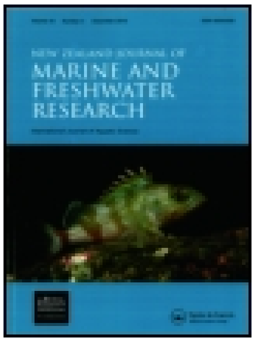

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RESEARCH ARTICLE

Diatom assemblages from surface sediments of the Río de la Plata estuary, Uruguay

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ABSTRACT
The Río de la Plata estuary (RdlP) exhibits environmental gradients associated with the freshwater input and oceanic water intrusion. The aim of this study was to assess diatom species distribution in surface sediment samples related to such environmental gradients. The internal section of RdlP was dominated by *Aulacoseira* spp., *Eunotia* spp., *Staurosirella martyi*, *Actinocyclus normanii* and *Thalassiosira baltica*, indicatives of low salinity levels and high trophic conditions, associated with the riverine and estuarine regimes. The external section was dominated by *Coscinodiscus radiatus*, *Thalassiosira* spp., *Paralia sulcata*, *Cyclotella striata*, among other marine taxa, indicatives of high salinity and low trophic conditions, associated with the influence of the Southwestern Atlantic Ocean. Furthermore, the intermediate section presents a mixture of both diatom groups representing mixing conditions. The observed diatom species groups capture fairly well the RdlP environmental variability and can be reliably used for paleoenvironmental studies in this and other similar estuarine systems.

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Diatoms; auto-ecology; southwestern Atlantic Ocean; sediments; turbidity; salinity; estuary

Introduction

Diatoms represent a very common tool in both paleolimnological and paleoceanographical studies. To use these biological indicators as proxies of the environmental conditions, correct identification of taxa and reliable knowledge about the environmental conditions they represent are required (ie auto-ecology; Denys and de Wolf 1999; Vos and de Wolf 1988, 1993, 1994; Hassan 2010). In estuaries, salinity is a major determinant of diatom distribution, hence, diatom species analyses have become widely used in paleoenvironmental studies in such environments, eg in determining the continental versus marine influence (Denys and de Wolf 1999; Hassan 2010; Perez et al. 2017). Diatom assemblages from surface sediments are widely used as modern analogues of paleoenvironments, as they

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reliably reflect the environmental conditions at the sampling point and have been shown to integrate the annual seasonal scale variability (Juggins 1992; Hassan et al.2008).

Diatoms in the Río de la Plata (RdlP) and adjacent coastal lagoons have been studied for taxonomic description (Frenguelli 1941, 1945; Müller Melchers 1945, 1952, 1953, 1959). In other studies, diatoms were utilised as proxies for paleosalinity changes to document Holocene sea level changes (coastal lagoons) and continental versus marine influence (RdlP) (García-Rodríguez et al.2004a, 2004b, 2004c, 2010; Inda et al.2006; Mourelle et al.2015; Perez et al. 2016, 2017). However, on only a few occasions (Licursi et al. 2006, 2010), auto-ecological data (ie abundance and distribution of diatoms in relation to environmental variables) have been presented. This means that there are only few studies on modern environmental data of diatoms, and hence, there is a need for further information on modern diatom distribution with respect to environmental gradients in the RdlP, a basis for more robust paleoenvironmental reconstructions (Hassan 2010).

This study aims to contribute information about modern diatom distribution by analysing surface sediment samples from the RdlP, from the riverine through to the marine section. We aim to identify representative diatom species groups associated with the environmental condition (ie salinity and trophic state) at different locations along a transect in the RdlP. Such diatom groups will be used as modern analogues for inferring continental versus marine influence within the RdlP system in future regional paleoenvironmental studies.

