

Planktic Cyanobacteria in the Lower Uruguay River, South America

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Abstract: The Uruguay River is the second most important river in the Río de la Plata Basin. Taxonomical composition, abundance and distribution of cyanobacteria collected at nine sampling stations in the Lower Uruguay River (Uruguay) were analyzed seasonally from 2006 to 2009. A total of 24 taxa were identified, including 13 Chroococcales, 4 Oscillatoriales and 7 Nostocales species. The genera *Dolichospermum* and *Microcystis* presented the highest number of species among the planktic water bloom-forming cyanobacteria. The highest densities of cyanobacteria were recorded in summer during a bloom, with 6.2×10^6 cells.ml⁻¹, and the most abundant species were *Microcystis aeruginosa* and *Dolichospermum* cf. *pseudocompactum*. In this case, the toxicity analyses by HPLC did not indicate the presence of microcystin-LR. Phytoplankton growth in the Uruguay River was found not to be nutrient-limited. The high correlation of cyanobacteria densities with nitrogen and phosphorous compounds is directly related to changes in flow. Cyanobacteria densities increased with summer high temperatures in low flow conditions. The ANOSIM analysis showed no significant differences between zones and sampling sites, but there were temporal significant differences in relation to seasonal samplings. *Radiocystis fernandoi* KOMÁREK et KOMARKOVÁ-LEGNEROVÁ was recorded for the first time in Uruguay and *Dolichospermum* cf. *pseudocompactum* (WATANABE) WACKLIN et al. was recorded for the first time in South America.

Key words: Cyanobacteria, *Dolichospermum*, *Microcystis*, monitoring, phytoplankton, Uruguay River

Introduction

The Uruguay River belongs to the La Plata Basin and stretches over 1,800 km. Its lower part flows between two countries: Argentina and Uruguay. It is one of the largest rivers in South America and ends in the Río de la Plata Estuary. Based on historic values (1983–2003) (ECOMETRIX 2006), the river's average annual discharge is 6230 m³.s⁻¹. One of the main factors affecting the quality of water is the construction of more than twenty hydropower dams for attending the energy demand of the economic growth in the region. In particular, the Salto Grande Dam, located 300 Km upstream the river mouth, have an important regulatory effect over the discharges above and within the Río de la Plata Estuary. In recent years, other human activities, such as an increasing urbanization and the expansion of agriculture, together with climate variations, have modified

the flow, as well as the quality of the water in the whole basin, resulting in conditions that favor the proliferation of algal blooms (CARMICHAEL 1992; SMAYDA 1997). The occurrence of such blooms is a potential health hazard that jeopardizes the sources of water used as drinking water and for other purposes such as fishing and recreation (CHORUS & BARTRAM 1999).

Agriculture is an important activity in the Lower Uruguay River Basin with a significant production of citrus fruit and other crops. The most important Uruguayan city in the studied area is Fray Bentos, which is also an active port. The most important industry in the area is the paper mill UPM, devoted to the production of paper pulp since 2007.

The climate of the region is humid subtropical (BAILEY 1998) with a mean annual air temperature ranging between 16 °C and 17 °C, and

rainfalls regularly distributed over the year, with an average of $6230 \text{ m}^3 \cdot \text{s}^{-1}$ (ECOMETRIX 2006).

Several authors have conducted phytoplanktonic studies that include the cyanobacteria in Argentinean and Uruguayan rivers (BONILLA 1997; GARCÍA DE EMILIANI 1981, 1990; GÓMEZ & BAUER 1998; LACOSTE DE DIAZ 1961; O'FARRELL et al. 1996; ONNA 1978; PÉREZ et al. 1999; PÉREZ 2002; SCHIAFFINO 1977; SCHIAFFINO 1981; ZALOCAR DE DOMITROVIC 2005; ZALOCAR DE DOMITROVIC & FORASTIER 2005; ZALOCAR DE DOMITROVIC et al. 2007). However, the Lower Uruguay River has been scarcely studied (O'FARRELL & IZAGUIRRE 1994; QUIROS & LUCHINI 1982), and the Salto Grande Dam was studied only by DE LEÓN & CHALAR 2003 and CHALAR 2009.

