SHORT TERM VARIABILITY OF CHLOROPHYLL *a* AND PHYTOPLANKTON COMPOSITION IN A SHALLOW AREA OF THE PATOS LAGOON ESTUARY (SOUTHERN BRAZIL)

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RESUMO

Variabilidade temporal em curta escala da clorofila *a* e composição de fitoplâncton em área rasa do estuário da Lagoa dos Patos (Sul do Brasil)

A variabilidade temporal em curta escala de clorofila *a*, abundância e composição de ftoplâncton e ciliados e de fatores abióticos foram analisados no estuário da Lagoa dos Patos durante dois períodos, o primeiro na primavera (Outubro/Novembro 2004) e o segundo no verão (Janeiro/Fevereiro 2005). As amostragens foram realizadas em uma estação fixa, a cada 2h30min para as análises de clorofila *a*, salinidade, temperatura, transparência da água, velocidade e direção da corrente e, uma vez ao dia, para as de fitoplâncton e ciliados, *seston* e nutrientes inorgânicos dissolvidos. Na primavera, a direção do vento variou em intervalos de aproximadamente dois dias, e a precipitação pluviométrica foi elevada (212.9 mm), enquanto que no período de verão a direção do vento variou menos, aproximadamente a cada cinco dias, e a precipitação pluviométrica foi menor (32.5 mm). A ação da precipitação pluviométrica e direção do vento controlaram a temperatura, salinidade, transparência da água e clorofila *a* na área rasa do estuário, associados com ciclos mais curtos na primavera do que no verão. O teor dos nutrientes inorgânicos dissolvidos foi diferente nos dois períodos, com o silicato mais alto na primavera (média 108 μM) do que no verão (média 69 μM), e nitrato e amônia, como os principais elementos nitrogenados na primavera e no verão, respectivamente. A presença de espécies lacustres e marinhas na área de estudo esteve associada à relação entre o vento e salinidade, com ventos de Sul favorecendo a entrada de diatomáceas e de dinoflagelados marinhos e, de Nordeste, associados com a descarga de água doce, contendo cianobactérias e clorófitas. A resposta da salinidade e da assembléia planctônica à ação do vento foi mais rápida (escala de horas) na primavera do que no verão (3-4 dias). Foi evidenciado que, processos de alta freqüência mediados pelo vento, gerando flutuações na descarga de água doce, em período similar ao da taxa de divisão celular, 1-2 dias, são de grande importância na ecologia da laguna. As variações no fluxo de água doce, associadas com a direção do vento, controlam a acumulação da clorofila *a* na área de estudo, podendo impedir, atrasar ou favorecer o início da floração de diatomáceas na primavera. No verão, processos herbívoros pelágicos e bentônicos aparentemente têm um importante papel no controle da biomassa do fitoplâncton.

PALAVRAS-CHAVE: vento, salinidade, nutrientes inorgânicos, clorofila *a*, protistas.

ABSTRACT

Short-term variability of chlorophyll *a* concentration, abundance and composition of phytoplankton and ciliates and of abiotic parameters were analyzed at the Patos Lagoon estuary during two seasons, in the austral spring (October/November 2004) and summer (January/February 2005). Sampling was carried out at a fixed station every 2h30min for chlorophyll *a*, salinity, water temperature, transparency, water flow velocity and direction and, once a day, for phytoplankton and ciliates, *seston* and dissolved inorganic nutrients analysis. In austral spring, wind direction changed approximately every two days between northerly and southerly, and rainfall was high (212.9 mm), while in the summer period the wind direction changed less, approximately every five days, and rainfall was low (32.5 mm). The action of rainfall and wind direction fluctuation controlled temperature, salinity, water transparency and chlorophyll *a*, associated with shorter cycles in the spring than in the summer periods. The concentration of inorganic nutrients also differed, silicate was high in the spring (mean 108 μM) compared to the summer (mean 69 μM) period, and the main nitrogen source in spring and summer was nitrate and ammonia, respectively. The presence of freshwater and marine species in the study area was typically a wind-salinity response, with southerly wind inducing the inflow of marine diatoms and dinoflagellates, and NE wind leading to water discharge containing freshwater cyanobacteria and chlorophytes. The time lag of the wind action on the salinity-biotic response was generally short (hour scale) but may be delayed with low rainfall as it was observed in summer. It was shown that high frequency processes, in the same period of cell-division, 1-2 days, are of primary importance for the lagoon ecology. The fluctuation of freshwater outflow and wind driven processes may prevent, delay or prompt phytoplankton biomass accumulation in the estuarine area, acting as the timing mechanism of the diatom spring bloom. In summer, the increased benthic and pelagic herbivore activity apparently acted as an important chlorophyll *a* control typical of top-down processes.

KEYWORDS: wind, salinity, inorganic nutrients, chlorophyll *a*, protists.

INTRODUCTION

The variability of phytoplankton abundance and composition is linked to physical and biotic factors. In estuaries and coastal lagoons, the time scale of water exchange with the sea plays a major role, and the temporal phytoplankton variation, biomass concentration and species composition will mainly be a response to the physical domain dictated by hydrology (Levasseur *et al.* 1984; Bonilla *et al.* 2005). The tidal and seasonal flushing cycles are important signals modulating events predictability in most estuaries and coastal lagoons (Cloern *et al.* 1985; Wolfe & Kjerfve 1986), but wind induced variability is also recognized as an important factor controlling phytoplankton biomass and production (Yin *et al.* 2004; Yeager *et al.* 2005). On the other extreme, climatic changes and anthropogenic impacts are coupled with phytoplankton variations (Lehman 2004). When attempting to

explain the characteristics of phytoplankton biomass and community, the generation time of the organisms must be considered in relation to environmental fluctuations (Harris 1986; Wang *et al.* 2004).

In the large, shallow and microtidal Patos Lagoon, phytoplankton data on seasonal cycles (Abreu *et al.* 1994; Persich *et al.* 1996; Bergesch & Odebrecht 1997), spatial and temporal mesoscale (Odebrecht *et al.* 2005) and a long-term study (Fujita *et al.* unpublished data) all indicate the importance of rainfall in the hydrographic basin on seasonal variability and phytoplankton biomass accumulation patterns.

In contrast, little is known about the phytoplankton short-term variability in the Patos Lagoon, which is fundamental to better understand basic environmental functioning mechanisms. The only short-term study was conducted in the relatively deep main channel (15 m depth) at the mouth of the Patos Lagoon estuary (Abreu 1987). In this area, phytoplankton chlorophyll *a* was highly variable in the scale of hours and days, closely related to the wind and water exchange between freshwater runoff (northerly winds) and coastal saltwater inflow (southerly winds). The wind regime was coupled with the passage of cold fronts in the region, and influenced the salinity, temperature, transparency, nutrient and chlorophyll *a* concentrations. The author suggested that the short time scale would influence large-scale phytoplankton variability in the estuary and lately the annual primary production. However, phytoplankton primary production in the deeper main channel is severely light limited, while inshore, light availability becomes less critical and nutrients may play a role (Odebrecht *et al.* 2005). In the shallow inshore estuary, high biomass is observed in the main growing seasons, the spring and summer (Seeliger *et al.* 1997). Conspicuous diatom blooms (chlorophyll *a* >20-70 µg L-1) are observed during this period, mainly of *Skeletonema costatum*, *Cerataulina bicornis* and *Cylindrotheca closterium* (Abreu *et al.* 1994; Bergesch & Odebrecht 1997; Odebrecht & Abreu 1997). The Patos Lagoon estuary sustains fisheries of shrimps (*Farfantepenaeus paulensis*) and fish (Ariidae, Atherinidae, Mugilidae, Sciaenidae) partly due the high primary productivity of the shallow areas, important to the reproduction and growth of species of economic importance (D'Incao 1991; Vieira & Castello 1997; Garcia *et al.* 2001).