Materials and methods

Study area

The RdlP estuary (35′00°; 36′10°S to 55′00°; 58′10°W) covering an area of 36,103 km^2 is shared by Uruguay and Argentina (Figure 1). This funnel-shaped river forms a large estuary, the second largest of South America, characterised by a semidiurnal tide with a low tidal amplitude (<1 m). It provides very important socio-economic and environmental

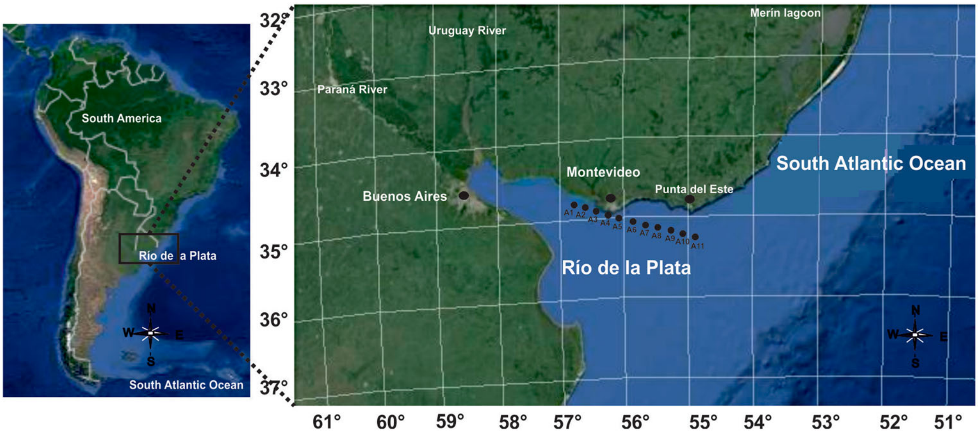

Figure 1. Map showing location of the study area. Black dots in the Río de la Plata indicate the position of the sampling stations A1 through A11.

services, and has a highly variable water chemistry because of human impacts (Bisbal 1995; Kurucz et al.1998; Nagy et al.2002) and natural variability at seasonal, inter-annual, decadal and centennial scales (López-Laborde et al.2000; Acha et al.2003). The main tributaries are the Paraná and Uruguay River, with an annual average flow of 16,000 and 6000 $m^3 s^{-1}$, respectively, thus the RdlP outflow exhibits an average value of 22,000 $m^3 s^{-1}$ (CARP 1989). The RdlP exhibits intra-annual variability regarding with the river discharge and wind patterns. In this sense, the RdlP outflow shows a maximum river discharge during summer (28,000 $m^3 s^{-1}$) and a minimum during winter (17,500 $m^3 s^{-1}$; Depetris and Pasquini 2007), associated with the intensification/weakening of the South American summer monsoon system, respectively (SAMS; Zhou and Lau 1998). In addition, a northeasterly/southwesterly wind pattern during summer/winter leads to a southward/northward displacement of the low salinity RdlP waters (Guerrero et al.1997; Möller et al.2008; Piola et al.2008). There is also inter-annual and inter-decadal hydrological variability (Garreaud et al.2009), related to the climatic mode of oscillations, ie El Niño–Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO), respectively. Increasing freshwater input into the RdlP is associated with the El Niño events and is enhanced by positive PDO phases, while the opposite is registered during La Niña and negative PDO phases (Depetris and Kempe 1990; Ciotti et al.1995; Depetris et al.2003; Depetris and Pasquini 2007; Garreaud et al.2009; Barreiro 2010). Some studies have identified changes in the salinity of the system and in the trophic state of the sediments related to such hydrological variability of the RdlP (García-Rodríguez et al.2014; Marrero et al.2014; Perez et al. 2016, 2017; Bergamino et al. 2017).

The location of turbidity and salinity fronts depends on the wind direction/intensity, rainfall in the RdlP watershed and the associated interaction between the freshwater input and the marine intrusions from the Southwestern Atlantic Ocean (SWAO, Möller et al.2008; Piola et al.2008; Acha et al. 2008). Thus the system is characterised by two salinity fronts: the bottom salinity front, located in the innermost part of the bottom salt wedge, and the surface salinity front, indicating the transition between the turbid river and the less turbid marine surface waters (Framiñan and Brown 1996).

The area of investigation of this study consists of a transect parallel to the Uruguayan coast (34°85′51″S, 56°88′64.3″W to 35°25′37″S, 54°90′56″W) (Figure 1; Table 1). The 11-station transect was undertaken on board the oceanographic vessel Aldebarán during May 2009. The 11 stations ranged between 6 and 26 metres depth, from the

Table 1. Geographical coordinates (latitude and longitude), depth (*Z*), and environmental variables and measurements (OM = organic matter, Chl a = chlorophyll a, bottom and superficial salinity) of all 11 stations from the Río de la Plata (A1–A11).