In this study we report the composition, density and distribution of cyanobacteria from the Lower Uruguay River. Relations between cyanobacterial blooms and environmental variables in this river were also discussed.

Materials and Methods

Study area. The studied area comprises three zones along the Lower Uruguay River, which belong to the Department of Río Negro: Nuevo Berlín (NB), Fray Bentos (FB) and Las Cañas (LC). A transect line was drawn perpendicular to the coastline in each zone, between the Uruguayan coast and the river channel, establishing three sampling points: littoral, center and channel (Fig. 1).

Samplings. Twelve seasonal samplings on the Lower Uruguay River were carried out from July 2006 to May 2009 (Table 1). An extra sampling was performed in the summer 2008 (February 4th) as a result of an alert of algae blooms in the area. Conductivity, temperature and pH were measured *in situ* with a YSI 600R and a YSI 6600 V2 sensors and the transparency was estimated with a Secchi disc. Water samples were taken directly for nutrient analyses, in accordance with ISO Standard 5667–3. Phytoplankton samples were taken for qualitative testing using a 20- μm mesh plankton net, towing horizontally in the central point of the transect station. Samples were then fixed *in situ* with 2–3% formaldehyde. Phytoplankton for quantitative analyses were collected with water bottles at successive extractions from 2m depth to surface with a van Dorn bottle, trying to cover an integrated surface water; the samples were fixed with Lugol's solution (SOURNIA 1978).

Analyses. Physico-chemical water analyses were performed following relevant standards: Nitrates (ISO



Fig. 1. Study area of the Uruguay River and sampling zones: Nuevo Berlín, Fray Bentos and Las Cañas (black-white circles).

10304 / 1:1992), Nitrites (ISO 6777), ammonium (ISO 6778:1984), total nitrogen (ISO 11905–2, modified detection electrochemical cell), soluble phosphorus (ISO 6878) and Chlorophyll a (ISO 10260:1992).

The taxonomic identification was carried out with light microscopes (Olympus CX41 and Nikon Eclipse E800), using a 1000x magnification. The organisms were measured and photographed with a DXM 1200 digital camera. The counts were performed with an Olympus CKX41 inverted microscope, following the methodology described by UTERMÖHL (1958). Counts included at least 100 cells of the most abundant species, to yield a confidence interval of 95% with a counting error under 20% (LUND ET AL. 1958). In the case of *Microcystis* spp. bloom, the methodology employed followed Box (1981), counting the number of

Table 1. Average and standard deviations: SDV (*italic*) of the main parameters recorded in the nine sampling points in the Lower Uruguay River: NO₃⁻ Nitrite (mg.l⁻¹), Soluble Reactive Phosphorus SRP (μg.l⁻¹), chlorophyll Chl-*a* (μg.l⁻¹), Secchi disk–SD (cm), temperature T (°C), Conductivity K (μS.cm⁻¹), flow Q (m³.s⁻¹), euphotic zone Ez (cm) and Kd (m).