The main objective of this study is to evaluate the short temporal phytoplankton variability (daily scale) in the shallow area at the western side of Patos Lagoon estuary during the main growing season, the spring and summer periods, and identify the main controlling factors of the biomass and taxonomic composition. The comparison of spring and summer periods will give additional insight in understanding the production processes in this economically important subtropical coastal lagoon.

STUDY LOCATION

Patos Lagoon in southern Brazil is the world's largest chocked coastal lagoon (Fig. 1), characterized by a single entrance channel, long residence time, and wind forced hydrology (Kjerve 1986). In the southernmost region, the estuary proper comprises approximately 10% of lagoon total area (~10,230 km^2) (Asmus 1997). The tidal range in the estuary is minimal (mean 0.40 m) because of the geographic location near an amphidromic point and its chocked condition restricting water exchange (Möller *et al.* 1991). Water circulation in the main channel shows two main patterns: (1) during low-river discharge the wind controls circulation driving marine water in (southwest winds) or brackish water out (northeast winds) the lagoon; (2) during flood periods, the seaward flow forced by river discharge can only be reversed by strong southwest winds. Water depth in the main channel, which is the navigation channel, is 6 m to >15 m deep. The remaining area is predominantly shallow, 70% is less than 2 m deep (Bonilla & Asmus 1994) and at the western side of the estuary adjacent to Rio Grande city, embayment and some islands restrict the circulation compared to the navigation channel. The main nutrient load in the estuary derives from land runoff of the drainage basin, domestic and industrial sewage from adjacent cities (Rio Grande and Pelotas, approximately 500,000 inhabitants) and the introduction of agricultural fertilizers (Niencheski *et al.* 1999).
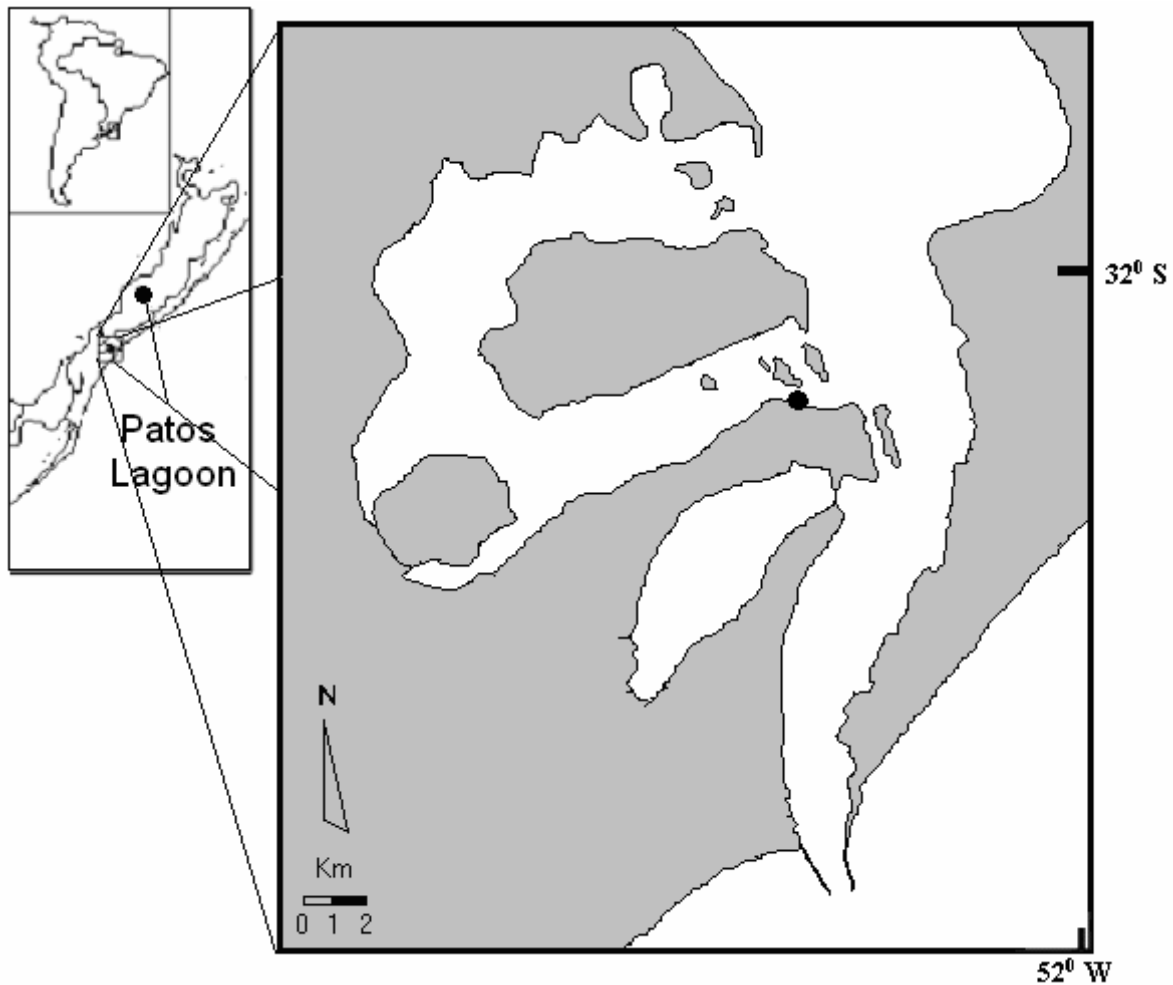
FIGURE 1 – Sampling station (●) at the pier of the Oceanographic Museum, Rio Grande city, in the Patos Lagoon estuary, southern Brazil.

MATERIAL AND METHODS

Daily sampling was performed in the shallow area (~2.0 meters), at the pier of the *Oceanographic Museum*, Rio Grande city, of the Patos Lagoon estuary (Fig. 1), during 35 days in austral spring (October/November 2004) and 30 days in summer (January/February 2005). Wind and rainfall data were obtained from the Meteorological Station of Rio Grande University. Surface water was collected every 2h30min during the light period (4 and 5 samples per day in spring and summer, respectively), and water temperature (T, ±0.1°C), salinity (S, ±0.01; thermosalinometer YSI) and transparency (Tr, Secchi disk) were measured in situ. The water flow intensity and direction were estimated by the time a buoy roamed a distance of 10 m. Two flow directions were considered, the outflow from the West to East, and the inflow from the East to West. Triplicate water samples (30-100 ml) were filtered (Whatman GF/F Ø25 mm) and extracted with acetone 90% v/v over 24 hours at low temperature (-16°C) in the dark. The chlorophyll *a* concentration (Chl *a*) was estimated measuring the fluorescence in a calibrated fluorometer (Turner TD-700), without acidification (Welschmeyer 1994).