Station	Latitude	Longitude	*Z* (m)	OM (%)	Chl a (μg g^{-1})	Bottom salinity	Superficial salinity
A1	34°85′51″	56°88′64.3″	6.0	6.83	1.25	4.8691	4.2009
A2	34°90′42.1″	56°68′33.3″	7.0	7.14	2.12	11.4303	11.4752
A3	34°94′30.33″	56°48′50.3″	7.0	7.94	1.72	16.6224	15.5211
A4	34°98′50.33″	56°28′67.33″	8.0	8.63	2.14	16.4045	15.2507
A5	35°01′98.67″	56°10′54″	9.0	8.49	2.11	19.7375	16.7086
A6	35°05′48″	55°90′76″	13.0	9.47	0.98	24.5	20.3708
A7	35°09′28.33″	55°70′68″	14.0	7.30	1.07	26.6909	22.9535
A8	35°13′50.33″	55°51′72.67″	21.0	6.81	2.63	29.874	22.6857
A9	35°18′39.33″	55°32′00.67″	20.0	2.17	0.24	30.143	24.5278
A10	35°21′75.67″	55°11′68.67″	23.0	1.95	0.79	30.6543	26.1826
A11	35°25′37″	54°90′56″	26.0	1.02	2.06	30.6248	28.5799

innermost (landward) to the outermost station (seaward, Table 1). During sampling, conductivity, salinity, temperature and depth were measured using a CTD SBE-19, and surface sediment samples (from the uppermost cm) were taken with a Smith–McIntyre bottom grab for measuring organic matter, chlorophyll a and diatom valve identification and counting.

Laboratory analyses

Organic matter and chlorophyll a

Organic matter (OM) and chlorophyll a (Chl a) concentration in surface sediments are commonly used as proxies for productivity changes within the estuarine systems, as their concentration change with a shift in trophic state of aquatic systems (Rabalais et al. 2007; García-Rodríguez et al. 2014).

Aliquots of ca. 1 g wet surface sediment (uppermost cm of the grab) were taken for OM and for Chl a determinations. OM measurements were performed using the loss on ignition technique at 550°C according to Byers et al. (1978). For Chl a determinations, the samples were extracted in 90% acetone in the dark at 4°C for 24 h, and centrifuged at 3000 rpm and absorbance was measured using a UV/VIS Beckman DU-650 at 750 and 665 nm (Strickland et al.1972).

Diatom analyses

Diatoms samples were first treated with $Na_2P_2O_7$ to defloculate the sediment and eliminate clay particles. Then the samples were treated with 35% HCl to remove inorganic carbonate material. Finally, the samples were boiled with 30% H_2O_2 for 2 hours to eliminate OM (Metzeltin and García-Rodríguez 2003). Between each treatment samples were rinsed at least four times with distilled water. Permanent slides were mounted using Entellan® mounting medium (Refractive Index: 1.54). A minimum of 400 valves was counted on each slide with a light microscope at 1250× magnification with oil immersion. Diatom species were identified according to Frenguelli (1941, 1945), Müller-Melchers (1945, 1953, 1959), Hasle and Syversten (1996), Witkowski et al. (2000), Metzeltin and García-Rodriguez (2003), Metzeltin et al. (2005), Sar et al. (2010). Furthermore, the species were separated into groups according to their ecological salinity preference, ie in groups indicating freshwater (F), marine (M) and brackish (b) conditions; and their habitat type, ie in groups indicating benthic (B), planktonic (P), Tychoplanktonic (T) according to Pankow (1970), de Wolf (1982), Vos and de Wolf (1988, 1993, 1994), Juggins (1992), Van Dam et al. (1994), Hasle and Syversten (1996), Gómez and Bauer (2000), Al-Kandari et al. (2009) and Guiry and Guiry (2017). Relative abundances of individual species were calculated by dividing the number of valves from each species by the total number of valves counted on each slide/station.