			NO3 (mg.l ⁻¹)	SRP (μg.l ⁻¹)	Chl a (μg.l ⁻¹)	SD (cm)	T (°C)	K (μS.cm ⁻¹)	Q (m ³ .s ⁻¹)	Ez (cm)	Kd (m)
2006	Jul	Mean	1.11	22.68	0.63	78.33	13.8	0.339	2078	188.0	2.4
		<i>SDV</i>	<i>0.26</i>	<i>15.25</i>	<i>0.28</i>	<i>7.50</i>	<i>0.8</i>	<i>0.01</i>	<i>654</i>	<i>18.0</i>	<i>0.2</i>
	Oct	Mean	0.37	22.62	1.63	50.56	23.9	0.054	4514	121.3	3.9
		<i>SDV</i>	<i>0.27</i>	<i>15.09</i>	<i>0.40</i>	<i>10.14</i>	<i>0.9</i>	<i>0.00</i>	<i>1686</i>	<i>24.3</i>	<i>0.6</i>
2007	Feb	Mean	1.22	69.49	1.09	65.00	27.8	0.059	2213	156.0	3.0
		<i>SDV</i>	<i>0.03</i>	<i>13.92</i>	<i>0.49</i>	<i>10.00</i>	<i>0.9</i>	<i>0.00</i>	<i>40</i>	<i>24.0</i>	<i>0.5</i>
	May	Mean	1.19	58.89	0.37	47.78	20.7	0.160	5538	114.6	4.4
		<i>SDV</i>	<i>0.16</i>	<i>26.71</i>	<i>0.10</i>	<i>14.81</i>	<i>1.6</i>	<i>0.23</i>	<i>1717</i>	<i>35.5</i>	<i>1.5</i>
2007	Aug	Mean	2.59	26.56	0.40	47.78	12.2	0.070	6366	114.6	4.1
		<i>SDV</i>	<i>1.16</i>	<i>6.77</i>	<i>0.15</i>	<i>9.72</i>	<i>0.3</i>	<i>0.00</i>	<i>1184</i>	<i>23.3</i>	<i>0.8</i>
	Nov	Mean	0.17	49.44	0.68	48.89	21.2	0.057	8018	117.3	4.0
		<i>SDV</i>	<i>0.50</i>	<i>24.22</i>	<i>0.33</i>	<i>7.82</i>	<i>0.5</i>	<i>0.00</i>	<i>239</i>	<i>18.7</i>	<i>0.6</i>
2008	Feb	Mean	0.06	17.37	41.55	101.11	27.9	0.067	2667	242.7	1.9
		<i>SDV</i>	<i>0.01</i>	<i>21.32</i>	<i>57.74</i>	<i>6.01</i>	<i>0.5</i>	<i>0.00</i>	<i>712</i>	<i>14.4</i>	<i>0.1</i>
	May	Mean	0.05	4.89	11.21	150.00	18.8	0.064	4176	360.0	1.3
		<i>SDV</i>	<i>0.01</i>	<i>14.67</i>	<i>28.14</i>	<i>10.00</i>	<i>0.6</i>	<i>0.00</i>	<i>260</i>	<i>24.0</i>	<i>0.1</i>
2008	Aug	Mean	1.26	11.66	0.10	47.78	12.2	0.070	4891	114.7	4.1
		<i>SDV</i>	<i>0.04</i>	<i>6.99</i>	<i>0.14</i>	<i>8.33</i>	<i>0.4</i>	<i>0.01</i>	<i>274</i>	<i>20.0</i>	<i>0.7</i>
	Nov	Mean	1.25	26.23	0.10	65.56	14.4	0.063	18461	157.3	2.9
		<i>SDV</i>	<i>0.09</i>	<i>23.02</i>	<i>0.09</i>	<i>5.27</i>	<i>0.4</i>	<i>0.00</i>	<i>400</i>	<i>12.6</i>	<i>0.2</i>
2009	Feb	Mean	0.79	11.47	1.37	101.11	26.1	0.069	799	242.7	1.9
		<i>SDV</i>	<i>0.20</i>	<i>6.42</i>	<i>0.57</i>	<i>6.01</i>	<i>1.1</i>	<i>0.01</i>	<i>116</i>	<i>14.4</i>	<i>0.0</i>
	May	Mean	0.66	9.33	0.18	96.67	19.9	0.072	535	232.0	2.0
		<i>SDV</i>	<i>0.06</i>	<i>0.00</i>	<i>0.24</i>	<i>5.00</i>	<i>0.7</i>	<i>0.00</i>	<i>15</i>	<i>12.0</i>	<i>0.1</i>
Period	Min		0.1	<28	0.03	30	11.6	0.046	522	72.0	0.0
	Max		1.0	101.0	185.0	160	28.8	0.362	18890	384.0	0.1
	Media		0.6	38.5	5.9	75	19.9	0.089	5021	178.9	0.0
		<i>SDV</i>	<i>0.2</i>	<i>25.4</i>	<i>22.8</i>	<i>31</i>	<i>5.7</i>	<i>0.076</i>	<i>4679</i>	<i>75.2</i>	<i>0.0</i>

cells per ml in a Sedgewick–Rafter gridded chamber.

