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Influence of El Niño Southern Oscillation phenomenon on coastal phytoplankton in a mixohaline ecosystem on the southeastern of South America: Río de la Plata estuary

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ABSTRACT

The aim of this study was to analyze the density, diversity, biomass and assemblage composition of the phytoplankton in relation to environmental conditions (physical, chemical, hydrological and meteorological variables), measured under the different scenarios caused by the ENSO phenomenon in the period between 2005 and 2012, in six sampling sites in the tidal freshwater zone of the Río de la Plata estuary, covering almost 100 km of coastline. The results revealed changes in the structure of the phytoplankton, such as a significant reduction of diversity, and decreases in biomass and phytoplankton density, particularly during El Niño phases. Cyanobacteria were more abundant in the neutral periods, Chlorophyceae dominated La Niña phase while Bacyllariophyceae dominated El Niño. However, no complete replacement of species between cycles was observed. The results obtained were highly variable due to the inherent natural variability of the Río de la Plata, emphasized by the anthropogenic impact in this area.

1. Introduction

Phytoplanktonic communities dominate the pelagic ecosystems, which cover over 70% of the surface of the planet, among which estuaries are found. Changes in phytoplankton community composition are important indicators of estuarine and coastal ecological condition and health, since it plays a major role in primary production, eutrophication (including harmful algal blooms), nutrient cycling, water quality, and food web dynamics (EPA, 2005). There is evidence that phytoplankton is sensitive to environmental changes, and since it is suspended and transported into the water column, is able to integrate the environmental impacts of a wide geographical area (Stevenson and White, 1995). Changes in the structure and activity of the phytoplankton community often precede larger-scale, longer-term changes in ecosystem function, including shifts in nutrient cycles, food webs, and fisheries (Paerl and Peierls, 2008). Given the importance and dynamic nature of estuarine ecosystems, there is an urgent need to develop sensitive and broadly applicable indicators for detecting changes in water quality and overall ecological condition.

The coastal areas of Latin America are highly vulnerable to the potential impacts of climatic changes, in addition to the natural inter-annual effects of the El Niño-Southern Oscillation (ENSO) phenomenon, which have a decisive influence on coastal dynamics (Piccolo, 2013; Soto and Quiñones, 2013).

The Plata basin, with an area of 3,170,000 km^2, drains to the Atlantic Ocean through the Río de la Plata estuary, and its main source of natural variability at an inter-annual scale is the ENSO phenomenon (Nagy et al., 1997). This estuary is under the effects of river discharge variations associated to the ENSO cycle, but their ecological consequences are not fully studied (Acha et al., 2008). The ENSO phenomenon involves two extreme phases characterized by anomalously warm and cold surface waters in the eastern tropical Pacific. "El Niño" corresponds to the warm phase of ENSO, and the opposite, "La Niña", corresponds to the cold phase, while cycles without temperature anomalies are called "neutral" phases (Trenberth, 1997). Cold and warm episodes of ENSO in the Pacific cause drought and abundant rainfall respectively in southern Brazil, Uruguay and north-eastern Argentina (Philander, 1990). In estuaries and riverine systems ENSO can affect salinity, temperature and water circulation patterns, disrupting seasonal cycles of primary production (Lehman and Smith, 1991). In the Río de la Plata the hydroclimatic changes have started to be more pronounced since the 70s as a consequence of the increase in

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frequency and intensity of the ENSO events (Nagy, 2006), and have introduced unstable and stressful conditions for the phytoplankton community. In this ecosystem, the Argentinean coastal area called Franja Costera Sur provides the main drinking-water supply for the adjacent cities, and many activities (related to industry, agriculture, cattle raising, navigation, tourism, and sports) are conducted throughout this area. While there are studies on the composition and structure of phytoplankton in the coastal area of this estuary (Gómez and Bauer, 1997; Gómez and Bauer, 1998; Gómez et al., 2002; Gómez, 2014) is still unknown how the ENSO phenomenon can affect this community, and how it can impact on the water quality. In order to explore these responses, the aim of this study was to analyze the density, diversity, biomass and assemblage composition of the phytoplankton in relation to environmental conditions (physical, chemical, hydrological and meteorological variables), measured under the different scenarios caused by the ENSO phenomenon in the period between 2005 and 2012.

2. Material and methods

2.1. Study area

The Río de la Plata is a temperate large coastal plain estuarine system, naturally rich in nutrients and trophically dominated by plankton (López Laborde and Nagy, 1999). The estuary is characterized by a low seasonality in the river discharge; low tidal amplitude (<1 m); a broad and permanent connection to the sea; and high susceptibility to atmospheric forcing, due to its large extension and shallow water depth (Mianzan et al., 2001; Simionato et al., 2004), and the residence time of the estuarine water is between 0.8 and 1.8 months (Nagy et al., 2002a). A submersed sandbar, called "Barra del Indio", divides the system into an inner tidal river and an outer mixing zone, that coincides with the isohaline region of 0.5 practical salinity units (~1000 μS cm^{-1}). The tidal freshwater zone, in which our study area is located, has depths lesser than 5 m and covers an area of about 13,000 km^2 (Mianzan et al., 2001; Acha et al., 2008). Over 97% of the water discharge to the Río de la Plata is provided by the Uruguay river (4600–5300 m^3 s^{-1}) and Paraná river, formed by two tributaries, Paraná Guazú and Paraná de las Palmas, discharging between 17,000 and 21,700 m^3 s^{-1}; the latter remains constrained along the straight edge of the southern shore (called Franja Costera Sur) of the Río de la Plata (FREPLATA, 2005; Silva et al., 2013).

