CHAPTER 7

Phytoplankton of the middle and lower stretches of the Uruguay River

Inés O'Farrell[1] and Irina Izaguirre[1]

1- Departamento de Ecología, Genética y Evolución, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires – IEGEBA (UBA-CONICET)

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Abstract

The Uruguay River is one of the largest lowland rivers of South America. At its middle section, its course is altered by the Salto Grande Reservoir, which constitutes a discontinuity factor affecting the main limnological characteristics and the plankton communities. In this chapter we present a review of the available information on the phytoplankton of the middle and lower stretches since 1978, a short time before the start of the Salto Grande dam operation. The studies show that phytoplankton communities are regulated by two main forces: water discharge and seasonality, with higher phytoplankton abundances usually associated to the warm season, and lower ones to high water discharge. Human activities in the river basin have been inducing changes in the potamoplankton. From the 70's to the 90´s the studies reported that potamoplankton was dominated by diatoms, with chlorophyceans co-dominating in summer. During the last decade, the phytoplankton assemblage showed a higher proportion of cryptophytes, which together with diatoms and chlorophyceans, conform the typical potamoplankton of the river. Recently, blooms of Cyanobacteria appeared in the river during the summer, mainly near the littoral zone, favored by a combination of high temperatures and enhanced water column stability.

Key words: river, Salto Grande Reservoir, Cyanobacteria blooms

Introduction

The bulk of the knowledge of phytoplankton ecology from large rivers in Argentina is focused in the Paraná River and its tributaries. Although the Uruguay River flows over more than 1,600 km through three South American countries and constitutes the international border between Argentina and Brazil and further downstream with Uruguay, the information concerning phytoplankton is scarce. The few studies on the Argentine stretch mostly make reference to the Salto Grande Reservoir and to the Lower Uruguay.

The first studies dealing with phytoplankton on the Uruguay River were produced by Sierra et al. (1977) and Onna (1978) short time before the Salto Grande dam started operating in 1979. The latter study focused on phytoplankton by listing algal genera and analyzing total abundance from the confluence of the Pepirí Guazú River near the Brazilian border, down to the Río de la Plata. A decade later, O'Farrell & Izaguirre (1994) performed an extensive study covering some 350 km of the Uruguay River, which dealt with the regulation of the phytoplankton species dynamics and tackled with the influence of the Salto Grande dam in the structure of the community.

Most of the existing information on the River Uruguay is concentrated on the Salto Grande impoundment. Quirós & Luchini (1982) analysed the phytoplankton from the Salto Grande Reservoir in relation to environmental variables such as flow and sediment characteristics. Conde et al. (1996) indicated that spatial heterogeneity established the difference in the structure of phytoplankton, determining the occurrence of frequent algal blooms in the lateral arms of the Reservoir. De León & Chalar (2003) analysed the succession of phytoplankton functional groups and its diversity pattern, and Chalar (2006) further described the relationship among biomass, total phosphorus and hydrologic load of this water body. Recently, Bordet (2009) monitored the bloom forming cyanobacteria in recreation areas of the impoundment, while O'Farrell et al. (2012) analysed them along the 100 km length of the reservoir, between its margins over a five-year summer survey. Chalar (2009) addressed the key variables related with phytoplankton diversity in order to predict the potential occurrence of such blooms.

In the last decade several limnological studies were performed some 230 km downstream the Salto Grande dam in order to assess the impact of the settlement of two pulp mills in the margin of the Uruguay River near Fray Bentos. These surveys were performed separately by working teams of Uruguay and Argentina and included phytoplankton analysis at different scales: from single occasions (Faroppa & Annala, 2004) to samplings designs with comprised varying frequency (Izaguirre et al. 2009; CELA, 2005; 2006; Ferrari et al., 2011). Only one pulp mill was actually installed and it started operating on November 2008.

In this chapter we will portray the main characteristics of the phytoplankton of the Middle and Lower Uruguay River, with special focus on the effects of the Salto Grande Dam and of the settlement of pulp mills in a stretch with summer reverse flows.

Study Area

The Uruguay River rises in the Serra Geral Mountains as the Pelotas River, runs inland until it joins the Canoas River and flows 600 km to the mouth of the Pepiri River, it then flows south for 1,324 km marking the borders between Brazil and Argentina, and Uruguay and Argentina, until it meets the estuary of the Plata River, which flows into the Atlantic Ocean (Figure 1). The watershed of the Uruguay lies between 28^{o}10’ S and 37^{o}08’ S, with a total course of 2,262 km. The beginning of the Uruguay River is considered to be the confluence of the Canoas and the Pelotas rivers 1,816 km from the mouth. The total area of the Uruguay River watershed is approximately 365,000 km^2 (Di Persia & Neiff, 1982).

The Uruguay River hydrographic basin rests upon the sedimentary and volcanic rocks that compose the Paraná Basin. Igneous extrusive rocks from the Serra Geral Mountains predominate and cover Mesozoic and Neo-Paleozoic sedimentary rocks. The soil normally has high clay content and, in general, has little depth. The river has a series of pools and rapids, the former Augusto César Gorge presently flooded by the reservoir of the Itá Hydroelectric Dam, the Moconá Falls, and the former Salto Grande Falls that were flooded in 1979 after construction of the Salto Grande Dam for hydroelectrical power generation. The Moconá Falls divide the Upper and Middle Uruguay, while the Salto Grande is considered the border between the Middle and Lower Uruguay (Fig. 1).

The different sections of the watershed have considerably different hydrological conditions. The upper river is steep, with an average slope of 1.76% and maximum average flow of 9,387 m^3/seg. Flooding occurs between June and October, although great annual variations in water level can be observed. The Middle Uruguay flows nearly 800 km with an average drop of only 0.16%, with some rapids. In the Lower Uruguay, the river runs nearly 350 km with a total slope of less than 1m. Hydrological conditions of the Lower Uruguay are strongly influenced by the Salto Grande Hydroelectric Dam. Historically the variation in the river level was small, dropping only 1.2 m during droughts. In spite of this, extraordinary floods exceeded 10 meters in height. Mean historical discharge was estimated as

4739 m^3s^{-1}, and extreme values from 92 to 36,100 m^3 s^{-1} .Vast floodplains accompany the main river stem.