A Draftsman Plot correlation analysis was performed to determine the environmental variables that would influence the dynamics of the seasonal variation, using Spearman's index for the correlation matrix. A one way ANOSIM analysis was performed to verify the spatial differences with the density matrix non parametric variances between the three points (litoral, center and channel) in the different zones (Nuevo Berlín, Fray Bentos and Las Cañas), and sampling month (time). Bray Curtis similarities were used with log transformed data. Statistical analyses

were performed with PRIMER 6 (CLARKE & GORLEY 2006).

Results

Environmental variables

The average monthly values of different parameters between 2006 and 2009 are showed in Table 1. Surface temperature varied seasonally, between 11.6 and 28.8 °C, the conductivity showed low

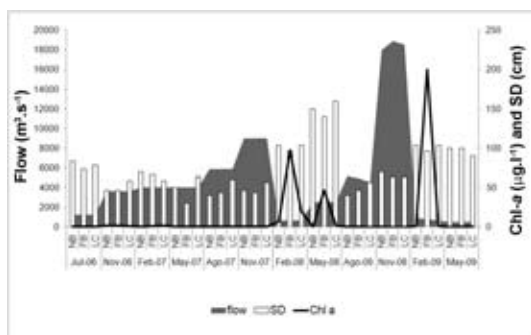


Fig. 2. Relationship between flow, Secchi disk and chlorophyll *a*, from July 2006 to May 2009 in the three zones: (NB) Nuevo Berlín; (FB) Fray Bentos; (LC) Las Cañas; (Chl-*a*) chlorophyll-*a*; (SD) Secchi disk.

variation along the three years (mean value 0.089 mS.cm^{-1}). The phosphate was maximum in the beginning of the studied period (92.4 µg.l^{-1}), but then its level decreased to undetectable values. The Redfield equation showed an N:P ratio under 16, ranging from 2.8 to 34.5 throughout the period, reaching a peak when inorganic nitrogen compounds increased to 1.4 mg.l^{-1} (average 8.6:1). Chlorophyll showed a peak in the summer of 2008 (185.0 µg.l^{-1}), related to a low flow ($2667 \text{ m}^3.\text{s}^{-1}$). The minimum flow was recorded in the autumn of 2008 ($533 \text{ m}^3.\text{s}^{-1}$), while the maximum flow ($18,890 \text{ m}^3.\text{s}^{-1}$) was observed in November of 2008. Fig. 2 shows the relationship between flow, transparency and chlorophyll *a*, from July 2006 to May 2009 in the three studied sites.

Cyanobacteria composition

Twenty four cyanobacteria taxa were recorded at the three studied sites. The highest species richness was found in Chroococcales, with 13 taxa, followed by 7 Nostocales and 4 Oscillatoriales. *Dolichospermum* and *Microcystis* were the genera with the highest number of species (Table 2). The highest species richness was found in February 2008 (10 species) and no taxa were found during the 2008 winter. *Radiocystis fernandoi* KOMÁREK et KOMÁRKOVÁ–LEGNEROVÁ and *Dolichospermum* cf. *pseudocompactum* (WATANABE) WACKLIN et al. reveals a national record for South America (Figs. 3 – 6). *Dolichospermum* cf. *pseudocompactum* presented the trichomes coiled very tightly, with diameters ranging from $7.6\text{--}8.3 \text{ µm}$, and often coiled in pairs, without any mucilaginous envelopes. Cells were generally spherical or barrel shaped, with $6\text{--}8 \text{ µm}$ long, spherical heterocytes with $12\text{--}15 \text{ µm}$ in diameter; one slightly ellipsoidal akinete (length 25 µm , width 10 µm in size) was

observed, although most of trichomes appeared without akinetes (Fig. 5 and Fig. 6).