The discharge shows peaks of variability at inter-annual timescales associated with the ENSO cycles, which induce floods (warm phase) or droughts (cold phase) with a variation of up to 80,000 m^3 s^{-1} from dry to humid extremes (Niño and Niña, respectively) (Clara et al., 2014).

For this study, six sampling sites located on the Franja Costera Sur of the Río de la Plata were selected, with depths between 0.4 and 1 m, covering almost 100 km of coastline. In this area there are three freshwater intakes in sites S1, S2 and S5, which provide 89% of the drinking water for mainly two urban centers (city of Buenos Aires and city of La Plata). In site S3 a sewage discharge point for the city of Buenos Aires is located, which affects site S4 directly, while the sewage discharge point for the city of La Plata is located upstream from site S6 (Fig. 1).

2.2. Samples collection

Twelve sampling campaigns from a monitoring program performed in the study area between 2005 and 2012 were selected,

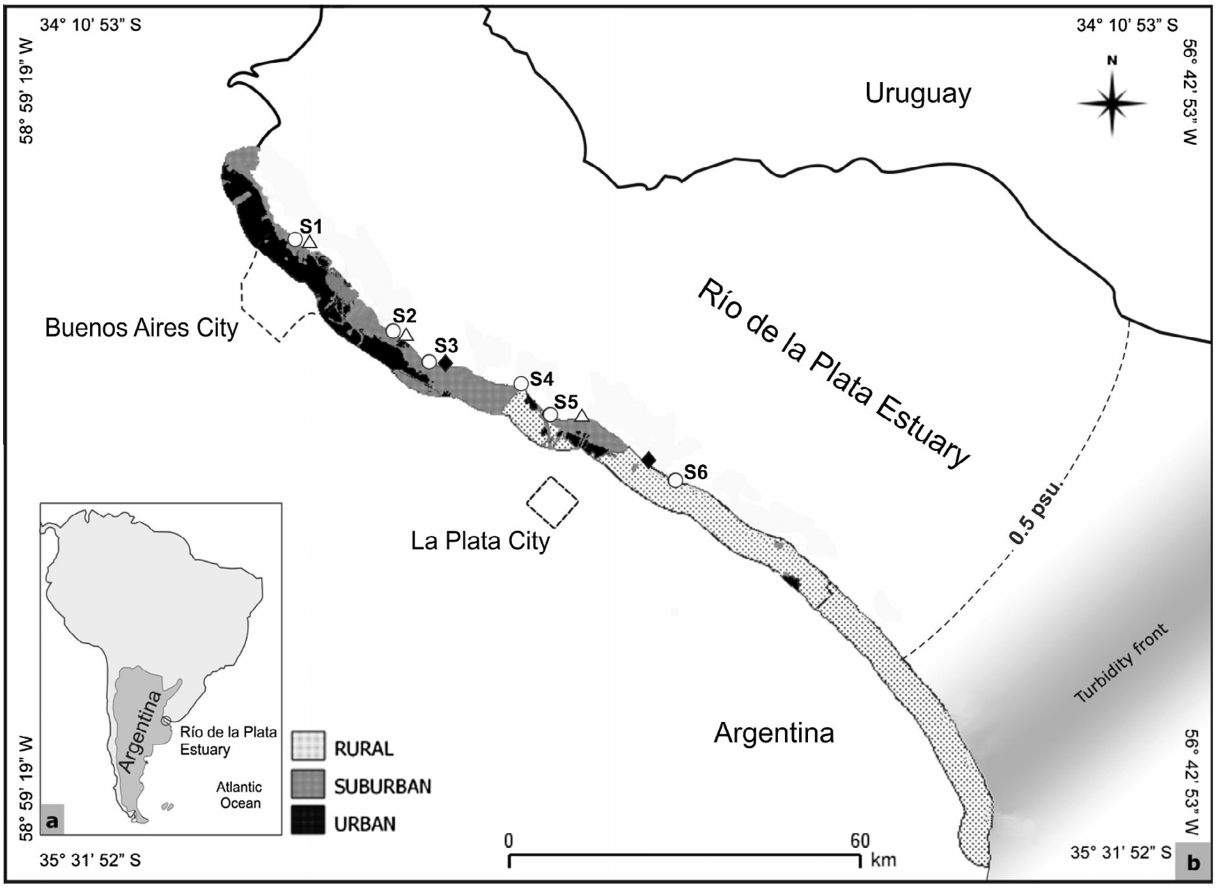

Fig. 1. Map of the study area, showing the different land uses on the coast (rural, suburban and urban). White circles indicate the sampling sites, triangles indicate the water intakes and diamonds indicate the sewage discharges.