Between the cities of Colón (236 km) and Fray Bentos (102 km) many large islands break up the Uruguay; 110 km from the mouth, at the outlet of the Gualeguaychú River, the islands disappear and the river widens substantially, reaching 8 to 12 km in breadth over a flat plain. A series of channels links the Uruguay and Paraná rivers in this stretch, with the Río de la Plata River strongly influencing the speed and direction of the currents in the Uruguay. During low water season, tidal influence is seen upstream Paysandú, 204 km from the mouth. Since the construction of the hydroelectric dam at Salto Grande, these tidal effects have become more pronounced, particularly when water volumes released by the dam are reduced. At Nueva Palmira, the Uruguay spills into the Rio de la Plata, a saline estuary covering approximately 18,000 km^2.

In the Upper Uruguay agriculture mainly produces soybeans, corn and black beans. In the Middle and Lower Uruguay, extensive cattle-raising and cultivation of soybean and rice prevail. Only fragments of the old forest remain along the boxed river valleys and on the steepest hillsides. In the Brazilian section of the river basin, primary and secondary vegetation cover nearly 17.5% of the land. Reforested areas, principally pines (*Pinus* *elliottii*), occupy another 3%. With the exception of a few small remaining patches of primary forest, nearly the entire region has been replanted to secondary vegetation, croplands and pasture. The population density of the Uruguay River Basin is approximately 39 inhabitants per square kilometer.

The Administration Commission of the River Uruguay (CARU), which initiated a water-quality monitoring program in the Middle and Lower Uruguay in 1987, considered this section of the river to be generally clean (CARU, 1993). There are isolated cases of contamination. The areas of higher pollution are downstream from the cities and industrial centers such as Salto-Concordia, Paysandú-Colón and the mouth of the Gualeguaychú River. Heavy metals and agricultural chemicals of the organophosphate and organochloride groups were not found at elevated levels and were not considered problems for the lower stretch.

Janiot & Molina (2001) characterized the main limnological variables of the Uruguay River in the Middle and Lower stretch showing mean summer and winter water temperatures of 24 °C ± 2.5 and 15.5 °C ± 3, respectively. Water conductivity (40-60 $\mu S\ cm^{-1}$) and suspended solids concentration (mean 24 $mg\ L^{-1}$) were typically low; the latter were enhanced in the tail of the impoundment, decreased after the dam and an increased once again near the river mouth. Dissolved oxygen saturation was higher than 80% in the main channel though lower values were encountered in the littoral waters close to populated or industrial areas. The dominant type of water is calcium-bicarbonate. Mean dissolved nitrogen and phosphorus concentrations in the main channel were 0.685 mg l^{-1} and 0.107 mg l^{-1}, respectively; their mean ratio ranges between 17 (in more polluted areas) and 22.

Spatial and temporal characterization of the phytoplankton

The first extensive study (1976-1977) in the section of the Uruguay River flowing along the border of the Argentine territory (Onna, 1978), revealed that diatoms represented the bulk of phytoplankton. This result is consistent with a previous reference that diatoms exceeded 80% of the community and green algae sub-dominated ranging from 2 to 15% (Sierra et al., 1977) in the stretch that would be affected by the construction of the Salto Grande Dam. An interesting feature described in Onna's survey (op. cit.) refers to the relation between pennate and centric diatoms, as the former prevail in the middle reach and the latter downriver. The reversal of this pattern occurs at different locations along the river (from Santo Tomé to the Salto Grande Reservoir, 768 and 379 km from the mouth respectively) and varies over the year; the shift to lower values of pennate:centric ratios takes place further downriver during low waters periods.

O'Farrell & Izaguirre (1994) described a temporal (1986-1987) and spatial pattern of species richness, decreasing strongly from the tail of the Salto Grande Reservoir at Monte Caseros (mean 76.3) to the widened section of the River Uruguay at the Ñandubayzal cove (mean 54.7). A detail of the section studied is illustrated in Fig. 1 (left panel). The big supply of species from the vegetated shallow lakes associated to the Mocoretá River inflowing at the upstream section of this water body may have accounted for the high local richness. For example, Desmidiaceae were very well represented in this tributary with low water conductivity, as well as in the adjacent section of the Uruguay River (Tell et al., 1994), but were not encountered downstream as they are not typically potamoplanktonic organisms and further, the increasing conductivity at downriver sites does not favour this group ($r=-0.67$; $p< 0.05$), known to be highly sensitive to enhanced dissolved solids concentrations (Coesel, 1982). Moreover, the limnological conditions prevailing in the reservoir differ from the lotic upstream stretch and probably did not benefit the thriving of several inflowing species. Despite the Lower River Uruguay presented a phycoflora not significantly affected by the contribution from tributaries in the Argentine territory, a high diversity spot was registered near the Palmar

National Park where a stream inflows. The influence on phytoplankton composition from courses inflowing from Uruguay was not assessed, but we assume that they may be comparatively more important due to the larger size of rivers.