Cyanobacteria abundance

The phytoplanktonic abundance reported in the monitoring sampling during the whole period of studied were $12.1 \times 10^3 \text{ cell.ml}^{-1}$ in Nuevo Berlín, $4.7 \times 10^3 \text{ cell.ml}^{-1}$ in Fray Bentos and $2.6 \times 10^3 \text{ cell.ml}^{-1}$ in Las Cañas. During summer of 2008 at the Fray Bentos station, a cyanobacteria bloom was reported. Total densities of cyanobacteria of $6.2 \times 10^6 \text{ cells.ml}^{-1}$ were recorded. *Microcystis aeruginosa*, *Microcystis wessenbergii*, *Dolichospermum circinale* and *Dolichospermum* cf. *pseudocompactum* were observed during the bloom, where *Microcystis aeruginosa* and *Dolichospermum* cf. *pseudocompactum* reach $5.7 \times 10^6 \text{ cells.ml}^{-1}$ and $4.2 \times 10^5 \text{ cells.ml}^{-1}$, respectively. In this bloom microcystin-LR were not quantified.

Relationship between cyanobacteria groups and environmental variables

A Draftsman Plot correlation determined a positive correlation between the density of cyanobacteria and temperature ($r = 0.4$) as well as with the euphotic zone ($r = 0.3$) and negative with flow ($r = -0.2$) all along the studied period. This correlations were higher when the analysis was carried out separately each year (temperature $r = 0.8$ and flow $r = -0.7$). The ANOSIM result between sampling (months) showed a marked seasonality: $R_{\text{global}} = 0.401$, $p < 0.001$. But it showed no spatial differences between points: $R_{\text{global}} = -0.014$, $p < 0.859$ and zones: $R_{\text{global}} = 0.023$, $p < 0.076$. Spring and winter were characterized by cryptophytes, while summer and autumn were characterized by cyanobacteria and diatoms.

Fig. 7 shows the relation between flow changes with euphotic zone, the main nutrients, temperature and pigment (Chl *a*) with the variation in phytoplankton density during August 2006 to May 2009. A negative relationship between flow and euphotic zone is shown. Phosphates and nitrates decreased from 2006 to 2009. Seasonal phytoplanktonic patterns were presented, with maximum density in summer (February 2008), due to the development of the biomass of cyanobacteria.

Discussion

In this study, water quality in lower Uruguay River was below limit values proposed by the guidance

Table 2. Presence of cyanobacteria taxa at the three zones at the Lower Uruguay River.

<i>Chroococcus</i> cf. <i>dispersus</i> (KEISSLER) LEMMERMANN
<i>Coelosphaerium</i> cf. <i>dubium</i> GRUNOW in RABENHORST
<i>Cuspidothrix issatschenkoi</i> group (USAČ.) RAJAN ET AL.
<i>Dolichospermum circinale</i> (RABENHORST ex BORNET et FLAHAULT) WACKLIN et al.
<i>Dolichospermum crassum</i> (LEMM.) WACKLIN et al.
<i>Dolichospermum flos-aquae</i> (LYNGBYE) WACKLIN et al.
<i>Dolichospermum planctonicum</i> (BRUNNTHALER) WACKLIN et al.
<i>Dolichospermum</i> .cf. <i>pseudocompactum</i> (WATANABE) WACKLIN et al.
<i>Dolichospermum viguieri</i> DENIS et FRÉMY
<i>Geitlerinema splendidum</i> (GREVILLE ex GOMONT) ANAGNOSTIDIS
<i>Merismopedia glauca</i> (EHREN.) NÄGELI
<i>Merismopedia tenuissima</i> LEMMERMANN
<i>Microcystis aeruginosa</i> (KÜTZING) KÜTZING
<i>Microcystis novacekii</i> (KOMÁREK) COMPÈRE
<i>Microcystis panniformis</i> KOMÁREK et al.
<i>Microcystis protocystis</i> CROW
<i>Microcystis wesenbergii</i> (KOMÁREK) KOMÁREK in KONDRATEVA
<i>Planktolynghya limnetica</i> (LEMMERMANN) KOMÁRKOVÁ–LEGNEROVÁ et CRONBERG
<i>Pseudanabaena catenata</i> LAUTERBORN
<i>Pseudanabaena mucicola</i> (NAUM. et HUB.–PEST.) SCHWABE
<i>Radiocystis fernandoi</i> KOMÁREK et KOMÁRKOVÁ–LEGNEROVÁ
<i>Snowella lacustris</i> (CHODAT) KOMÁREK et HINDÁK
<i>Sphaerocavum brasiliense</i> AZEVEDO et SANT' ANNA
<i>Woronichinia</i> sp.