and were classified by their ENSO status in Niño/Niña/neutral, using the Southern Oscillation Index (SOI) values (Kiladis and van Loon, 1988) provided by the Argentinean meteorological service (Servicio Meteorológico Nacional, www.smn.gov.ar). The SOI is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia. The SOI is one measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific during El Niño and La Niña episodes. Three months sustained negative values of the SOI below −8 often indicate El Niño episodes while sustained positive values of the SOI above +8 are typical of La Niña episodes (Trenberth, 1997). Monthly mean values for discharge and rainfall were provided by Prefectura Naval Argentina (www.prefecturanaval.gov.ar) and the Argentinean meteorological service respectively.

Samples collected in November 2005, February 2007, March 2009, and May 2012 corresponded to neutral cycles; samples collected in September and December 2009, March 2010 and September 2012 corresponded to El Niño cycles; and samples collected in November 2007, May 2008, October 2010 and March 2011 corresponded to La Niña cycles.

Subsurface water samples (125 mL) for the analysis of phytoplankton were collected in triplicate at each sampling site during ebb tide. They were preserved with formalin (final concentration, 2% [v/v]).

Temperature, pH, conductivity, turbidity and dissolved oxygen were measured in the field with an Horiba U-50 multiparametric sensor. Subsurface water samples for dissolved nutrient analysis (200 mL) and for chlorophyll-*a* analysis (1 L) were collected, promptly filtered through glass fiber filters (Whatman GF/C, 1.2 μm pore) and transported refrigerated to the laboratory for analysis.

2.3. Phytoplankton analysis

Phytoplankton counts were carried out using an inverted microscope Olympus IX51 at 400X and 600X, using 5 mL sedimentation chambers, which were left to settle at least twelve hours. The amount of fields counted depended on the frequency of the species present, since it is recommended that at least 100 individuals of the most present species are counted. Algal density was expressed in cell mL^{-1} according to the equation (Lund et al., 1958; Clesceri et al., 1998; Elosegui and Sabater, 2009):

$$\text{Cells mL}^{-1} = CA_t/A_c T_c V$$

being C: number of counted organisms
A_t: total area of the chamber (mm^2)
T_c: total number of counted fields
V: volume of sedimented sample (mL)

Specific keys were used for taxonomic identification of phytoplankton.

The species diversity was calculated by the Shannon–Wiener index $H' = \Sigma\ (P_i \times \log_2 P_i)$, where $P_i = n_i/N$. Results were expressed in bits ind^{-1}, since the base of the logarithm in the equation is two (Shannon and Weaver, 1949).

2.4. Analytical methods

Soluble reactive phosphorus, nitrite and ammoniacal nitrogen were determined colorimetrically; nitrate was reduced to nitrite before colorimetric measurement (Mackereth et al., 1978).

Chlorophyll a was determined spectrophotometrically using a Labomed spectrophotometer. Chlorophyll-*a* extraction was conducted using 90% [v/v] aqueous acetone as solvent (Clesceri et al., 1998) and its final concentration calculated according to Lorenzen (1967).

2.5. Statistical analysis

Nonparametric Kruskal–Wallis ANOVA was used to find significant differences between neutral, La Niña and El Niño cycles, and Dunn's method was used as the *a posteriori* test.

A Canonical Correspondence Analysis (CCA) was employed to explore the relationship between the species density and the environmental variables. For this analysis only those species with a frequency greater than 10% and a relative abundance greater than 1% in at least one sample were taken into account. The exclusion of rare taxa is a common practice since it complicates the output of the analysis, masking any possible effects on the more abundant taxa, due to random chance. (Marchant, 2002). Since the gradient length in standard deviation units in a preliminary Detrended Correspondence Analysis (DCA) was close to 4 units, unimodal species response model could be expected and a CCA is recommended (ter Braak and Smilauer, 1998). Only the environmental variables with a variance inflation factor <10 were retained in the analysis, because a greater value would indicate multicolinearity among variables (ter Braak and Verdonschot, 1995). The overall significance of the ordination and the significance of the first axis were tested with a Monte Carlo permutation test ($p < 0.01$) using unrestricted permutations.

The percentage of similarity between communities was used to analyze the assemblages at different periods, calculated from the formula proposed by Whittaker (1952 in Stevenson and Bahls, 1999), where 0% indicates no similarity between groups and 100% maximum similarity.