This annual study performed in the 80's revealed that phytoplankton, just like in other large rivers of the world, was dominated by centric diatoms (Fig. 2). Nevertheless, the river stretch comprising the tail of the reservoir differed from the reach below the dam since at this site centric diatoms are not so abundant and otherwise, pennate diatoms and desmids frequently appear (Izaguirre, 1991; O'Farrell & Izaguirre, 1994). Centric diatoms increased downriver to a maximum of 331 ind.ml^{-1} at the Ñandubayzal Cove, representing 63% of total phytoplankton. Chlorophyceae and Cyanobacteria were abundant in the warm seasons (max: 59 and 20 % respectively), the latter group achieved highest development downstream the dam (Concordia and Colón). Phytoplankton seasonal succession was mainly regulated by temperature and water discharge. The species present all along the gradient were: *Aulacoseira granulata*, *A. granulata* var. *angustissima*, *A. granulata* var. *curvata*, *Melosira varians*, *Eudorina elegans*, *Pandorina morum*, *Dolichospermum spiroides* (Syn: *Anabaena spiroides*) and *Microcystis aeruginosa*. Despite phytoplankton total densities were higher than those registered by Onna (1978) (836 ind.ml^{-1} at km 90 *vs.* 37 ind.ml^{-1} at km 583), the minimum and maximum values were coincidentally registered in winter and spring, respectively. Likewise, Onna (*op. cit.*) also registered an abundance drop in summertime when discharge was least and transparency diminished due to increasing suspended solids.

The studies performed in the present century depict a somewhat different scenario both in terms of total phytoplankton density and composition. The initial study for the environmental impact assessment for the establishment of a pulp mill performed on December 2003 by Botnia (Faroppa & Annala, 2004) at three sampling points in the area of Fray Bentos (Uruguayan margin) indicated that the high suspended solids content limited phytoplankton photosynthetic activity rendering low chlorophyll *a* values (from non-detectable values to 0.98 μg L^{-1}) and densities (1260 to 5330 cells ml^{-1}). Diatoms, mainly represented by species of *Aulacoseira* were very frequent but their abundance was less than 4%. Surprisingly, nanoplanktonic flagellates prevailed over diatoms as cryptophyceans constituted more than 70% of the phytoplankton bulk and volvocaleans contributed with 5%. The occurrence of *Dolichospermum spiroides*, *D. circinalis (*Syn: *Anabaena circinalis)* and *Microcystis aeruginosa* was also registered, though in the counting only *D. circinalis* appeared achieving 15% of total abundance at site 1. Species richness ranged between 51 and 58.

Later on, a seasonal study was carried out between 2005 and 2006 (April. July, October, January) at three sites of the Uruguayan river margin (Nueva Berlin, Fray Bentos, Las Cañas) to establish a baseline for the plankton communities (CELA, 2006). Phytoplankton assemblages at the three sites had similar structure and composition and were comparable to those registered in the previous analysis; no significant differences were observed between the littoral area and the middle of the channel. Despite phytoplankton was dominated by nanoplanktonic flagellates (several *Cryptomonas* species and *Rhodomonas minuta*) for most of the study period, cyanobacteria and diatoms of a larger size prevailed in summer time. Temporal variation in composition and abundance was probably related to the hydrological regime; mean cell concentration ranged between 19 cells/ml (autumn at New Berlin) and 31900 cells/ml (summer at Fray Bentos). The highest summer abundance occurred simultaneously at the three sites with *Microcystis aeruginosa* as the major contributor, accompanied by *M. wessenbergii*, *M. novacekii, Dolichospermum spiralis, Aulacoseira* af. *islandica*, *A. granulata* var. *granulata* and *A. granulata* var. *angustissima*. Despite diatoms usually require turbulent conditions to remain suspended in the water column, these species were represented by very long filaments (mostly with more than 10 cells) that, just as cyanobacteria with aerotopes, benefit from a less turbulent scenario. The authors assert that these are the first blooms registered in this river stretch. Nitrogen, pH and temperature were indicated as the environmental variables more correlated to composition and abundance. The authors inferred that discharge affecting nutrient input, and seasonality associated to temperature variation, regulated the phytoplankton structure in this river stretch. Regarding species richness, highest values were observed in spring in coincidence with previous information given by O'Farrell & Izaguirre (1994).

Within the framework for the assessment of the impact of the mentioned pulp mills on water quality, seasonal to bimonthly surveys were also performed in the Argentine section of the Uruguay River channel between 2006 and 2009 (pre-operational and operational period of the former Botnia). Izaguirre et al. (2009) analysed a longer stretch, between the progressive kilometers 111.9 and 73.3, and registered large fluctuations in the water discharge released from the dam (439 to 18,335 m^3 sec^{-1}) (Fig. 3). During 2006 and up to March 2007 discharge mostly remained below the historical mean (4739 m^3 sec^{-1}), it then nearly doubled its flow over 2007 but diminished on summer 2008 to gradually increase to its maximum on

November and decreased once again on summer 2009 to extremely low levels. In the pre-operational period mean total phytoplankton density ranged between 4.5 ind ml^{-1} (October 2007) and 3116 ind ml^{-1} (December 2006) influenced by water discharge and temperature as abundance dropped during 2007 when high discharge enhanced re-suspension and transport of fine materials decreasing light penetration and accelerating algal displacement due to high flows. On the other hand, warm periods promoted algal development at intermediate discharge values with relatively low suspended solids content. Likewise, in the post-operational period abundance ranged between 36 ind.ml^{-1} (July 2008), in coincidence to lowest temperatures and relatively high water discharges, to 3434 ind. ml^{-1} (November 2008) in spring independently of water discharge. Although in terms of density, the values registered in January 2009 did not exceed those observed in November 2008, the contribution of colonial and filamentous forms (particularly Cyanobacteria) to the phytoplankton bulk was much more important. These large multicellular individuals accounted for the highest number of cells and chlorophyll *a* concentrations (9.58 $\mu g\ l^{-1}$).

Despite the relative contribution of algal groups to total phytoplankton differed strongly between hydrological periods, the share of Cryptophyceae was always significant in this stretch of the Uruguay River all over the study period. This group was accompanied alternatively by Bacillariophyceae, Chlorophyceae and Chrysophyceae. During warm periods Cyanobacteria achieved quite high concentrations at the Ñandubayzal Cove provided water level and wind driven turbulence were low; otherwise diatoms prevailed at this shallow site.