Data analyses

For analyses of the surface sediment diatom species, we used the most significant taxa (ie 2% in at least three stations, Karst and Smol 2000). Diatom Association Zones (DAZ) were determined using stratigraphically constrained cluster analyses (CONISS) using the software Tilia v. 2.0.38. To identify the most representative species of each DAZ and its association with environmental variables, a Canonical Correspondence Analysis (CCA) was performed using the CANOCO (ver. 4.5) program.

The CCA included the most significant diatom taxa and the associated environmental physical variables (ie salinity and temperature), proxies of productivity, ie P (phosphorus), TN (total nitrogen), Corg (organic carbon), OM (organic matter) and chlorophyll a (Chl a). Furthermore, we used Ti/Ca ratio as proxy for the terrigenous versus marine input and C/N ratio as proxy for the composition of the OM. P, C/N, TN, Corg and Ti/Ca data were extracted from Burone et al. (2013).

Results

Environmental variables

We registered an increasing trend in the values of salinity from the innermost (landward) to the outermost (seaward) stations (A1–A11), with bottom salinity ranging between 4.9 and 30.6 and superficial salinity ranging from 4.2 and 28.6 (Table 1). Furthermore, OM ranged between 1.02% and 9.47% (A11 and A6, respectively) and the highest values were recorded from A1 to A8 (6.81–9.47%) and the minimum values were found in A9–A11 with a decreasing trend (2.17–1.02%). Regarding the Chl a, it ranged between 0.98 and 2.63 $\mu g\ g^{-1}$ and there is no specific trend in the values, with the maximum value found in A8 and the minimum in A6 (Table 1).

Diatoms

A total of 78 diatom taxa representing 47 genera were identified in the surface sediment samples from the RdlP transect. Of the taxa, 52 were identified to species level using an optic microscope. The significant taxa belong to 17 genera (ie *Aulacoseira*, *Staurosirella*, *Eunotia*, *Actinocyclus*, *Thalassiosira*, *Coscinodiscopsis*, *Coscinodiscus*, *Cyclotella*, *Paralia*, *Thalassionema*, *Chaetoceros*, *Trigonium*, *Diploneis*, *Fallacia*, *Psammodictyon*, *Fragilariopsis*, *Actinoptychus*). In addition, we identified *Chrysophyte* cysts and *Dictyocha fibula* (Figure 2).

Diatom species with freshwater preference dominate the landward sample sites (A1–A4) and those with marine preference dominate the seaward sites (A7–A11) as indicated by the relative abundances of diatom salinity preference groups in Figure 2. Furthermore, stations A5 and A6 showed intermediate abundances of species with freshwater and marine preference in relation with the landward and the marine sites (Figure 2). These diatom abundances displayed a similar trend to that of salinity (Figure 2). Planktonic taxa dominated in all samples throughout the RdlP, while the benthic taxa showed low abundances but an increasing trend towards the marine sites was recorded, especially in A11 (20%).

The cluster analysis (Figure 2) identified three DAZ: A1 through A4, A5–A6, and A7 through A11 (group 1, 2 and 3, respectively). The inner RdlP stations (group 1), A1 through A4, exhibited clear dominance of the freshwater genera *Aulacoseira*, *Eunotia* and *Staurosirella*, and also brackish taxa, ie *Actinocyclus normanii* and *Thalassiosira baltica* were observed. On the other hand, stations A7 through A11 (group 3) were dominated by marine genus *Thalassiosira*, and the species *Coscinodiscus radiatus*,