3. Results

3.1. Hydrological, meteorological and physical chemical

The fluctuations observed in the SOI values during the period under review showed a maximum negative value of −10.6, corresponding to a period of the El Niño, in March 2010. While the highest positive SOI value in the sampling period was 21.4,

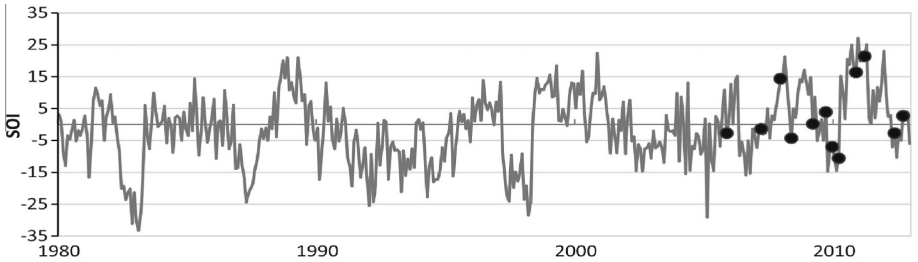

Fig. 2. Southern Oscillation Index, monthly values for the last three decades. Black circles indicate the analyzed periods.

Table 1
Mean values (± standard deviation) of physical chemical variables, and *a posteriori* test (Dunn's method) results for neutral (*n*), La Niña (LN) and El Niño (EN) periods.

	Neutral	La Niña	El Niño	Dunn's test
Temperature (°C)	26.1 ± 6.3	25.4 ± 5	21.2 ± 9.4	
Turbidity (NTU)	74 ± 62	309.4 ± 131.6	222 ± 223.1	LN > *n*
Conductivity (μS cm^{-1})	352 ± 110	562.1 ± 622.9	446.3 ± 179.3	
pH	8.2 ± 0.6	8.2 ± 0.4	8.2 ± 1.2	
Oxygen saturation (%)	101 ± 28	95 ± 34	94.2 ± 21.4	
PO_4^{3-}–P (mg L^{-1})	0.3 ± 0.11	0.28 ± 0.12	0.33 ± 0.34	
NO_3^-–N (mg L^{-1})	1.37 ± 1.03	1.23 ± 0.48	0.75 ± 0.51	LN > EN
NO_2^-–N (mg L^{-1})	0.06 ± 0.06	0.07 ± 0.06	0.12 ± 0.23	
NH_4^+–N (mg L^{-1})	0.26 ± 0.46	0.16 ± 0.19	0.36 ± 0.45	
DIN (mg L^{-1})	1.7 ± 1.16	1.5 ± 0.6	1.2 ± 0.9	
DIN/SRP	5.8 ± 2.7	5.9 ± 3.3	6.3 ± 5.5	
Rainfall (mm)	107.3 ± 56.4	31.8 ± 13.1	128 ± 49.6	LN < *n* = EN
Discharge (m^3 s^{-1})	4472 ± 941	4460 ± 516	5892 ± 1624	

corresponding to a La Niña cycle, in March 2011, and was one of the highest in recent decades (Fig. 2).

The highest rainfalls in the study area and discharges of the Paraná de las Palmas river were observed during El Niño cycles, while the highest values of turbidity and conductivity corresponded to La Niña periods. Nutrients showed that, while the concentrations of phosphate and reduced forms of nitrogen were slightly higher during El Niño periods, nitrate concentrations were higher during neutral periods. DIN/SRP ratios were slightly higher during El Niño cycles (Table 1).

Of the variables mentioned above, only rainfall, turbidity and nitrate concentrations showed significant differences ($p < 0.05$) among the different cycles (Table 1).

3.2. Phytoplankton density and biomass

The average density and chlorophyll-*a* values were lower during periods of El Niño, being lower than 7000 cells mL^{-1} and 21 mg L^{-1} in density and chlorophyll *a* concentrations respectively. In neutral periods the highest average densities of phytoplankton (16,300 cells mL^{-1}) and chlorophyll *a* (32 mg L^{-1}) were measured. However, extreme values in total density were observed from October to November 2010, corresponding to a period of La Niña, reaching concentrations of 137,000 cells mL^{-1}, which coincided with the highest chlorophyll-*a* values (peaking at 124.3 mg L^{-1}) (Fig. 3a and b).

3.3. Phytoplankton composition and diversity

Of a total of 164 euplanktonic species identified in the samples, 45 had a frequency higher than 10% and a relative abundance greater than 1% in at least one sample (Table 2).

The diversity was significantly lower during El Niño periods ($p < 0.05$), with mean values of 1 bit ind^{-1} and a maximum of 3 bit ind^{-1}. During neutral and La Niña periods the mean values were similar, with maximum values up to of 3.7 bits ind^{-1} in both periods (Fig. 3c).

The analysis of major phytoplankton groups (Fig. 4) showed that during neutral periods Cyanobacteria was the most abundant group, peaking at 38,000 cell mL^{-1}; during periods of La Niña the Chlorophyceae were the dominant group, with a maximum of 136,000 cell mL^{-1}; while during periods of El Niño, Bacillarophyceae dominated with a maximum of 27,000 cell mL^{-1}. Other groups such as Euglenophyceae and dinoflagellates were less represented, not exceeding 150 cell mL^{-1} and 900 cell mL^{-1} respectively, both values corresponding to El Niño periods.