for national legislation according to Digest of Quality by the binational Commission: Comisión Administradora del Río Uruguay (CARU 1988) and by the Decree 253/79 on the Water Code to prevent environmental pollution. An exception was total phosphorus which was above the limit ($> 25 \mu\text{g.l}^{-1}$) during the period 2006–2007; after that (2008–2009), values decreased until being undetectable.

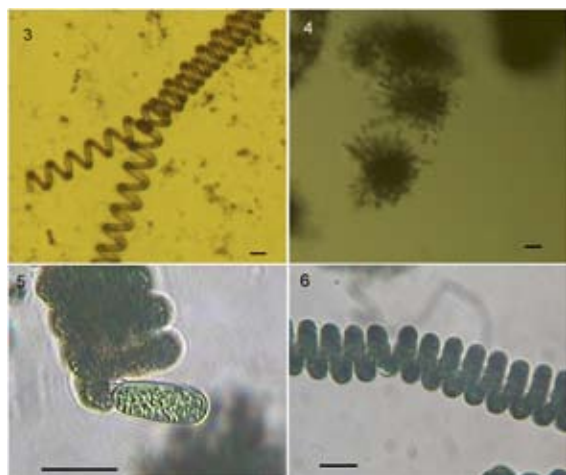
Previous studies in the 80's showed similar results, when nutrient values of phosphate were $< 2 - 14 \mu\text{g.l}^{-1}$ nitrate $0.8 - 2.0 \text{ mg.l}^{-1}$ in the region of Salto Grande (DI PERSIA & NEIFF 1986; QUIRÓS & CUCH 1981; QUIRÓS & LUCHINI 1982). Phosphates were $1 - 32 \mu\text{g.l}^{-1}$ while total nitrogen values were $3.5 - 18.9 \text{ mg.l}^{-1}$ in the lower Uruguay River (O'FARELL & IZAGUIRRE 1994).

Basic stoichiometry (N:P ratio) was evaluated as an indicator of the physiological state of the organisms, showing that the system was not limited by phosphorous (average: 7.1:1). However, in previous studies this ratio was over

14:1 in all running waters studied including the Uruguay River and its tributaries (QUIRÓS & LUCHINI 1982; O'FARELL & IZAGUIRRE 1994).

The number of cyanobacteria species found in our study was in general lower than the results reported by other authors. A previous study in 1986, considering the whole Lower Uruguay River and eight tributaries, reported 54 cyanobacteria taxa (O'FARELL & IZAGUIRRE 1994). GARCÍA DE EMILIANI (1981), ZALOCAR (2002), ZALOCAR et al. (2007) and ZALOCAR & FORASTEIR (2007) who studied the northern and subtropical regions, along the Paraná and Paraguay Rivers also found higher cyanobacteria richness (16, 12 and 49 species respectively).

The nostocacean *Dolichospermum* cf. *pseudocompactum* was previously known only from eutrophic lakes in Central Japan (WATANABE et al. 2004, KOMÁREK & ZAPOMĚLOVÁ 2007) and from Jehay Douves, a small artificial lake in Belgium (WILLAME & HOFFMANN 1999). *D. pseudocompactum* Uruguayan population



Figs. 3–6. (3) *Dolichospermum* cf. *pseudocompactum* general aspect of the filament with regular coiled, one filament twisted inside the other; (4) *Radiocystis fernandoi*; (5) *Dolichospermum* cf. *pseudocompactum* trichoma with one akinete; (6) *D.* cf. *pseudocompactum* trichome with one heterocyte. Scale bar 20 μm .

differs from the Japanese and Belgian ones in the diameter of the trichome coiling and in the akinete, which was bigger in the Uruguayan population (Table 3). From morphological point of view *D. pseudocompactum* is closer to *D. compactum* when akinetes are not present, but *D. compactum* has smaller cell dimensions. Likewise, *D. compactum* was classified in different clusters according to molecular studies (RAJANIEMI et al. 2005). Molecular analysis of the Uruguayan species is not possible with the currently available data; further research is needed in order to achieve a more complete analysis of the population.