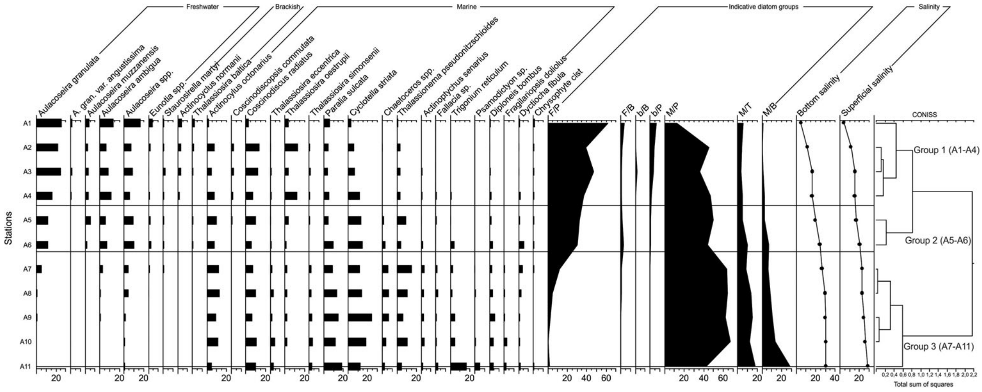

Figure 2. Relative abundance of diatom species. Individual species are grouped according to salinity preferences on left side of diagram and into salinity-habitat group at right side as follows: the freshwater planktonic (FP) and benthic (FB), brackish planktonic (bP) and benthic (bB), and marine planktonic (MP), benthic (MB) and tychoplanktonic (MT). Furthermore, clustering groups and observed superficial and bottom salinity are shown to the right of the plot.

Coscinodiscopsis commutata, *Cyclotella striata*, *Diploneis bombus*, *Triceratium reticulum*, *Actinoptychus senarius*, *Fragilariopsis doliolus* and *Thalassionema pseudonitzschioides*. Furthermore, intermediate stations A5 and A6 (group 2) were co-dominated by freshwater, brackish and marine species (Figure 2).

The axes 1 and 2 of the CCA ordination diagram shown in Figure 3 presented 60.9% and 75.5% of the accumulated variance, respectively. Salinity and temperature explained much of the variation in the diatom data as shown by their strong correlation with axis 1 in the CCA ordination diagram (Figure 3). Axis 2 explains a fair amount of variation between the marine samples (A7–A11) and it appears to be strongly correlated with the productivity proxies, ie P, Corg and TN. Stations A1 through A4 were positively associated with Ti/Ca ratios, Chl a, and negative with both salinity and temperature (ie they are low salinity, low temperature stations). The most representative species of these sites *Aulacoseira granulata*, *A. granulata* var. *angustissima*, *A. muzzanensis*, *A. ambigua*, *Staurosirella martyi*, *Eunotia* spp., *Actinocyclus normanii*, *Thalassiosira baltica* and *Coscinodiscopsis commutata* relate well to cluster group 1. Station A7 through A11 showed a positive relationship with salinity and temperature and negative with the rest of the variables. The most representative species were those related to cluster group 3, ie *Coscinodiscus radiatus*, *T. oestrupii*, *Actinocyclus octonarius*, *Thalassiosira eccentrica*, *T. simonsenii*, *Paralia sulcata*, *Cyclotella striata*, *Actinoptychus senarius*, *Diploneis bombus*, *Triceratium reticulum*, *Fragilariopsis doliolus* and *Thalassionema pseudonitzschioides*. Finally, stations A5 and A6 (cluster group 2) occur in the middle of the salinity gradient and were positively associated with the productivity proxies P, Corg, OM and TN, especially A5, but no diatom species were clearly associated to these stations (Figure 3).

Discussion

The salinity gradient observed in this study (Figure 1; Table 1) is the characteristic of the RdlP system, and previous studies have reported distinguished domains (ie riverine,

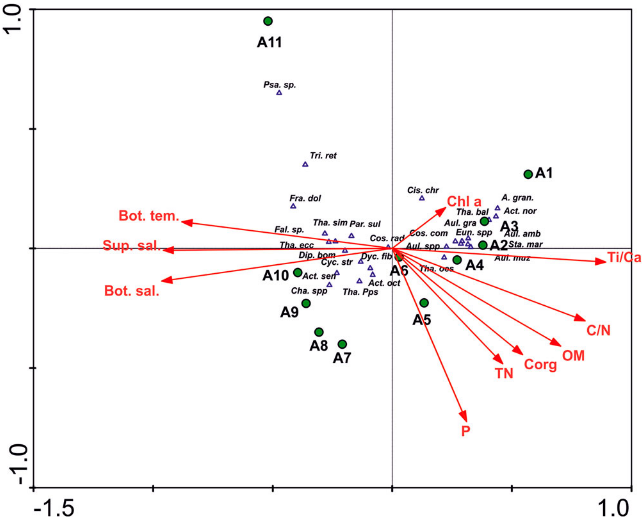

Figure 3. CCA tripolt ordination diagram showing position of species (triangles), sites (circles) and environmental variable (arrows). The axes 1 and 2 presented 60.9% and 75.5% of the accumulated variance, respectively. P, C/N, TN (total nitrogen), Corg (organic carbon) and Ti/Al data were extracted from Burone et al. (2013).