The phytoplankton and ciliates (daily samples) were fixed with neutral Lugol's solution 1% v/v (Throndsen 1978; Gifford & Caron 2000). Aliquots of 2.0, 5.0 or 10.0 ml were counted in sedimentation chambers with an inverted Nikon microscope (magnification 200x) according to the Utermöhl's method (1958). The whole chamber or fields was analyzed and at least 100 cells were counted, in order to maintain the relative error of 20%. The organisms were identified to genus and whenever possible to the species level. Nanoflagellates were not identified

but counted (fields) in the size classes, 5 to 10 μm and 10 to 20 μm. Counting of flagellates <5 μm was handicapped by the presence of high *seston* content in samples.

Surface water was sampled daily for the analysis of *seston* (Strickland & Parsons 1972) and dissolved inorganic nutrients (NO_2^-, NO_3^-, SiO_2, PO_4^{-3} – Strickland & Parsons 1972; NH_4^+ – UNESCO 1983), except in the spring between October 10 and November 3, when sampling was conducted every three days.

STATISTICAL ANALYSIS

The Chl *a* dataset was analyzed by the Kendall-τ test aiming the search of variation patterns. The cycles found were tested by the analysis of variance (ANOVA) with *post-hoc* test-t for unequal samples (Sokal & Rohlf 1981). Seasonally, the Chl *a* and abiotic parameters were compared with the non-parametric Kruskal-Wallis test, as data did not attend parametric methodos criteria (normal distribution and homogeneity).

RESULTS
ENVIRONMENTAL CHARACTERISTICS

In the spring sampling period, rainfall was high in the first week of the study (212.9 mm) and wind direction changed frequently, approximately every two days between northerly and southerly (Fig. 2). In the summer sampling, the wind direction changed less, approximately every five days (Fig. 3), and rainfall was always low (32.5 mm). The wind direction showed influence on the time scale variability of S, T and Tr with higher oscillation in spring than in summer (Figs. 2, 3).

In austral spring, the values of water T (mean 19.9 ^{o}C) and S (mean 8.2) were lower than in the summer period (T mean 25.0 ^{o}C; S mean 29.0) (T H = 48.152, p = 0.000; S H = 37.642, p = 0.000) (Table 1). In the former, cycles of high S (10-30) and low water T coincided with the passage of cold fronts while in the summer high S prevailed (>30), except the two periods following northerly winds when S decreased to $\cong$10 (Figs. 2, 3). The Secchi disk Tr was generally small (0.2-1.4 m; mean 0.7 m), lowest values coinciding with highest *seston* load.

In spite of marked differences in T and S values in both sampling periods, the mean Chl *a* was similar (spring 6.4 μg L-1; summer 6.7 μg L-1; H = 0.2202; p = 0.639) (Table 1), and no statistical significant relatedness was found between Chl *a* and wind direction and velocity, water T, S or Tr, due to relatively high Chl *a* diurnal and daily variability (Figs. 2, 3). However, in the spring period, a significant bimodal pattern was evident (F = 60.788; p <0.05) with low Chl *a* (mean 4.8 μg L-1) in the beginning of the study period (October 10-27), and higher values (mean 8.2 μg L-1; maximum 18 μg L-1) at the end (October 28 to November 13). In addition, this pattern was closely associated with the bimodal water flow regime at the sampling station, where outflow prevailed during the former, when rainfall was high, and oscillating water flow between strong in- and outflow coincided with the second half sampling period, when rainfall was low. In the summer period, Chl *a* fluctuation was not statistically significant, and the water flow was relatively low oscillating without any significant tendency (Figs. 2, 3).