The phytoplankton of the Lower Uruguay River was characterized by few species of frequent occurrence and many with an occasional presence. Among the former, *Dolichospermum spiroides, Microcystis aeruginosa, Pandorina morum, Pediastrum duplex, Spermatozopsis exsultans, Dinobryon eurystoma, Aulacoseira granulata, A. granulata* var. *angustissima, A. granulata* fo. *curvata, Aulacoseira islandica, Melosira varians, Nitzschia palea, Surirella guatimalensis, S. tenera, Synedra ulna, Cryptomonas marsonii, Plagioselmis lacustris* and *P. nannoplanctica* were registered in more than 50% of the samples. Species richness ranged from 18 (low waters, windy late winter 2006 at the Ñandubayzal cove) to 108 (high waters, spring 2008 downstream km 78.8). Despite no definite spatial pattern was observed along the stretch here studied, low species richness was recurrently observed during low water periods, either due to highly inorganic turbid waters with few diatoms or quiescent water columns with cyanobacteria blooms.

In this sense, several species potentially toxic and capable of producing blooms were registered in the main channel of the lower stretch Uruguay River and in the Ñandubayzal cove. The most conspicuous taxa were *Microcystis aeruginosa*, *Dolichospermum spiroides* and *D. circinalis*, which were usually detected at low levels in the main channel from September 2006 to November 2008 (Fig. 4). An exceptional peak slightly exceeding the alert level 1 (2000 cells ml^{-1}, according to the World Health Organization= WHO) was registered in the central littoral area of the Ñandubayzal cove in December 2006. Quite a different scenario was observed on January 2009 when along some 20 km of the main channel cyanobacteria largely exceeded alert level 1 (14,100 cells ml^{-1}) with abundances in the cove similar to spring 2006. The bloom turned into a scum event by February 2009 achieving values up to 18,000,000 cells ml^{-1}, which exceeded the alert level 2. These concentrations of potentially toxic cyanobacteria have been never before registered in the Uruguay River, not even in the Salto Grande Reservoir.

Why did cyanobacteria developed to such levels? The reverse flows produced by the influence of tides and winds in this section of the river intensify during summer months when flow is reduced. In early February 2009 low and reverse flows combined to create five days of stagnant waters (http://www.icj-cij.org/docket/files/135/15469.pdf) that benefited the buoyancy of these cyanobacteria with aerotopes that can migrate in the water column to optimum nutrient and light conditions. This situation, together with the increase of temperature (around 28-30°C), promoted the explosive growth of these organisms.

Parallel to the study carried out by Izaguirre et al. (2009) at the Argentinean side of the river, Ferrari et al. (2011) analysed the composition, abundance and distribution of cyanobacteria in three zones of the Lower Uruguay River at the Uruguayan side (Nuevo Berlín, Fray Bentos and Las Cañas). Phytoplankton samples were collected seasonally from 2006 to 2009 along perpendicular transects to the coastline, between the Uruguayan coast and the river channel. This study showed the presence of 24 cyanobacteria taxa, and in agreement with that reported for the Argentinean side, different species of the genera *Dolichospermum* and *Microcystis* were dominant among the bloom-forming. For the period of this study, the highest abundance of cyanobacteria was recorded in summer, reaching 6,200,000 cells ml^{-1} during the bloom of February 2009, which was constituted mainly by *M. aeruginosa* and *D.* cf. *pseudocompactum*, but the toxicity analyses performed by HPLC did not indicate the presence of microcystin-LR. These authors found a high correlation between the Cyanobacteria densities and the nutrient concentrations (nitrogen and phosphorous), and attributed the changes in nutrients to the variations of the river flow: under a scenario of low flow conditions the blooms would be favoured by both high water column stability and sediment resuspension caused by the wind. On the other hand, based on the results of the spatial analysis performed, these authors dismissed that the wastes of the pulp mill could have influenced the cyanobacterial blooms.

Salto Grande Reservoir

Salto Grande is a river –like reservoir with multiple arms located along 100 km of the main channel of the River Uruguay (29° 43' to 31° 12' S and 57° 06' to 57° 55' W). It is characterized by a high water period from April to November and a low water phase at summer time (December to March). Mean flow ranges from 2800 to 5563 $m^3 s^{-1}$ with minimum and maximum records of 216 and 22,000 $m^3 s^{-1}$ in dry and rainy periods respectively. The reservoir is polymictic with short lasting stratifications under low flow conditions; it has a mean depth of 6.4 m (max. 35 m) and a mean retention time of 11.3 days.

The first study performed from January 1980 to February 1981 after the reservoir was filled in 1979 (Quirós & Cuch, 1982), described a central zone of high flushing rate with physico-chemical characteristics similar to the main river before the impoundment, but with differing features at the five lateral arms. The exception to this pattern corresponded to total suspended solids that diminished from the tail of the reservoir (96 mg l^{-1}) to the dam (29 mg l^{-1}), regulated by the morphometry of the central zone and the inflowing characteristics of the river to the reservoir. Moreover, inorganic turbidity was comparatively higher upstream and lower downstream than before the impounding of the river. For this same period, Quirós & Luchini (1982) registered higher chlorophyll *a* concentrations in the lateral arms (max. 205 µg l^{-1} at the ends of the arms) than in the center (max. 18.4 µg l^{-1}); these correlated negatively with the water flow. Phytoplankton was dominated by diatoms, mainly *Aulacoseira granulata var. angustissima* with the exception of the Mandisoví and Gualeguaycito arms where *Microcystis aeruginosa* thoroughly developed providing that water level was low. This cyanobacteria species was least in the main channel during periods of high water turnover. Despite the authors made an interesting reference to inoculation of small flagellates from the reservoir arms, we consider no further comparisons can be done as countings were performed on net samples. The comparison of chlorophyll *a* concentrations in Salto Grande reservoir between the summer series of 1982-1989 and 1994-1995 evidence increasing phytoplankton biomass both at the dam (1.98 to 10.87 $\mu g\ l^{-1}$) and the Mandisoví and Gualeguaycito arms (3.92 to 6.19 and 3.91 to 8.9 $\mu g\ l^{-1}$ (up to 28.49 in the end of this arm), respectively) (Otaegui, 1997).