The analysis of similarity between the assemblages of each period (La Niña, El Niño and neutral) showed about 60% similarity between them. The assemblages were mainly composed of

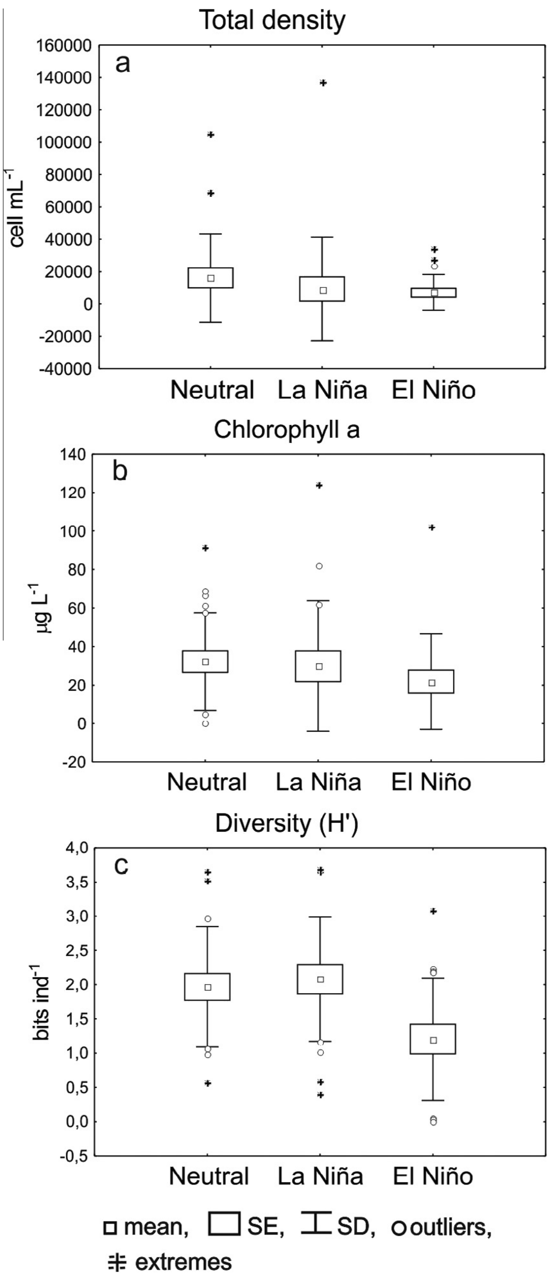

Fig. 3. Boxplots showing total density (a), chlorophyll *a* (b) and Diversity index (c) for the three analyzed periods.

Table 2
Mean densities of most abundant and frequent species: *>0–1 cell mL^{-1}, **>1–10 cell mL^{-1}, ***>10–100 cell mL^{-1}, ****>100–1000 cell mL^{-1}, *****>1000 cell mL^{-1}. The acronyms used in the CCA are shown here.

Acronym	Species	Neutral	La Niña	El Niño
	Cyanobacteria			
CLIM	*Chroococcus limneticus* Lemm.	***	*	
MGLA	*Merismopedia glauca* (Ehr.) Kütz.	*****	***	**
MTEN	*M. tenuissima* Lemm.	*****	****	*****
MAER	*Microcystis aeruginosa* Kütz.	**	**	
PAGA	*Planktothrix agardhii* (Gom.) Anagn. et Kom.	*	*	***
	Euglenophyceae			
EACU	*Euglena acus* Ehr.		*	*
ELIM	*E. limnophila* Lemm.	*	*	**
ESPP	*Euglena* spp.	**	*	
PGRA	*Phacus granum* Drezepolski	*	*	**
	Chlorophyceae			
AHAN	*Actinastrum hantzschii* Lagerh.	***	**	***
CACV	*Closterium acutum* var. *variabile* (Lemm.) Krieger	*		
CAST	*Coelastrum astroideum* De-Not	**		**
CMIC	*C. microporum* Näg.	**	*	**
CQUA	*Crucigenia quadrata* Morr.	***	**	**
CREC	*Crucigeniella rectangularis* (Näg.) Gay	**	**	**
DEHR	*Dictyosphaerium ehrenbergianum* Näg.	***	***	
DPUL	*D. pulchellum* Wood	*****	*****	****
DSUB	*D. subsolitarium* Van Goor	***	**	
EFOT	*Eutetramorus fotti* (Hind.) Kom.	***	****	***
KAPE	*Kirchneriella aperta* Teil.	*	*	*
KCON	*K. contorta* (Schmidle) Bohl.	**		
KOBE	*K. obesa* (W. West) Schmidle	***	**	**
MARC	*Monoraphidium arcuatum* (Korš.) Hind.	**	*	**
MGRI	*M. griffithii* (Berk.) Kom.-Legn.	**	*	**
MKOM	*M. komarkovae* Nyg.	**	*	*
MMIN	*M. minutum* (Näg.) Kom.-Legn.	***	*	**
MTOR	*M. tortile* (W. & G. S. West) Kom.-Legn.	**	*	*
OBOR	*Oocystis borgei* Snow	**	**	**
PMOR	*Pandorina morum* (Mull.) Bory de Saint-Vincent	**	*	**
PDUP	*Pediastrum duplex* Meyen	***	***	
SACU	*Scenedesmus acuminatus* (Lagerh.) Chod.	***	**	**
SECO	*S. ecornis* (Ehr.) Chod.	**	**	**
SINT	*S. intermedius* Chod.	***	**	**
SOPO	*S. opoliensis* P. Richt.	**	**	*
SQUA	*S. quadricauda* (Turpin) Brébisson	**	**	**
TGLA	*Tetrastrum glabrum* (Roll) Ahlstr. & Tiff.	***	**	***
	Bacillariophyceae			
ANMN	*Actinocyclus normanii* (Greg. Ex Grev.) Hust.	****	***	**
AUDI	*Aulacoseira distans* (Ehr.) Sim.	**	***	*
AUGR	*A. granulata* (Ehr.) Sim.	**	**	*
AUGA	*A. granulata* var. *angustissima* (Müll.) Sim.	***	**	**
CAGR	*Cyclotella atomus* var *gracilis* Genkal et Kiss	*****	**	***
CMEN	*C. meneghiniana* Kütz.	****	***	***
CYC	*Cyclotella* spp.		**	
SKEL	*Skeletonema* spp.	*****	****	*****
TRUD	*Thalassiosira rudolfii* (Bachmann) Hasle	**	*	**