FIGURE 2 – Short term variation (intervals of 2h30min; n=4 samples d^{-1}) of wind direction and velocity (m s^{-1}), surface water temperature (^{0}C), salinity, depth of Secchi disk (m), water flow (arbitrary scale) and chlorophyll a (µg L^{-1}) in the spring sampling period.
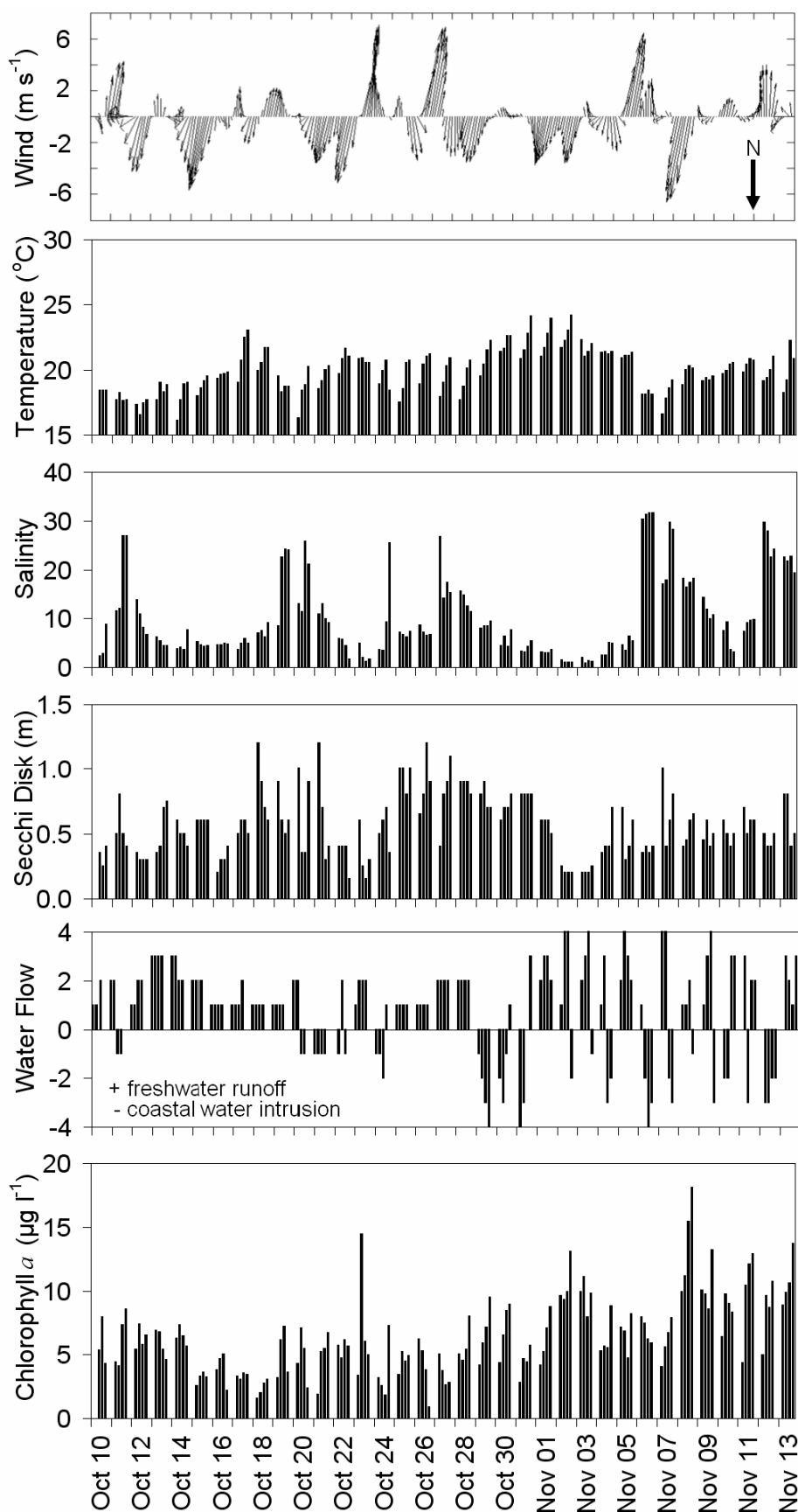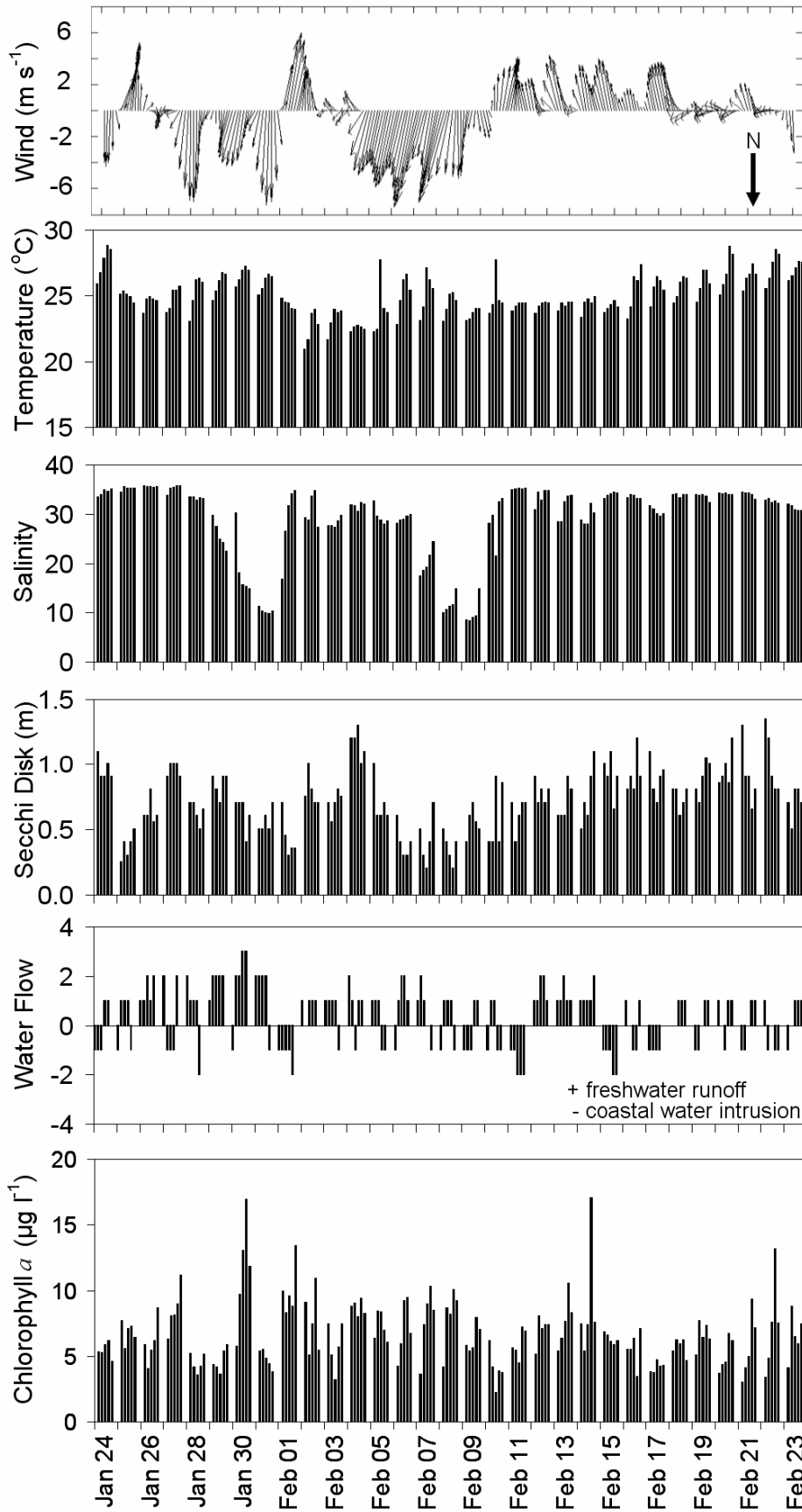
FIGURE 3 – Short term variation (intervals of 2h30min; n=5 samples d^{-1}) of wind direction and velocity (m s^{-1}), surface water temperature (^{0}C), salinity, depth of Secchi disk (m), water flow (arbitrary scale) and chlorophyll *a* (μg L^{-1}) in the summer sampling period.

TABLE 1 – Seasonal mean, range and Kruskal-Wallis analysis results for the parameters measured in the spring and summer periods.