Conde et al. (1996) pointed out that relevant limnological differences between the main channel and lateral arms of the reservoir were due to different circulation patterns. They assumed that the sharp seasonality of the hydrological cycle was the main force driving the system, asserting that the dendritic shape and complex morphometry develops a lacustrine-type reservoir during summer that promotes phytoplankton development, whereas a river-like system characterised by low biomass occurs in winter. These authors also indicated that runoff from the northern area of the basin was the main source of phosphorus entering the reservoir, whereas nitrogen and silicate entered the lacustrine area of the reservoir through lateral arms receiving local runoff.

De León & Chalar (2003) also made reference to these spatial differences in 2000-2002 and described them in terms of organisms density; thus, abundance ranged from 16 ind. ml^{-1} in the central zone close to the dam to 1,963 ind. ml^{-1} at the Itapebí arm in the Uruguayan side. They registered a succession of the C-S-R strategies in response to an increasing gradient of temperature, light and water residence time. In autumn and winter, under high discharge, suspended solids and nutrient concentrations, there was a high abundance of nanoplanktonic phytoflagellates, which were replaced in late winter and spring by centric diatoms (*A. granulata, A. distans, A. ambigua*) and later on by cyanobacteria (*Dolichospermum planctonicum (*Syn: *Anabaena planctonica)* and *Raphidiopsis mediterranea*) in summer. Interestingly, in this study there was a compositional difference in the cyanobacteria summer assemblage, as *Microcystis* was not dominant. Chalar et al. (2002) also indicated a difference in composition between the arms in response to their morphological and hydrological characteristics: in the Itapebi arm (left margin) phytoflagelates prevail as the turbulence is enhanced due to the high discharge provided by the inflowing stream, whereas cyanobacteria blooms are frequent in the Gualeguaycito arm (right margin) with a deeper and calmer water column. Chalar (2009) pursued the research work (2000-2002) in the arms of the reservoir with the aim to predict the occurrence of algal blooms. Based on the idea that variations in Kd integrates several disturbance processes (water inputs, wind-induced resuspension, changes in reservoir level) and at the same time it estimates light availability for phytoplankton, he found that at Kd < 2.5 m^{-1} light limitation disappeared, diversity dropped from it threshold value of 1.9 to the minimal registered records. Thus, the author asserted that stable conditions at Salto Grande were maintained by external inputs (water load, wind-induced resuspension, changes in the water level), and if such energy was reduced, the eutrophic character of the reservoir was confirmed by a bloom formation (*Microcystis aeruginosa*).

Chlorophyll *a* concentrations further increased over time as by February 2003, Bordet (2003) registered a maximum of 97.2 µg l^{-1} at the end of the Gualeguaycito stream. The most abundant species on this study was *Microcystis aeruginosa* that was accompanied by *Dolichospermum* spp.; the former prevailed with higher temperatures (summer) and were partially replaced by the latter in autumn and winter. The abundance of these cyanobacteria taxa differed among the arms sampled, which had different depths (ca. 20 to 30 meters) and widths (ca. 100 to 350 meters) and were influenced differentially by river flow, as previously pointed by Chalar et al. (2002). Nevertheless, values certainly exceeded alert level 2 (100.000 cell ml^{-1}) at the three sites in summertime; *M. aeruginosa* achieved more than 2,500 ind.ml^{-1} and *Dolichospermum* spp. more than 50 ind.ml-^{1}. In a more recent analysis, Bordet (2009) found that maximum values were still increasing, with total cyanobacteria abundance of 1,875,700 cell ml^{-1} and chlorophyll *a* concentrations up to 118.2 µg l^{-1}; the right margin presented the highest densities. *Microcystis aeruginosa* was still the dominant species, though *M. wesenbergii*, *Dolichospermum circinalis*, *D. spiroides* and *Raphidiopsis mediterranea* frequently appeared. O'Farrell et al. (2012) found a difference in the behaviour of the cyanobacterial dominant complexes, *Microcystis* and *Dolichospermum*. and indicated that the hydrological cycle explains the interannual fluctations of the intensity and frequency of the algal blooms, while the spatial differences respond to the morphometrical and hydrological characteristics of the reservoir.

Summary of the impact of the human influence in the Uruguay River Basin on potamoplankton

The historical analysis of the studies on phytoplankton carried out in the Uruguay River showed important variations in the structure of the community through time (Table 1), which are probably associated to the increase of the different human activities in the river basin. In the decade 1977-1987 the mean phytoplankton abundance registered in the main channel of the river never exceeded 800 ind. ml^{-1}, whereas the maximum values increased fivefold in the decade 2000-2010. Moreover, during the last decade some events of Cyanobacteria blooms (*Microcystis* spp. and *Dolichospermum* spp.) were recorded in the main channel, which have never been observed before. These blooms are favored by a combination of high temperatures, high irradiances, low water level, and a high stability in the water column. Also the presence of the Salto Grande Reservoir contributes to the development of algal blooms. According to standards proposed by the WHO, the cell abundances of Cyanobacteria registered in the Uruguay River in some occasions during the last decade exceeded the alert level 1, and even in one opportunity surpassed the alert level 2 (February 2009). Over the entire period analysed, several species of *Aulacoseira* were among the most representative taxa in the river, which were frequently accompanied by different species of Chlorococcales and Volvocales, mainly in summer. Nevertheless, the studies of the last years also revealed a high abundance of some opportunistic nanoflagellated species of the genera *Cryptomonas*, *Plagioselmis, Spermatozopsis* and *Rhodomonas*, which were usually more abundant in autumn, winter and spring. In addition, the summer periods of the last decade showed a recurrent increment of Cyanobacteria, more evident near the littoral zones or in stretches with lower current velocity.