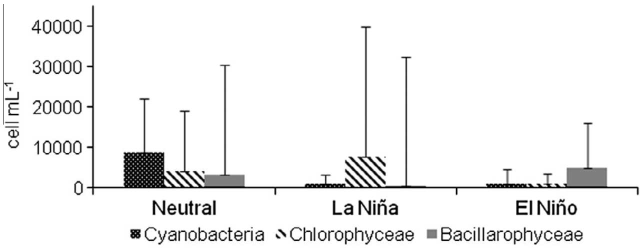

Fig. 4. Mean densities (+standard deviation) of major phytoplankton groups in the three studied periods.

chlorococcalean as *Dictyosphaerium pulchellum* and *Eutetramorus fottii*, diatoms as *Skeletonema* spp., *Cyclotella atomus* var. *gracilis* and *Cyclotella meneghiniana* and cyanobacteria as *Merismopedia tenuissima*, *Merismopedia glauca*, *Microcystis aeruginosa* and *Planktothrix agardhii* (Table 2). The potentially harmful cyanobacteria were represented in all the analyzed periods in low densities, except for *P. agardhii*, with abundances that reached 200 cell mL^{-1} in one El Niño period (September 2012). The most abundant potentially harmful cyanobacteria in La Niña was *M. aeruginosa*, also reaching 200 cell mL^{-1} (Table 2). Other harmful species, less abundant, were *Dolichospermum spiroides*, *Microcystis flos-aquae*, *Raphidiopsis mediterranea* and *Raphidiopsis curvata*.

The results of the CCA conducted to identify the relationship between the environmental variables, the species' densities and the samples from the different cycles, are shown in Fig. 5a and b. The two first axes explained 76.3% of the species-environment relationship. The first axis, which modulated primarily the distribution of the species, correlated with conductivity, DIN/SRP rates, rainfall, nitrates and the Paraná de las Palmas discharge. Subordinated to these variables, pH, turbidity, temperature and phosphate were associated with the second axis. The species analysis, after classifying the samples in La Niña, El Niño and neutral periods, revealed an overlapping of assemblages, not allowing a clear differentiation of exclusive species between periods. These results are consistent with the high percentage of similarity between the assemblages in the different periods, as noted above.

4. Discussion

Hydrologic events caused by El-Niño conditions have been clearly identified in rivers of South America (Mechoso and Pérez-Iribarren, 1992; Pisciottano et al., 1994; Caviedes and Waylen, 1998). Nagy (2006) recognizes that the hydroclimatic change in the Río de la Plata, as a consequence of the increase in frequency and intensity of ENSO events, have introduced unstable conditions and stress factors for the phytoplankton. The results obtained in this study support this idea, revealing changes in the structure of the phytoplankton in the study area, such as a significant reduction in phytoplankton diversity during El Niño periods. During this period, we also observed a reduction in biomass and density, and changes in species proportion, but they were not statistically significant. These responses were fluctuant in the study area, as a result of the natural variability of the estuary and the anthropogenic impacts to which the coastal area is exposed to (Gómez, 2014). It is recognized that estuarine and coastal systems are highly dynamic in their hydrology, nutrient cycles, and biotic resources. Hydrologically, freshwater runoff interacts with tidal saltwater and variable winds, leading to complex circulation and mixing patterns. These patterns, shaped by climatic forcing features (i.e., temperature, rainfall, winds) that vary over multiple time and space scales, strongly influence the chemical and biological characteristics and responses of these ecosystems to environmental changes, and to natural and anthropogenic perturbations (Paerl et al., 2010). Jennerjahn and Mitchell (2013) identified the major hazards to estuarine ecosystems as belonging to three categories: human activities, global climate change and extreme events. Coincidently, the Río de la Plata estuary is affected by increasing human and climatic pressures, such as changes in land use and soil erosion, inputs of nutrients and untreated sewages, increments in atmospheric temperature, rainfall, fluvial discharge and ENSO variability (López Laborde et al., 2000; Menéndez, 2002; Nagy et al., 2002a,b,c).