Parameter	Unity	SPRING Mean (min-max)	SUMMER Mean (Min-max)	Kruskal-Wallis (Spring x Summer)
Temperature	(^{o}C)	19.9 (16.1 - 24.2)	25.0 (20.9 - 28.8)	H = 48.152; p =0.000
Salinity		10.2 (0.8 - 31.5)	29.1 (8.2 - 35.7)	H = 37.642; p =0.000
Secchi	(m)	0.6 (0.15 - 1.20)	0.7 (0.2 - 1.35)	H = 5.190; p =0.022
Seston	(mg l^{-1})	158.0 (90.7 - 212.5)	177.4 (79.0 - 261.5)	H = 3.640; p =0.056
SiO$_2$	(µM)	106.9 (59.0 - 144.0)	44.6 (27.20 - 72.7)	H = 33.252; p =0.000
PO$_4^{-3}$	(µM)	1.0 (0.37 - 1.58)	0.9 (0.31 - 1.61)	H = 1.232; p =0.267
NO$_x^-$	(µM)	4.0 (0.51 - 6.72)	1.0 (0.29 -1.94)	H = 28.374; p =0.000
NH$_4^+$	(µM)	3.1 (0.70 - 4.94)	25.6 (3.31 - 60.93)	H = 32.792; p =0.000
DIN	(µM)	7.1 (4.17 - 10.71)	26.6 (4.70 - 61.68)	H = 26.282; p =0.000
Chlorophyll a	(µg l^{-1})	6.4 (0.89 - 18.05)	6.7 (2.17 - 17.02)	H = 0.220; p =0.639
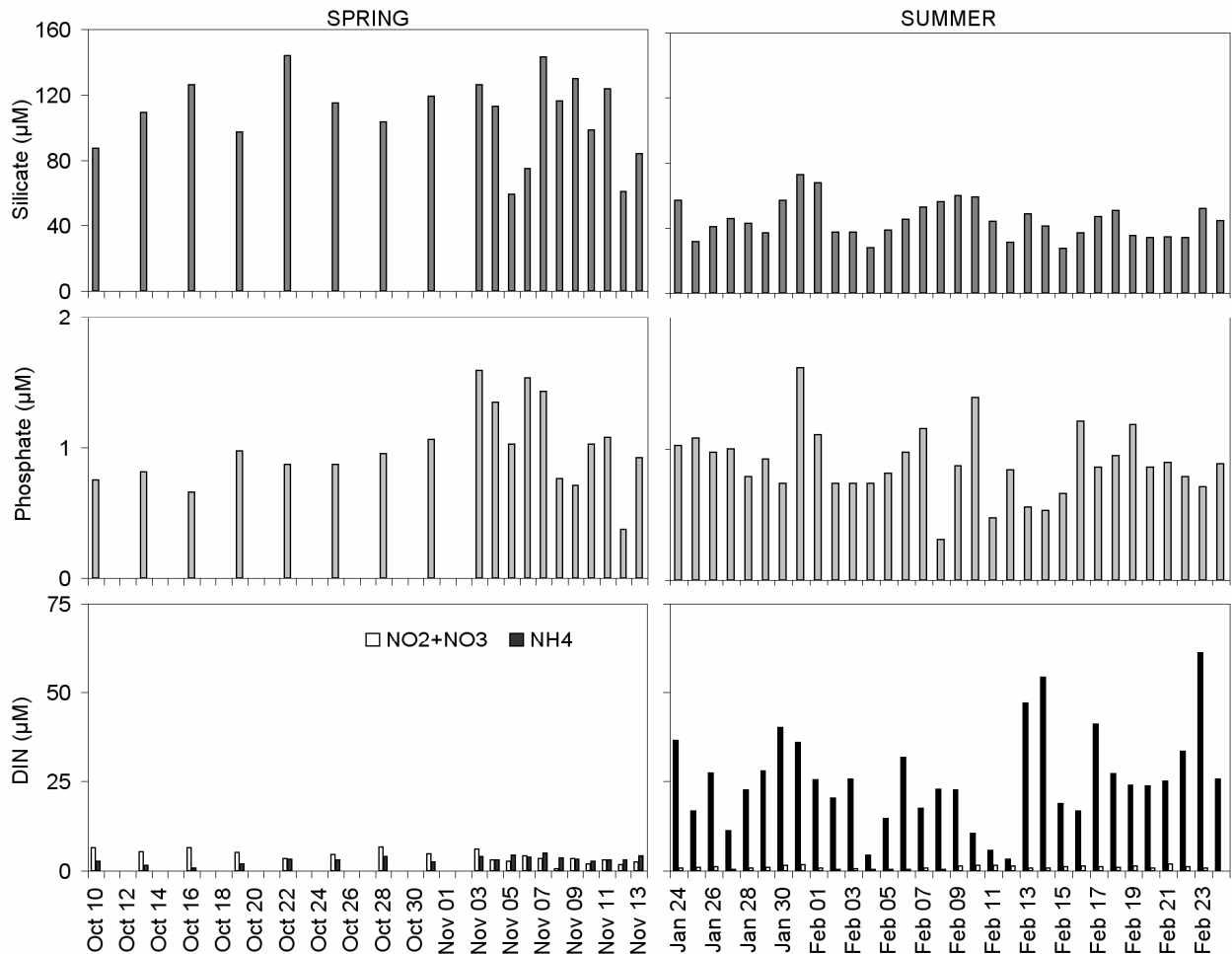
FIGURE 4 – Concentration (µM) of silicate, phosphate and dissolved inorganic nitrogen (DIN) in the spring (n=19 samples) and summer (n=31 samples) sampling periods.

The concentration of dissolved inorganic nutrients differed largely in the two sampling periods (Fig. 4; Table 1). Silicate concentration was higher in the spring (mean 108 µM) than in summer (mean 69 µM) (H = 33.252, p = 0.000), coinciding with lower and higher salinity, respectively. In contrast, dissolved inorganic nitrogen was high in the summer (mean 26.58 µM) (H = 26.282, p = 0.000), mainly due to NH_4 (mean 25.61 µM), while in the spring period the concentration of NH_4 (mean 3.17 µM) and of NO_2+NO_3 (mean 3.80 µM) was similar. Phosphate showed low and similar concentration (H = 1.232, p = 0.267) in both periods (mean ~1 µM). The resulting N:P atomic ratio, indicated that nitrogen availability was always low in spring (N:P 4-11; mean 7) compared to the summer period (N:P 6-104; mean 34). Silicate availability in spring was always high (N:Si 0.04-0.12; mean 0,07) while in summer, nitrogen sometimes exceeded silicate concentration (N:Si 0.15-1.33; mean 0.60).

PHYTOPLANKTON AND CILIATES

Nanoflagellates (5 to 20 µm) were the most abundant organisms in the two sampling periods, with concentration of 10^6 cells L^{-1} in the spring and 10^5 cells L^{-1} in the summer, showing minor oscillations during the sampling periods (not shown).

FIGURE 5 – Daily variation of diatoms, in the spring and summer sampling periods.