In temperate rivers, the development of phytoplankton is strongly correlated with the concentration of nutrients (BASU & PICK 1995; DODDS 2006). Coastal morphology, presence of protected areas and low-speed currents are also important factors in phytoplankton development (REYNOLDS 1988). According to REYNOLDS (2000), hydrological factors such as discharge and dead zones (areas of high resilience) are the most important factors in the development of rivers' phytoplankton. The bottom of the basin, which was object of this study, acts as a natural receptor of the dragged nutrient burden and processes drift; consequently, nutrients would not be a limiting factor for the development of cyanobacteria blooms. Consequently, the dynamics of phytoplankton would be regulated by rains and Salto Grande dam management in the lower Uruguay River.

The flow is the main physical factor in the dynamics of phytoplankton, being the main access of nutrients. According to previous studies in the Salto Grande reservoir and upstream, the main access route of nutrients to the system was also the channel flow of the Uruguay River (BERON 1990; CONDE et al. 1996; CHALAR et al. 2002). When flow increases, not only do levels of phosphorous increase, but also the basin bottom is removed by increasing turbulence and suspended solids, which in turn, decreases transparency and increases the light extinction coefficient, resulting in decreasing values of phytoplankton density. *Cryptomonas* were the organisms which turned out to be better adapted to these conditions. The second key factor for growth is temperature. In spring phytoplankton biomass increase with temperature increments, then in summer cyanobacteria becoming dominant. In the Uruguay River, phytoplankton development is limited because of light, not by nutrients. N:P relationship is never limiting for P, as it happens in other aquatic systems. Cyanobacterias blooms in Lower Uruguay River were reported since 1974 (ONO 1978; OSE 1978; QUIRÓS & LUCCHINI 1982; DI PERSIA & NEIFF 1986; BERÓN 1990; CONDE et al. 1996; CHALAR et al. 2002). In the summer 2005, a bloom of *Microcystis aeruginosa* was reported in the study area, reaching 20000–30000 cells. mL^{-1} (CELA 2006); the levels of microcystin-LR detected in the water at that same time reached 0.79 mg.L^{-1} in Nuevo Berlín, but its peak was reported in February (1.14 mg.L^{-1}) in Fray Bentos (SAIZAR et al. 2010). In these situations, factors such as the nutrient values (soluble phosphorous: 37 $\mu\text{g.L}^{-1}$ and nitrate: 0.57 mg.L^{-1} in average), high temperature (29 °C in average) and low flow (less than 1000 m^3s^{-1} during summer, promoted the growth of cyanobacteria. Upstream, in the summer of 2008, a bloom of *Dolichospermum spiroides* was reported in Monte Caseros on the Argentine coast with peak densities reaching 8.8×10^6 cell. mL^{-1} (OTAÑO & ROMÁN 2008). The mentioned authors consistently described the bloom with the same conditions in low level (max: 2m) and low turbidity (range 25 – 40 NTU).

Two possible scenarios could account for the cyanobacteria bloom dynamics in the Lower Uruguay River. One is that in high flow conditions, the bloom is generated in the dam and reaches open water of the Río de la Plata estuary as a result of rainfalls or by the management of the Salto Grande Dam. In low flow conditions (lentic characteristic) the bloom is generated by

Table 3. Dimensions (μm) of *Dolichospermum pseudocompactum*, comparison between Japanese (WATANABE 1996), Belgian (WILLAME & HOFFMANN 1999) and Uruguayan populations (n=number of measured cells or filaments).