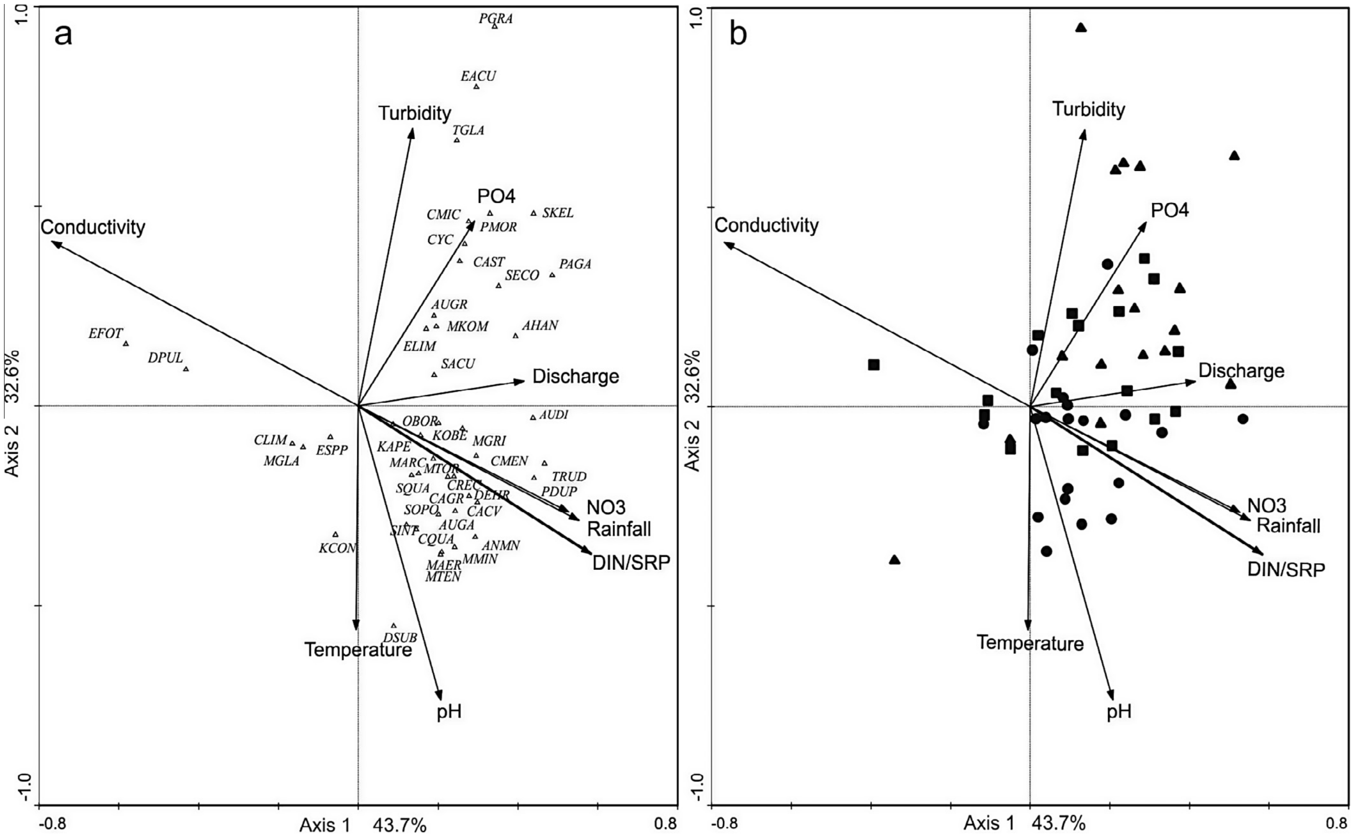

Fig. 5. (a) Biplot of the CCA showing the species distribution (species names corresponding to the acronyms are shown in Table 2). (b) Biplot of the CCA showing the different cases, circles: neutral samples, squares: La Niña samples, triangles: El Niño samples.

As a result of the changes caused by the ENSO phenomenon in the Río de la Plata, in this study it was possible to notice changes in the trophic status of the estuary. Nutrients are the primary cause, but there are many other factors that determine the ultimate level and type of expression of eutrophic symptoms within an estuary including tidal exchange, freshwater inflow, etc (Cloern, 1999; NRC, 2000; Boesch, 2002). Chlorophyll *a* is considered a primary symptom of eutrophication (Bricker et al., 2003). According to the boundary limits of chlorophyll *a* values suggested by Dodds et al. (1998), 47% of the cases during the El Niño cycles corresponded to an oligotrophic state ($<10\ \mu g\ L^{-1}$), while in the remaining periods (La Niña and neutral) it was observed that in over 60% of the cases the chlorophyll-a values corresponded to meso-eutrophic states ($>10\ \mu g\ L^{-1}$). Bricker et al. (2003) suggested another thresholds for chlorophyll *a* as a symptom of anthropogenic impact; using these values we observed that El Niño periods had the greatest percentages of cases (47%) with a Medium impact level ($>5 \leqslant 20\ \mu g\ L^{-1}$), while in the neutral and La Niña periods, most of the samples (45% and 33% respectively) showed a High impact level ($>20 \leqslant 60\ \mu g\ L^{-1}$).