Diatoms were the second most abundant organisms in the two periods (mean 17.4 10^3 cells L^{-1}). With few exceptions, most diatom species were observed in both the spring and summer samplings (Table 2), but pennate benthic *taxa* predominated in the 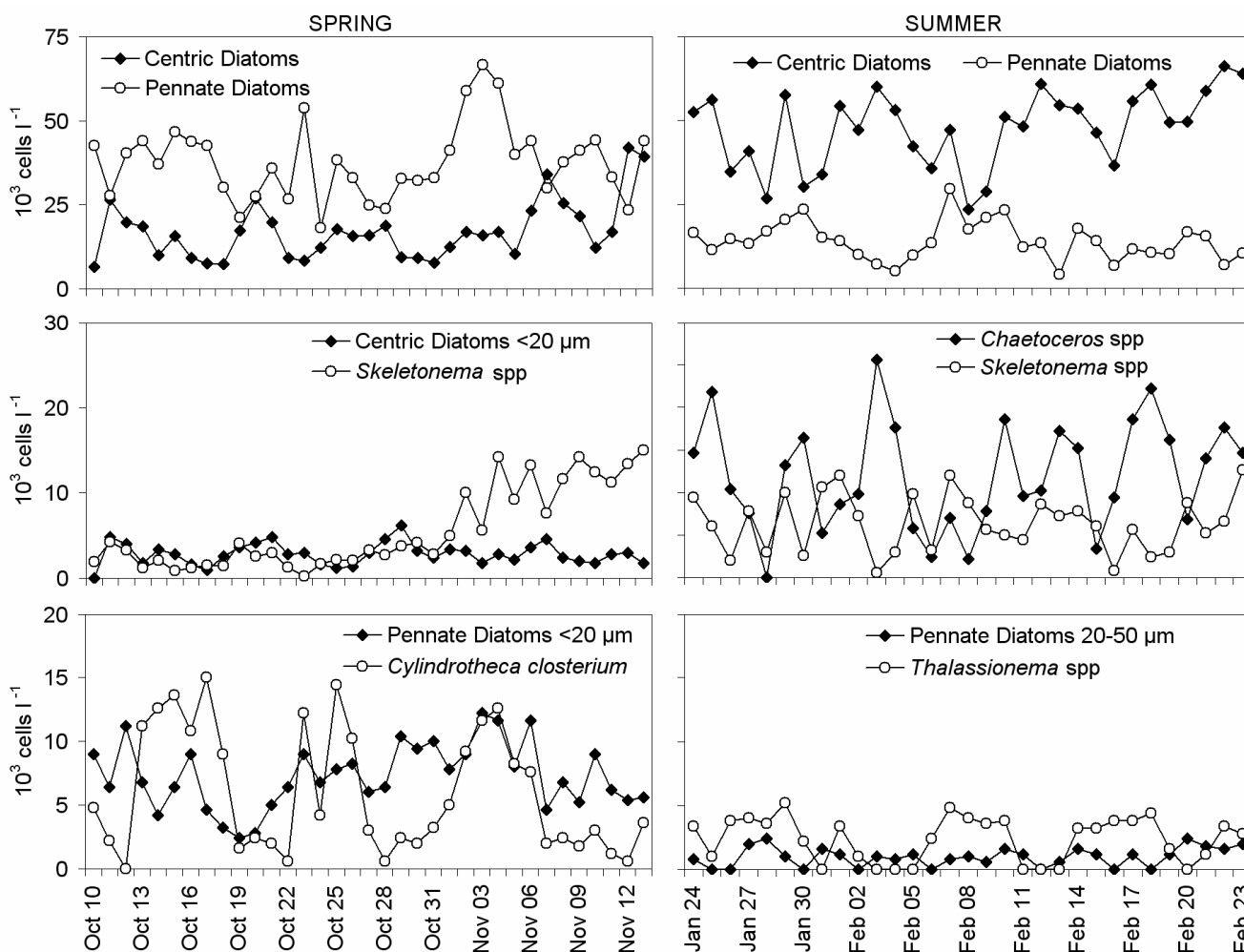former and centric diatoms in the latter, presenting an opposite short-term variation trend (Fig. 5). The daily fluctuation of some pennate diatoms was inversely related to the salinity variation in spring, as shown for *Cylindrotheca closterium* (see Figs. 2, 5), while the centric *Skeletonema costatum* presented a parallel trend with increased abundance (15 10^3 cells L^{-1}) and salinity at the end of sampling. The main pennate diatoms in spring were *Bacillaria paradoxa*, *Entomoneis alata*, *Rhopalodia* sp., *Surirella* sp., *Synedra* sp., and small species (< 20 μm; mean 7.2 10^3 cells L^{-1}). In summer, the main cells were centric marine (*Chaetoceros* species, mean 11.9 10^3 cells L^{-1}), other coastal marine diatoms, (*Asterionellopsis glacialis*, *Campylosira cymbelliformes*, *Cerataulina* spp., *Guinardia spp.*, *Odontella* spp., *Rhizosolenia* spp., *Skeletonema* spp. *Thalassionema* spp.), and pennate cells in the size range of 20-50 μm, in low abundance (<2.4 10^3 cells L^{-1}; Table 2).
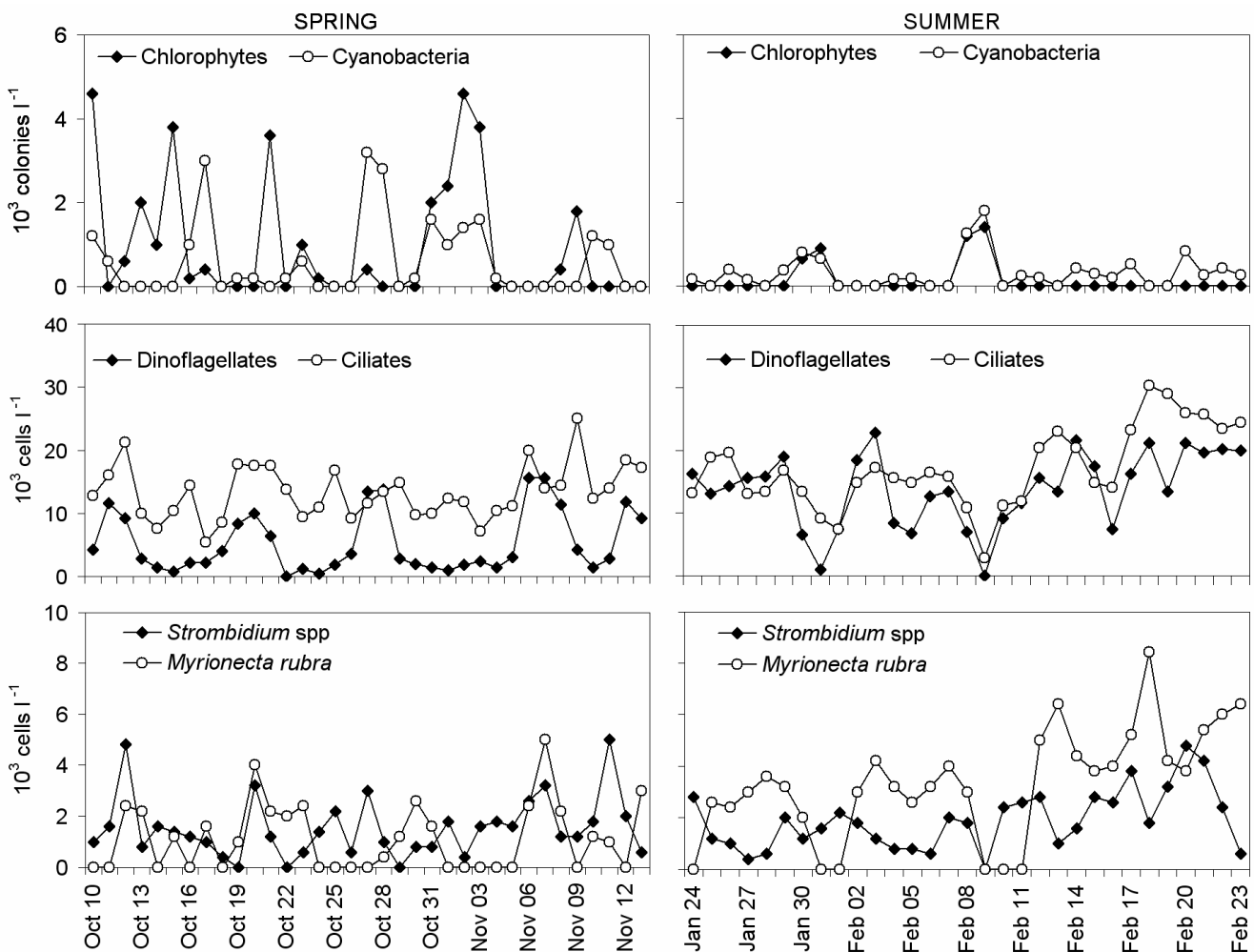
FIGURE 6 – Daily variation of chlorophytes, cyanobacteria (colonies L^{-1}), dinoflagellates and ciliates, *Strombidium* spp. and *Myrionecta rubra* in the spring and summer periods.

The cyanobacteria (mean 0.6 10^3 colonies L^{-1}) and chlorophytes (mean 0.8 10^3 individuals L^{-1}) were more abundant in the spring but were also observed in the summer period, typically related to low salinity (Fig. 6; Table 2). Freshwater species of the orders Nostocales (*Anabaena*, *Aphanizomenon*), Oscillatoriales (*Lyngbia*, *Oscillatoria*, *Planktolyngbia*) and Chroococcales (*Aphanocapsa*, *Aphanothece*, *Merismopedia* and *Microcystis*), and the marine filamentous *Trichodesmium* were the main cyanobacteria. The chlorophytes included *Closterium*,

Scenedesmus, *Staurastrum*, *Pediastrum* and *Planctonema* species. In the summer, these groups were restricted to the two low salinity periods, the cyanobacteria *Oscillatoria* and *Merismopedia* and the chlorophytes *Closterium* and *Scenedesmus*.