estuarine and marine) (Guerrero et al. 1997; Nagy et al. 2002; Calliari et al. 2009; Martínez and Ortega 2015). The OM and Chl a values recorded in the superficial sediments (Table 1) are in accordance with other studies carried out in the RdlP (Burone et al. 2013; García-Rodríguez et al. 2014). The maximum OM concentration values recorded in the present study from the innermost station A1 to A8 could be associated with the high seston load related to the terrestrial supply in the RdlP waters (Calliari et al. 2009; Burone et al. 2013), and the maximum OM recorded in A6 could be a consequence of the flocculation process related to the position of the maximum turbidity front (Table 1, Framiñan and Brown 1996; Burone et al. 2013). Burone et al. (2013) assessed the sediment footprint of riverine versus marine influence along the salinity gradient between the RdlP estuary and the adjacent SWAO shelf, and observed a transition from a tidal river to estuarine and marine zones based on foraminiferous, geochemical and sedimentological analyses. They observed increases in sand and clay content at the transition between tidal river and the estuarine zone associated with the maximum turbidity zone, where increased organic matter content and productivity was observed. In addition, Bergamino et al. (2017) showed that the isotopic signals of surface sediments of the RdlP determined that the upper reaches (ie riverine domain) were influenced by riverine particulate matter, ie δ^{13}C range: −24‰ to −26‰ relative to Pee Dee Belemnite (PDB). The lower reaches represented a depositional environment of marine algae, ie δ^{13}C range: −21‰ to −23‰ relative to PDB.

The high diatom species number and the co-occurrence of both freshwater and marine diatom species (Figure 2) is probably associated with the intrinsic high productivity and the RdlP estuarine hydrological dynamics (Acha et al. 2008; Möller et al. 2008; Piola et al. 2008). Through this study, we determined that diatom distribution was associated with the hydrological features of the RdlP, related to the continental input of freshwater from the rivers and the intrusion of marine waters. Thus we recorded a strong correlation among salinity, sites and diatom species, ie the landward sample sites were associated with low salinity and high abundance of freshwater diatom species while seaward stations were related to high salinity and marine diatoms (Figure 3).

The diatom composition/distribution from surface sediments, the environmental variables and the proxies of productivity, origin of OM and terrigenous versus marine input, registered in this study, allowed us to divide the study area into three sections (Figure 3). The inner RdlP section related to group 1 was influenced by continental input of freshwater, which exhibits low salinity and temperature values, high trophic state as recorded by the productivity proxies (OM, P, TN, Corg and Chl a), and continental input (Ti/Ca and C/N), all determining a dominance of freshwater diatom species. The marine section (group 3), which is characterised by low productivity and low supply of terrestrial OM, and therefore low trophic state, and high salinity and temperature values, was related to marine diatom species. We also identified a transitional section, related to group 2, characterised by mixing conditions. Such a transitional zone is related to the position of the turbidity front (Burone et al. 2013), and it is characterised by increases in the productivity proxies and a co-dominance of both freshwater and marine species. Burone et al. (2013) also divided the study area into such sections and determined for the inner section (up to the station 7) a high influence of terrigenous material, ie finer sediments, high particulate OM, Chl a, Corg, TN, P, C/N, Fe/Ca, Ti/Ca and more negative $\delta^{13}C$, while the opposite was registered for the marine section highly influenced by the SWAO waters.