Final remarks

The limnological features of the Uruguay River and the phytoplankton structure fluctuate in relation to the annual seasonality and the hydrological variations. As in other rivers located in warm temperate regions, higher temperatures generally favour higher phytoplankton abundances, whereas periods of high water discharge are usually associated to lower algal densities. The different phytoplankton studies conducted in the river have coincided in showing a relatively high species richness (around 200 – 400 taxa). The centric diatoms are an important component of the potamoplankton, among which different *Aulacoseira* species are the best representative taxa. Several volvocaleans and chlorococcaleans are also frequent, mainly in spring, whereas Cyanobacteria are usually more important in summer, particularly near the littoral zones. Studies carried out during the last decade have also revealed a high proportion of nanoflagellated species that usually constitute another important component of the potamoplankton in terms of abundance. At its middle section, the course of the river is altered by the Salto Grande Reservoir, which represents a discontinuity factor affecting the main limnological characteristics of the river and the phytoplankton structure. In particular, the presence of this reservoir, together with different human activities that take place in the river basin (mainly agriculture, industries and urbanization), favor the development of Cyanobacteria blooms, usually dominated by several species of *Microcystis* and *Dolichospermum*. The events of algal blooms in the Uruguay River have become more pronounced in the last summers, and even have affected the main channel when the environmental conditions were particularly favorable (high temperature, low water level, stability of the water column).

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Figure Captions and Table Legends

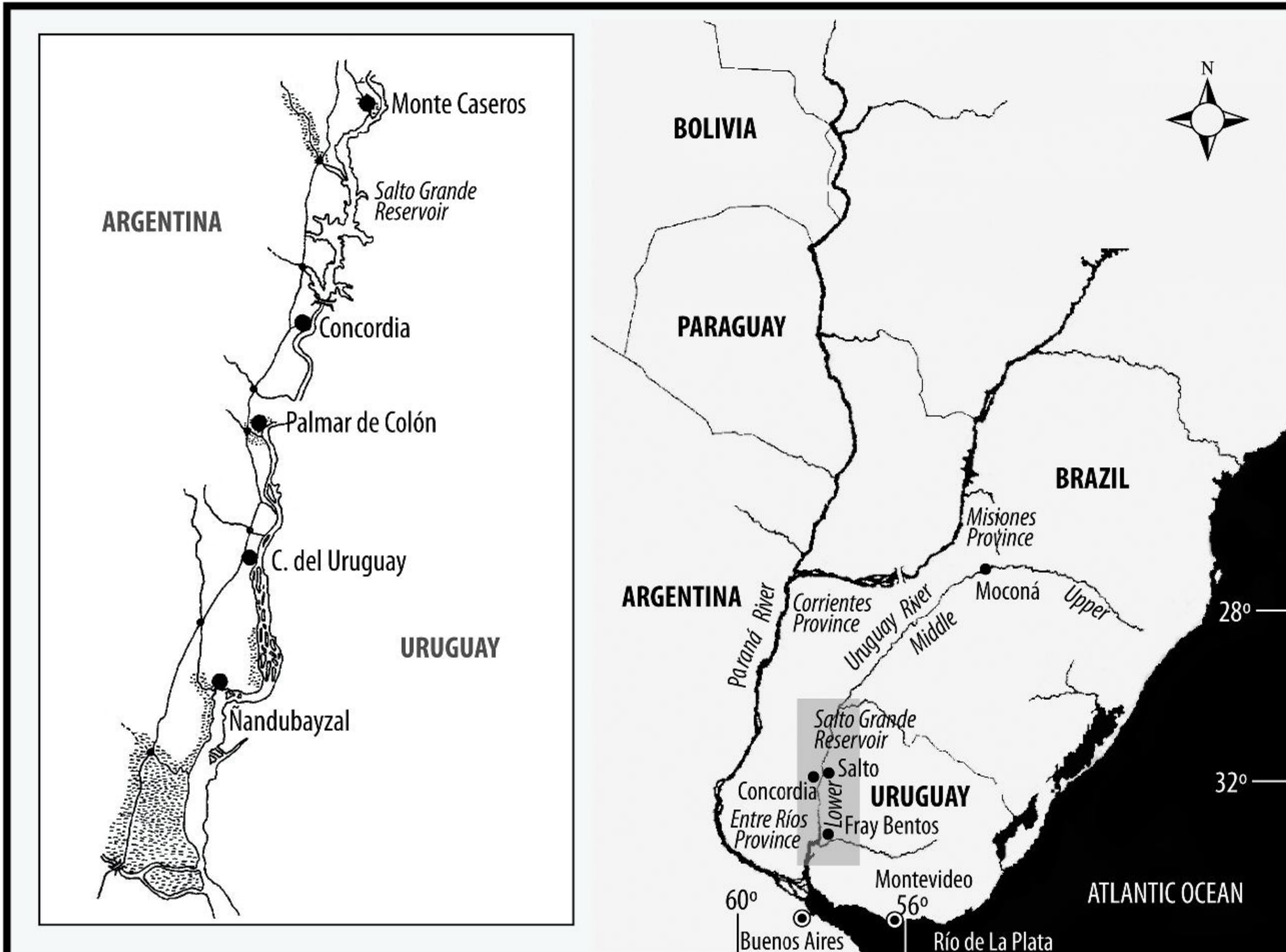
Fig. 1. The Uruguay River Basin. Left panel: detail of the stretch studied by O´Farrell & Izaguirre (1994).

Fig. 2. Seasonal variation of total phytoplankton showing the contribution of the main groups from autumn 1986 to summer 1987 (Au: autumn; Wi: winter; Sp: spring; Su: summer).