The higher abundance of dinoflagellates coincided with coastal water intrusion, presenting higher number in the summer (mean 13.7 10^3 cells L^{-1}) than in spring samples (mean 5.3 10^3 cells L^{-1}) (Fig. 6). The harmful, DSP (diarrhetic shellfish poisoning) producer *Dinophysis acuminata* was observed in both periods together with *Akashiwo sanguinea*, *Amphidinium*, *Ceratium*, *Cochlodinium*, "naked species" (Gymnodiniales), *Noctiluca scintillans*, *Oxyphysis oxytoxoides*, *Prorocentrum gracile*, *Protoperidinium*, *Scrippsiella* and *Torodinium*. Some species, e.g. *Ceratium tripos*, *Dinophysis caudata*, *Gonyaulax* sp., *Polykrikos schwartzii*, *Prorocentrum micans* and *P. minimum* were observed in summer samples only (Table 2).

Ciliates showed slightly higher abundance in the summer (mean 17.1 10^3 cells L^{-1}) than in the spring period (mean 13.4 10^3 cells L^{-1}), with predominance of oligotrich ciliates, the tintinnids *Tintinnopsis* spp., the "naked" *Strombidium* spp. and the phototrophic *Myrionecta rubra*, besides small organisms in both periods (Fig. 6; Table 2).

DISCUSSION

It was shown that freshwater derived nutrients is an important controlling factor of Chl *a* in the shallow estuary (Abreu *et al.* 1995). The action of water exchange influenced the variability of nutrient concentration, with different sources of nitrogen in the two periods, *i.e.*, nitrate as the main nitrogen form in the spring and ammonium dominating in the summer. The nitrate input in the system was related to the freshwater outflow, while ammonium derives from macrophytes decomposition and sewage. Ammonium concentration was extremely high (3-61 µM; mean 25 µM) in our study, in comparison to previous data in this embayment (maximum 12 µM), and to Saco da Mangueira, the more eutrophic embayment south of Rio Grande city (1.6-67 µM; mean 9 µM) (Persich *et al.* 1996). The location of the sampling station at the pier of the Oceanographic Museum, close to domestic sewage effluents, probably influenced absolute concentration of ammonia. However, the tendency of higher values in summer was observed previously, with increasing residence time of coastal water (Baumgarten *et al.* 1995). In this case, the local sewage of Rio Grande city is not exported, as in other estuaries with low residence time (Wang *et al.* 2004). In addition, high benthic (Bemvenuti 1997) and pelagic herbivore activity in the shallow Patos Lagoon estuary in summer (Montú *et al.* 1997; Jesus & Odebrecht 2001) increases ammonium regeneration.

The statistically similar values of phosphate in both studied periods (mean spring 0.98 µ M; summer 0.89 µM), despite different salinity, may be explained by the high *seston* load (79-261 mg L^{-1}), increasing adsorption of suspended matter on seawater anions (Cl^- and SO_4^{-2}) (Liss 1976; Niencheski & Baumgarten 1997). The silicate concentration was always high although peaks were 40% lower (73 µM) in summer than in the spring sampling (~130 µM), and abrupt reduction (60%) was caused by the coastal water inflow with southerly winds, in spring.

During the summer sampling, environmental conditions of small salinity fluctuation, weak flow intensity, and frequent changes of flow direction should favor Chl *a* accumulation. However, this was not observed and production was apparently balanced by losses, *i.e.* grazing, export and/or deposition, similarly as in other shallow estuary (Litaker *et al.* 1987; 1993). With the intrusion of marine water, the main loss mechanism, cell advection, was diminished and the relevance of other factors as nutrients availability and increased herbivory probably became more important. It must be considered that this period of the year was characterized by small nutrient input in comparison to spring.

TABLE 2 – List of taxons observed in spring (SP) and summer (SU) periods.

	SP	SU		SP	SU
Diatoms			*Synedra* sp.	x	x
Amphora sp.	x		*Tabellaria* sp.	x	x
Asterionellopsis glacialis (Castracane) Round	x	x	*Terpsinoe* sp.	x	
Aulacoseira granulata (Ehrenberg) Thwaites	x	x	*Thalassionema* sp.	x	x
Bacillaria paradoxa (Gmelin) Grunow in Cleve & Grunow	x	x	*T. frauenfeldii* (Grunow) Hallegraeff	x	x
Bacteriastrum sp.	x	x	*T. nitzschioides* Grunow ex Hustedt	x	x
Campylosira cymbelliformis (Schmidt) Grunow in Van Heurck	x	x	*Thalassiosira* sp.	x	x
Cerataulina sp.	x	x	*T. rotula* Meunier	x	x
C. bicornis (Ehrenberg) Hasle in Hasle & Sims	x	x	*Triceratium* sp.		x
C. pelagica (Cleve) Hendy	x	x	**Dinoflagellates**		
Chaetoceros affinis (Lauder)	x	x	*Akashiwo sanguinea* (Hirasaki) Hansen & Moestrup	x	x
C. curvisetus Cleve		x	*Amphidinium* sp.	x	x
C. debilis Cleve	x	x	*Ceratium* sp.	x	x
C. decipiens Cleve		x	*C. furca* Claparède & Lachmann	x	x
C. didymus Ehrenberg		x	*C. fusus* (Ehrenberg) Dujardin	x	x
C. peruvianus Brightwell		x	*C. tripos* (Müller) Nitzsch		x
C. socialis Lauder		x	*Cochlodinium* sp.	x	x
C. subtilis Cleve	x	x	*Dinophysis acuminata* Claparède & Lachmann	x	x
Coscinodiscus sp.	x	x	*D. caudata* Saville-Kent		x
C. wailesii Gran & Angst	x	x	*Gonyaulax* sp.		x
C. granii Gough		x	*Gymnodinium* sp.1, sp.2	x	x
Cyclotella sp.	x	x	*Gyrodinium* sp.	x	x
Cylindrotheca closterium (Ehrenberg) Reinmann & Lewin	x	x	*G. spirale* (Bergh) Kofoid & Swezy	x	x
Dactyliosolen fragilissimus (Bergon) Hasle	x	x	*Noctiluca scintillans* (Macartney) Kofoid & Swezy	x	x
Detonula pumila (Castracane) Gran	x	x	*Oxyphysis oxytoxoides* Kofoid	x	x
Diploneis sp.	x		*Polykrikos schwartzii* Bütschli		x
Ditylum brightwellii (West) Grunow in Van Heurck	x	x	*Prorocentrum* sp.	x	x
Entomoneis alata Ehrenberg	x	x	*P. gracile* Schütt	x	x
Eunotia sp.	x		*P. micans* Ehrenberg		x
Hemiaulus hauckii Grunow in Van Heurck		x	*P. minimum* (Pavillard) Schiller		x
Guinardia delicatula (Cleve) Hasle	x	x	*Protoperidinium* sp.	x	x
G. flaccida (Castracane) Peragallo	x	x	*Scrippsiella* sp.	x	x
G. striata (Stolterfoth) Hasle	x	x	*Torodinium* sp.	x	x
Gyrosigma sp.	x	x	**Cyanobacteria**		
Grammatophora sp.	x		*Anabaena* sp.	x	x
Lauderia annulata Cleve	x	x	*Aphanocapsa* sp.	x	
Leptocylindrus danicus Cleve	x	x	*Aphanothece* sp.	x	x
L. minimus Gran	x	x	*Aphanizomenon* sp.	x	
Lithodesmium undulatum Ehrenberg		x	*Lyngbya* sp.	x	
Melosira sp.	x	x	*Merismopedia* sp.	x	x
M. dubia Kützing	x	x	*Microcystis aeruginosa* Kützing *sensu* Teiling	x	x
M. numuloides Agardh	x	x	*Oscillatoria* sp.	x	x
Nitzschia sp.1	x		*Planktolyngbya* sp.	x	x
Nitzschia sp.2		x	*Trichodesmium* sp.	x	x
N. longissima (Brébisson, in Kützing) Ralfs in Pritchard	x	x	**Chlorophytes**		
Odontella aurita (Lyngbye) Agardh	x	x	*Ankistrodesmus* sp.	x	
O. mobiliensis (Bailey) Grunow		x	Chlorococcales	x	
O. rhombus (Ehrenberg) Smith		x	*Closteriopsis* sp.	x	
O. sinensis (Greville) Grunow	x	x	*Closterium* sp.	x	x
Plagiogramma sp	x		*Cosmarium* sp.	x	
Planktoniella sp.		x	*Pediastrum* sp.	x	x
Pleurosigma sp.	x	x	*Planctonema* sp.	x	x
Proboscia alata Sundström	x	x	*Scenedesmus* sp.	x	x
Pseudo-nitzschia sp.1	x	x	*Staurastrum* sp.	x	
Pseudo-nitzschia sp.2, sp.3		x	**Ciliates**		
Pseudosolenia calcar-avis Sundström	x	x	*Lohmaniella* sp.	x	x
Rhaphoneis sp.	x	x	*Myrionecta rubra* (Lohmann) Jankowski	x	x
Rhizosolenia sp.	x	x	*Strobilidium* sp.	x	
R. pungens Cleve-Euler	x	x	*Strombidium* sp.1, sp.2	x	x
R. setigera Brigtwell		x	*Strombidium conicum* (Lochmann) Wulff	x	x
R. robusta Norman in Pritchard		x	*Tontonia* sp.	x	x
Rhopalodia sp.	x		Tintinnid sp.	x	
Skeletonema costatum Greville	x	x	Tintinnid sp.2, sp.3		x
S. tropicum Cleve	x	x	*Tintinnopsis* complex	x	x
Stauroneis sp.	x	x	Vorticellid	x	x
Surirella sp.	x	x			