	Lake Teganuma (Japan)		Lake Jehay Doves (Belgium)		Uruguay River (Uruguay)	
	Width	Length	Width	Length	Width	Length
Vegetative cells	5.2–7.0	3–6.8	5.4–6.0	5.6–7.2	7.6–8.3	6.0–8.0 (n >100)
Heterocytes	5.5–7.5		7.1–7.9		9–12.0	(n=5)
Akinetes	7.5–11.3	16.8–21.3	6.8–9.0	13–19	10.0–12.6	22.3–25.0 (n=2)
Diameter of trichome coiling	18–24	50–250	21.6–25		27.0–30.0	(n >100)

both: high water column stability and sediment resuspension caused by the wind. In both cases, temperature, nutrient supply and turbidity would be the main factors leading to the development of cyanobacteria.

In spite of the heterogeneous geomorphology in the three sampling sites, no significant differences were found in the composition and density of cyanobacteria. That means that the cyanobacteria community showed a similar behavior, favoring the hypothesis, so the bloom could not have been an impact caused by wastes from the pulp mill.

Several authors have modeled the growth and movement of cyanobacteria in river systems (LUNG & PEARL 1988; MAIER & DANDY 1997; GUVEN & HOWARD 2006), establishing that the varying flow conditions play a major role in initiating blooms, with the strong vertical mixing generated by high river flows eliminating conditions favorable for cyanobacteria. MITROVIC et al. (2003) investigated the critical flow velocity in the Darling River (Australia) for an *Anabaena circinalis* bloom. The bloom was stopped in areas where the turbulent river velocity exceeded a critical value of 0.05 m.s^{-1} . In the case of the Uruguay River, near Fray Bentos, where the width is 1800 m, we noticed that the critical value could be higher, ranging around 2000 m.s^{-1} .

Future studies may envisage the application of other models, such as PROTECH-C (ELLIOT et al. 2001), which was developed for lakes, also to include the effect of climate change. “El Niño” events have also had an impact on stream flows in the Rio de la Plata Basin, and we suggest that flow rates of the Uruguay River into the Rio de la Plata drifting the bloom toward the beaches in the capital city, Montevideo, would have a potential risk impact upon public health (SIENRA

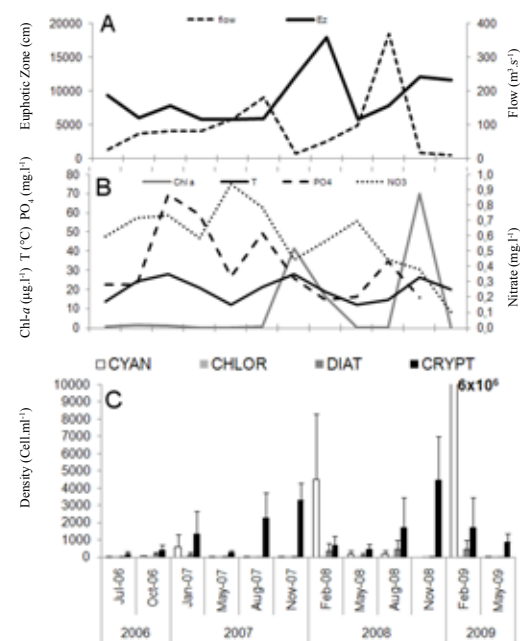


Fig. 7. Average and standard deviation in the three zones in the study area, from July 2006 to May 2009 of: (A) flow ($\text{m}^3.\text{s}^{-1}$) and euphotic zone (cm); (B) nitrate ($\text{NO}_3 \text{ mg.l}^{-1}$), phosphate ($\mu\text{g.l}^{-1}$), temperature ($^{\circ}\text{C}$) and chlorophyll-*a* ($\mu\text{g.l}^{-1}$); (C) density phytoplankton group (cells.ml⁻¹), Cyanophyceae (CYAN), Chlorophyceae (CHLOR), Bacillariophyceae (DIAT) and Cryptophyceae (CRYPT).

& FERRARI 2006).

The occurrence of species of the genera *Microcystis* and *Dolichospermum* in the Uruguay River should be viewed as a warning, showing the importance of preventing any incidents due to toxins, taste and odor production in the drinking water supplies and recreational waters.

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