Each of the identified sections, ie inner, transitional and marine, are characterised by specific trophic conditions and salinity values, with distinct diatom associations. The inner section was dominated by planktonic freshwater species (group 1), ie *Aulacoseira granulata*, *A. granulata* var. *angustisima*, *A. ambigua*, *A. muzzanensis* and the benthic *Eunotia* spp. (Coste and Prygiel 2000), but some planktonic brackish species *Actinocyclus normanii* and *Thalassiosira baltica*, were also dominant (Hasle and Syvertsen 1996). Such a mixture of species is the characteristic of estuarine environments and has been previously recorded by other authors for the riverine and estuarine sections of the RdlP (Frenguelli 1941; Müller Melchers 1953; Gómez and Bauer 2000; Ferrari and Pérez 2002; Licursi et al. 2006, Hassan 2010). Furthermore, the most significant species of the inner RdlP (*Aulacoseira* spp., *Actinocyclus normanii* and *Staurosirella martyi*) are all indicators of fairly eutrophic conditions (Table 2, Vos and de Wolf 1993; Van Dam et al. 1994; Coste and Prigiel 2000).

Within diatom group 1, the most abundant species were *Aulacoseira* spp. (Figure 2). These planktonic species show an adaptive advantage, as they can form long filamentous chains and have a morphology that allows them to have a greater surface light absorption and contain accessory pigments that increase their spectrum of absorption (Gómez and Bauer 2000). Consequently, they are adapted to live in systems with a high load of suspended particulate material (Wang et al. 2008), such as the case of the RdlP (Licursi et al. 2006). These species (ie *Aulacoseira granulata*, *A. granulata* var. *angustisima*, *A. ambigua* and *A. muzzanensis*) were recorded previously for the RdlP coastal waters (Gómez and Bauer 2000; Licursi et al. 2006; Hassan 2010). Furthermore, they are also indicators of eutrophic conditions (Van Dam et al. 1994; Bicudo et al. 2016), hence, this group

Table 2. Significant (ie 2% in at least three stations, Karst and Smol 2000) diatom species recorded from the RdlP superficial sediment transect (A1–A11), their ecological preferences and the RdlP environmental condition.

Diatom species	Diatom ecological preferences	RdlP environmental condition (Burone *et al.* 2013)
Aulacoseria granulata (Ehrenberg) Simonsen	Freshwater, planktonic, alkaliphilic and indicative of eutrophic conditions (Pankow 1970; Vos and de Wolf 1993; Van Dam *et al*. 1994; Bicudo et al. 2016)	A1, A2, A3, A4, Riverine and estuarine environment (ie brackish water). Associated with: Low and intermediate salinity. High organic matter High chlorophyll a High Ti/Ca ratio High Fe/Ca ratio More negative values of δ^{13}C isotope signal (in sediments)
A. granulata var. *angustissima* (O. Müller) Simonsen		
Aulacoseira ambigua (Grunow) Simonsen		
A. muzzanensis (Meister) Krammer	Freshwater, planktonic, cosmopolite and indicative of eutrophic conditions (Gómez and Bauer 2000)	
Eunotia Ehrenberg spp.	Freshwater, epiphytic, acidiphilic and indicative of oligotrophic conditions from shallow regions (Van Dam et al. 1994)	
Staurosirella martyi (Héribaud) Morales and Manoylov	Freshwater, epiphytic, alkaliphilic and indicative of meso-eutrophic conditions from temperate and shallow regions (Frenguelli 1941; Pankow 1970; de Wolf 1982)	
Actinocyclus normanii (Gregory) Hustedt	Brackish, planktonic and indicative of eutrophic conditions from temperate regions (de Wolf 1982; Gómez and Bauer 2000)	
Coscinodiscopsis commutata (Grunow) Sar and Sunesen	Marine, planktonic and cosmopolite (Guiry and Guiry 2017)	
Thalassiosira baltica (Grunow) Ostenfeld	Brackish, planktonic (Hasle and Syvertsen 1996)	
Coscinodiscus radiatus Ehrenberg	Marine (oceanic and neritic), planktonic and cosmopolite (Frenguelli 1941; de Wolf 1982; | Hasle and Syvertsen 1996; Al-Kandari et al. 2009)	A7, A8, A9, A10, A11 Marine environment. Associated with: High salinity Low organic matter and relatively low chlorophyll a Low Ti/Ca ratio Low Fe/Ca ratio More positive values of δ^{13}C isotope signal (in sediments)
Thalassiosira eccentrica (Ehrenberg) Cleve	Marine (neritic), planktonic and cosmopolite (Vos and de Wolf 1994; Hasle and Sylversten 1996; Gómez and Bauer 2000; Al-Kandari et al. 2009)	
T. simonsenii Hasle and Fryxell	Marine, planktonic and warm water region to temperate (Hasle and Syvertsen 1996)	
T. oestrupii (Ostenfeld) Proschkina-Lavrenko ex Hasle	Marine (mainly neritic), planktonic and warm water region to temperate(Sar et al. 2001; Al-Kandari et al. 2009)	
Paralia sulcata (Ehrenberg) Cleve	Marine (neritic), tycoplanktonic, cosmopolite and commonly found after winter storms (Vos and de Wolf 1994; Hasle and Syvertsen 1996; Al-Kandari et al. 2009)	
Cyclotella striata (Kützing) Grunow	Marine (neritic), planktonic, cosmopolite, eurihaline and abundant in estuaries and coastal lagoons (de Wolf 1982; Vos and de Wolf 1994; Hasle and Syvertsen 1996; Gómez and Bauer 2000; Al-Kandari et al. 2009)	
Actinocyclus octonarius Ehrenberg	Marine (neritic), planktonic, cosmopolite (de Wolf 1982; Hasle and Syvertsen 1996; Al-Kandari et al. 2009)	
Actinoptychus senarius (Ehrenberg) Ehrenberg	Marine (neritic), tychoplanktonic, cosmopolite (de Wolf 1982)	
Diploneis bombus (Ehrenberg) Ehrenberg	Marine and benthic (Guiry and Guiry 2017)	
Triceratium reticulum Ehrenberg	Marine (neritic) and benthic from warm waters (de Wolf 1982; Al-Kandari et al. 2009)	
Fragilariopsis doliolus (Wallich) Medlin and P.A. Sims	Marine and benthic from warm water regions (Hasle and Syvertsen 1996)	
Thalassionema pseudonitzschioides (Schuette & Schrader) Hasle	Marine. planktonic and probably from warm water regions (Hasle and Syvertsen 1996)	