The Chl *a* fluctuation showed different patterns in both sampling periods. A bimodal Chl *a* cycle found in spring was coupled to the water flow in the study area. Water outflow prevailed at the beginning of sampling (October 10-28) and Chl *a* changed diurnal and daily, without any significant statistical pattern. Apparently the water outflow at the sampling station prevented biomass accumulation; in contrast, Chl *a* concentration increased threefold (5 to 15 μg L^{-1}) after October 28, coinciding with alternating water flow direction in the daily scale and salinity increase. The high change in flow direction favored the maintenance of marine phytoplankton cells in the estuary and since light and nutrient availability in spring favors primary production in the Patos Lagoon estuary (Abreu et al., 1994; Persich et al., 1996), we may conclude that high frequency processes, in the same period of cell-division times, *i.e.* 1-2 days (Harris 1986), are of primary importance in triggering and timing the spring bloom in this environment. The small cell sized diatom *Skeletonema costatum* was previously observed forming spring blooms in the Patos Lagoon estuary (Abreu *et al.* 1994; Persich *et al.* 1996; Bergesch & Odebrecht 1997), and the close relationship observed in our study between water flow and the abundance of this diatom, confirms the water flow-cell division mechanism in the shallow study area. It may be inferred that freshwater runoff ultimately controls the timing of the spring bloom in the Patos Lagoon estuary. The winter/spring is the main rain season and freshwater runoff is highest during this period, when enrichment of adjacent coastal zones with nutrients and Chl *a* advection is expected (Abreu & Castello 1997; Wang *et al.* 2004). The spring bloom initiation will be prevented until the freshwater runoff diminishes, explaining the large interannual variability observed in the timing of the diatom bloom.

Phytoplankton taxonomic composition was closely associated with the salinity fluctuation, which was controlled by the wind direction. The frequency of wind direction changes between southerly (marine intrusion) and NE winds (terrestrial runoff) corresponded approximately to the period of cold fronts passage in the area (Klein 1997). The presence of freshwater chlorophytes and cyanobacteria coincided with low salinit, in response to the action of NE wind. On the other hand, pennate and centric diatoms showed highest abundance in the spring and summer periods, respectively. They were highly influenced by salt water intrusion, as shown by the reduction of *Cylindrotheca closterium* (pennate) abundance and dominance of *Skeletonema costatum* (centric), which were respectively hampered and enhanced by marine intrusions in spring.

The temporal fluctuation of marine dinoflagellates and the ciliate *Myrionecta rubra* in both sampling periods, reinforce the importance of the wind direction–salinity component as determinant of the plankton taxonomic composition in the shallow estuarine embayment. Moreover, the occurrence in the water column of benthic diatoms characteristic of the shallow estuary, e.g. *Entomoneis alata*, *Amphora*, *Surirella*, *Plagiogramma* and *Rhopalodia* (Bergesch *et al.* 1995), indicate that cell suspension induced by high wind velocity (Figs. 2, 3 and 5) was also an important mechanism, reflecting different life strategies of microalgae during situations of high water mixing (Guarini *et al.*, 2000).

The time lag between the wind action, the salinity variation and modification of the phytoplankton assemblage in the shallow inshore embayment was as short as few hours in spring, in spite of the significant distance (±20 km) of the sampling station from the lagoon mouth. Current velocity at the main channel of the lagoon reaches high values (60-80 cm s^{-1}) during both freshwater runoff and marine inflow (Möller *et al.* 1991), and the time lag in Rio Grande for water level elevation in response to 5 m s^{-1} SW and NE winds, was estimated to be less than 10 h (Möller *et al.* 1996), in agreement with our spring data. However, a longer time lag for the salinity-biotic response to the wind action was observed in the summer sampling: at least four days of NE wind was necessary to elicit a salinity decrease and assemblage change. The low river discharge and high temperature observed in the summer period, propitiate a water deficit (Klein 1997) and diluted saltwater reaches the central lagoon as far as 180 km inshore (Odebrecht *et al.* 2005), explaining the longer time taken for the salinity change in the study area.

CONCLUSION

Wind direction and the rainfall controlled the water exchange and the short-term variability of environmental parameters in the shallow embayment at the western side of Patos Lagoon estuary. The presence of freshwater and marine species in this shallow area was typically a wind-salinity-plankton assemblage response, with southerly wind inducing the inflow of marine diatoms and dinoflagellates, and wind from the Northeast leading to water discharge containing freshwater cyanobacteria and chlorophytes. The time lag of the wind action on the salinity-biotic response was short (hour scale) in spring and delayed (3-4 days) with low rainfall, as observed in summer. It was shown that high frequency processes, in the same period of cell-division, 1-2 days, are of primary importance for the lagoon ecology. The fluctuation of freshwater outflow and wind driven processes may prevent, delay or prompt phytoplankton biomass accumulation in the estuarine area, acting as the timing mechanism of the spring bloom. In summer, the increased benthic and pelagic herbivore activity apparently act as an important Chl *a* control typical of top-down processes.

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