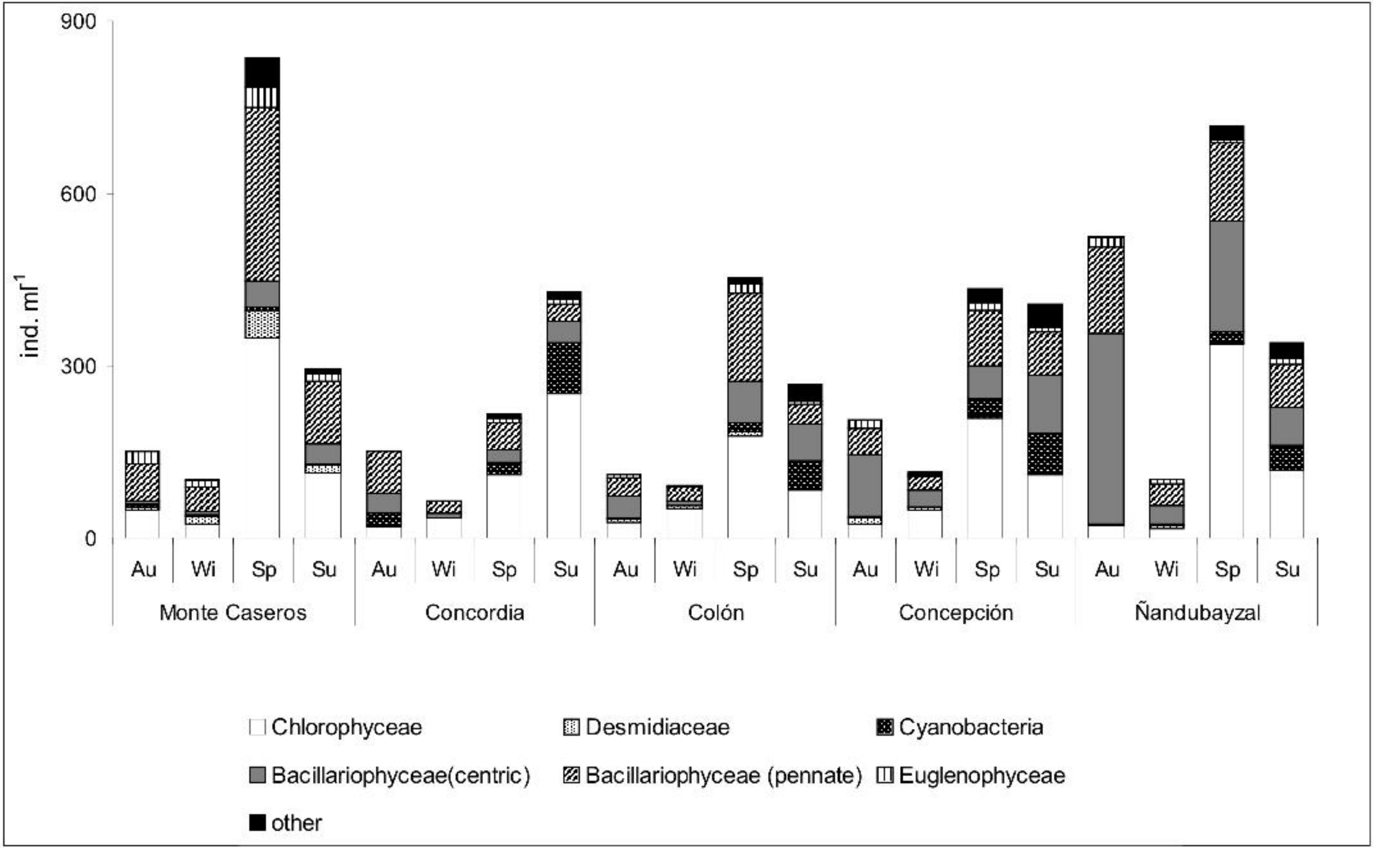
Fig. 3. Uruguay River discharge variation from July 2006 to April 2009.

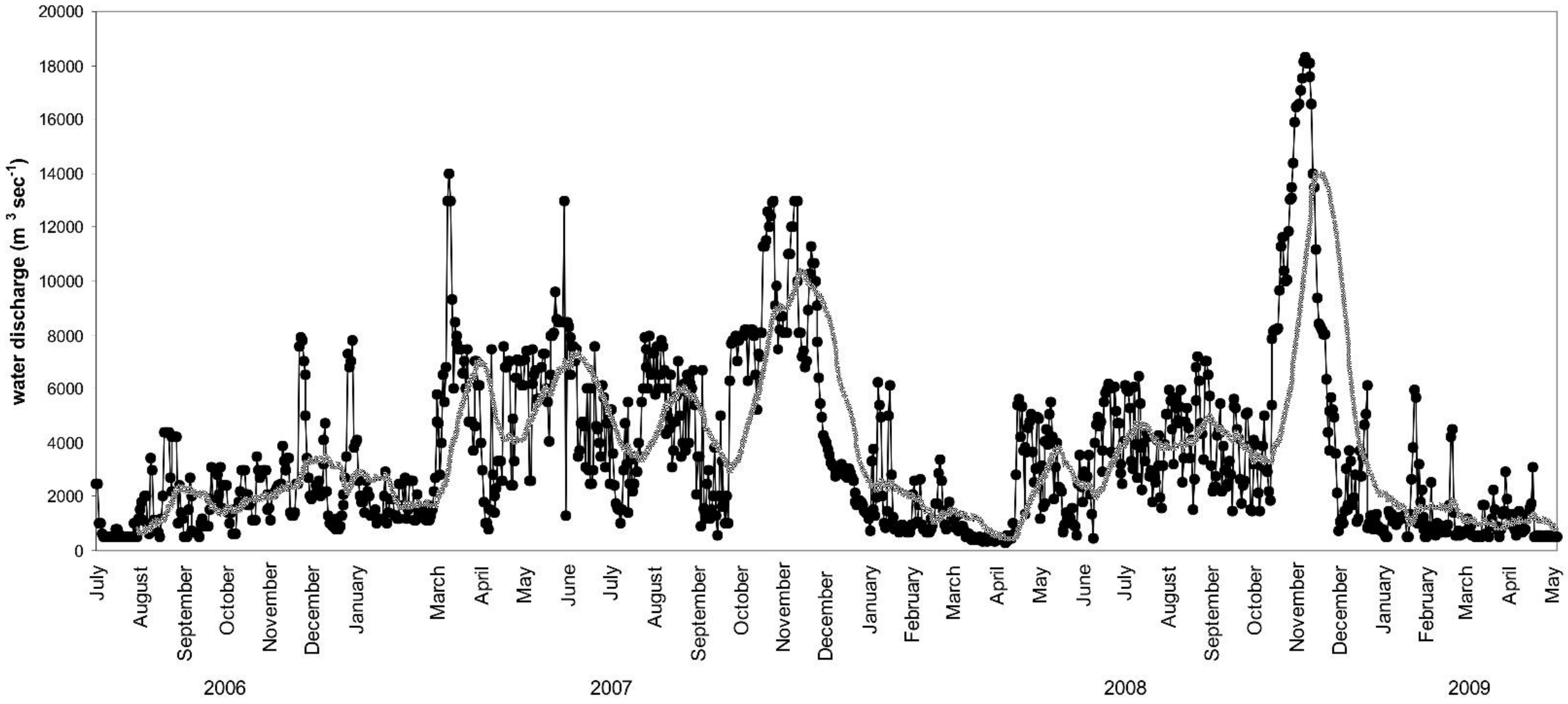
Fig. 4. Mean concentration of potentially toxic cyanobacteria in the river channel in the stretch “near Botnia (UPM)” from 2006 to 2009, indicating the alert levels of the WHO.