Although the residence time of the water in the estuary was not measured in this study, the river discharge is of importance in its regulation; during periods of peak discharges of its tributaries (of $41{,}000\ m^3\ s^{-1}$), residence time is about 73 days, while for periods of lesser discharge ($22{,}000\ m^3\ s^{-1}$) it reaches 136.5 days (Menéndez, 2002; Silva et al., 2013). This factor is considered by Ferreira et al. (2005) as a diversity regulator since it is related to the capacity of algal species to divide faster than they are washed away; hence species composition is at least partly determined by estuarine physics. Therefore the flushing effect that is generated during periods of El Niño, due to a higher flow and lower water residence time, promotes the dilution of phytoplankton, changing its concentration. Variations in community structure were observed in others rivers of the region, also associated with fluctuations in the fluvial discharge (Zalocar de Domitrovic et al., 2007; Devercelli, 2010; Solari et al., 2014).

While the temperature values in the data set analyzed showed no significant differences between neutral, La Niña and El Niño cycles, it was possible to notice that at higher temperatures, such as those observed in the neutral and La Niña periods, phytoplankton growth was higher. Considering that the increase in temperature favors the reduction of generational times (Domis et al., 2007), it is possible to recognize that warmer conditions contribute to increased algal growth by promoting eutrophication in the study area.

The changes related to major phytoplankton groups, even though they were not significant, showed that Cyanobacteria were more abundant in neutral periods, while Chlorophyceae dominated La Niña phase and Bacyllariophyceae dominated El Niño. It was also possible to observe changes in morphology that dominated the phytoplankton at different periods; during La Niña and neutral cycles the development of colonial forms increased, mainly Chlorococcales and Chroococcales groups. This morphological type is functionally related to a more stable condition in the water column (Reynolds, 2006; Huisman et al., 2005). During periods of El Niño, with greater instability in the water column, filamentous forms were dominant, being better adapted to the higher flow rate and increased turbulence accompanied by an increased incidence of winds.

The development of cyanobacteria was more abundant during neutral phases, coinciding with data reported by Andrinolo et al. (2007) that described episodes of blooms during those periods. These organisms have a significant influence on the water quality of the coast of the Río de la Plata, as they have been reported to produce microcystins in hazardous levels to human health (Giannuzzi et al., 2012). The increasing expansion of cyanobacteria to higher latitudes, as a result of their ability to be more competitive in a variety of habitats including estuaries, is an important aspect in relation to water quality. Hydrological changes, such as more extensive droughts, favor cyanobacteria, which prefer longer water residence times (Paerl and Huisman, 2008). Other factors, primarily related to land use, have shown a correlation between the development of cyanobacteria and pollution caused by the expansion of urbanization adjacent to the coast of the Río de la Plata (Gómez et al., 2012; Gómez, 2014), which often has a stronger effect on this sector as a result of a combination of the mechanical effects generated by the wind (direction and intensity) and tides, which favor the accumulation of cyanobacteria on the coast (Sathicq et al., 2014).

The response of the specific composition to the effects of ENSO revealed that there is no significant turnover of species between periods, and the observed pattern would be determined by changes in the relative abundances of taxa rather than by the replacement of some species; therefore it was not possible to differentiate exclusive assemblages for the different cycles (neutral, La Niña, El Niño). According to Reynolds (1997) this type of response would evidence that the structural resilience of the community is higher than the severity of the externally imposed changes.

Finally, in coastal areas of anthropized estuaries such as the one analyzed in this study, whose management requires the knowledge of multiple factors, it is essential to include those that operate at large time scales, such as the ENSO phenomenon. This comprehensive analysis is crucial for the Rio de la Plata as it is a water source to more than 8 million people (Agua y Saneamiento Argentina, www.aysa.com.ar), and therefore a necessary requirement to manage this resource and implement mitigation measures according to the different environmental scenarios, ensuring the ecological integrity of the coastal ecosystem.

In this regard it will be necessary to consider measures to mitigate the adverse effects of phytoplankton increments, particularly those related to water purification, for example, by adjusting the time scale of the monitoring programs on the coast especially during the most favorable development times for cyanobacteria. Considering with special emphasis the neutral and La Niña periods (dry periods), which may enhance the further development of *M. aeruginosa* (Giannuzzi et al., 2012; Sathicq et al., 2014) during such periods to prevent the presence of cyanotoxins in the drinking water.

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