lake by Werner (2002). A. circinalis blooms are common at lakes in the coastal state of Rio Grande do Sul State (Kleerekoper, 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 the 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 Lake Guaíba in the summer of 1983 (Torgan, 1989). The present study is the first record of the development of blooms of the two Anabaena species in Itapeva Lake, both for this body of water, and for this season of the year (autumn) in the state of Rio Grande do Sul.

Besides 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 proposed as a consequence of Langmuir-type convection cells, with cyanobacteria concentration, especially Microcystis, on the surface of long strips parallel to the direction of the wind. 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 at the 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 ind.L^{-1} 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 Lake Pinguela, with 109 and 70 ind.mL^{-1} (Salomoni, 1997). These lakes all belong to the North Tramandaí Lagoonal Subsystem. However, in Itapeva Lake, the bloom presented higher cell densities (mean of 1,915 ind.mL^{-1} and maximum of 4,116 ind.mL^{-1}).

At Juturnaíba 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 (Huszar et al., 2000). 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 1999, the densities and the biomass of the phytoplanktonic community in the sampling stations due to the homogenization of the A. circinalis blooms encompassing the entire extension of the lake (Becker, 2002).

In Huszar et al. (2000), all species of heterocytic cyanobacteria in the 8 environments studied were grouped together (density data percentage wise) to show the correlations with the environmental variables. Low 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), previously recorded correlations did not agree with the present study. The dominance of nitrogen-fixing cyanobacteria is supposed to be favored over other factors for their ability to develop in nitrogen-deficient systems (Huszar et al., 2000). This factor is probably important in Itapeva Lake, which is 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 trophic gradient of lakes. The trophic state may be seen simply as a function of the availability of phosphorus. This relationship was not found in the present study, as the reactive phosphorus concentration was mostly undetectable. The fast uptake by phytoplankton probably induces a non-linear relation between algae density and TP. Itapeva Lake is considered an eutrophic lake due to its 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 the re-suspension of nutrients.

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

Cyanobacteria often become dominant at the end of autumn in shallow eutrophic lakes. This phenomenon has not been recorded for Itapeva Lake and, consequently, the growth of plankton populations apparently does not depend on the simultaneous quantity of nutrients and their proportions in the lake water. Instead, it is determined by nutrients status in the sediment and the physical conditions that affect germination (Padisák & Dokulil, 1994). However, Itapeva Lake is not a eutrophic environment. 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 a correlation between water nutrient 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, which is a highly turbulent environment. Turbulence, however, did not limit the development of cyanobacteria in the present study. Thus, another environmental variable may be a key factor, e.g., as organic wastewater matter. The short time of residence at Lago de Fora may limit the development of organisms with a larger cellular volume, favoring those with a smaller biomass and shorter duplication time. This may be why the bloom at Lago de Fora was formed by the small Chroococales-cyanobacteria Synecocystis aquatilis (Domingos, 1991).

The available information regarding the influence of environmental variables (e.g. nutrients, wind) on the development of cyanobacteria blooms should not be generalized precipitously. Comprehensive investigations, including experimental, are required on the species and systems system involved. As different cyanobacteria species may have different physiological characteristics, this is likely to be another factor contributing to the variations observed in bloom development.

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