Table 1: Comparison of the phytoplankton structure from the Uruguay River between the decades 1977-1987 and 2000-2010, according to data from Onna (1978), O´Farrell & Izaguirre (1994), Cela (2006) and Izaguirre et al (2009)



Monte Caseros
Salto Grande
Reservoir
ARGENTINA
Concordia
Palmar de Colón
C. del Uruguay
URUGUAY
Ñandubayzal
N
BOLIVIA
PARAGUAY
BRAZIL
Misiones
Province
ARGENTINA
Corrientes
Province
Paraná River
Uruguay River
Moconá
Upper
Middle
28º
Salto Grande
Reservoir
Salto
Concordia
Lower
URUGUAY
32º
Entre Ríos
Province
Fray Bentos
Montevideo
60º
56º
ATLANTIC OCEAN
Buenos Aires
Río de La Plata


900
600
300
0
ind. ml-1
Au
Wi
Sp
Su
Au
Wi
Sp
Su
Au
Wi
Sp
Su
Au
Wi
Sp
Su
Au
Wi
Sp
Su
Monte Caseros
Concordia
Colón
Concepción
Ñandubayzal
Chlorophyceae
Desmidiaceae
Cyanobacteria
Bacillariophyceae(centric)
Bacillariophyceae (pennate)
Euglenophyceae
other



water discharge (m 3 sec-1)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
July
August
September
October
November
December
January
March
April
May
June
July
August
September
October
November
December
January
February
March
April
May
June
July
August
September
October
November
December
January
February
March
April
May
2006
2007
2008
2009

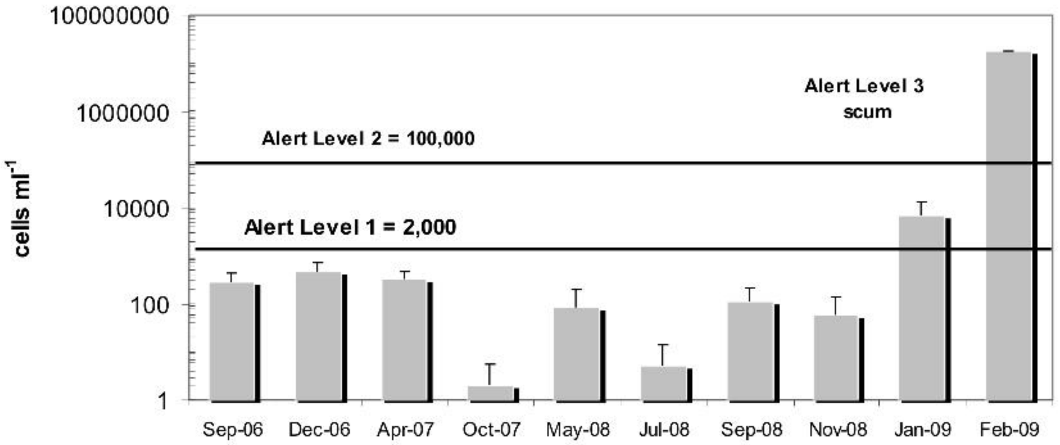

100000000
1000000
10000
100
1
cells ml-1
Alert Level 3
scum
Alert Level 2 = 100,000
Alert Level 1 = 2,000
Sep-06
Dec-06
Apr-07
Oct-07
May-08
Jul-08
Sep-08
Nov-08
Jan-09
Feb-09

Table 1.

	1977 - 1987	**2000 - 2010**
Total phytoplankton abundance at the main channel	< 10 - 800 ind. mL^{-1}	< 10 - 3400 ind. mL^{-1}
Dominant and subdominant algal groups (in density)	Bacillariophyceae - Chlorophyceae (in summer)	Cryptophyceae, Bacillariophyceae, Chlorophyceae, Cyanobacteria (in summer)
Some frequent taxa	*Aulacoseira* spp., *Eudorina elegans*, *Pandorina morum*, *Peridinium* spp., *Eunotia* spp., *Nizschia* spp., *Surirella* spp., *Synedra* spp., different species of Chlorococccales and Desmidiaceae	*Aulacoseira spp., Cyclotella meneghiniana, Cryptomonas* spp., *Rhodomonas* sp., *Plagioselmis* spp., *Spermatozopsis exsultans*, different species of Chlorococcales,Volvocales
Algal blooms	not registered in the main channel	*Microcystis aeruginosa*, *Microcystis wessenbergii*, *Dolichospermum spiroides, Dolichospermum* spp.