is indicative of high trophic levels in the RdlP. Thus the stations on the inner RdlP (related to group 1) are all influenced by nutrient-rich and suspended material coming from the Paraná and Uruguay Rivers (Nagy et al. 2002; Depetris and Pasquini 2007; Calliari et al. 2009).

The freshwater diatom assemblages, group 1, were gradually replaced along the transect by marine species (group 3), ie *Coscinodiscus radiatus*, *Thalassiosira eccentrica*, *T. simonsenii*, *T. oestrupii*, *Paralia sulcata*, *Cyclotella striata*, *Actinocyclus octonarius*, *Actinoptychus senarius*, *Diploneis bombus*, *Triceratium reticulum*, *Fragilariopsis doliolus* and *Thalassionema pseudonitzschioides*, which were most previously recorded for the RdlP and adjacent Uruguayan coastal waters (Müller Melchers 1959; Ferrando 1962; Burone 1984; Ferrari and Pérez 2002; Metzeltin et al. 2005; Calliari et al. 2009). Such a diatom assemblage was also observed in the adjacent coast of Brazil and Argentina (Lange and Mostajo 1985; Negri et al. 1988; Sar et al. 2001, 2007; Hassan 2010). The fact that both *Coscinodiscus* and *Thalassiosira* were the most abundant genera can be explained because these planktonic genera are the best adapted to neritic and oceanic waters worldwide (Hasle and Syvertsen 1996). Some of the species (*Actinoptychus senarius*, *Paralia sulcata*, *Cyclotella striata*, *Diploneis bombus* and *Coscinodiscus radiatus*) were also recorded in sediment cores of SE Uruguayan coastal lagoons during the Holocene transgressive phases, where the systems exhibited marine/brackish conditions because they were permanently connected to the ocean (García-Rodríguez et al. 2004a, 2004b, 2004c). This transgression event was also related to relatively low trophic state levels as low OM and nutrient levels were observed. In this sense, such diatom species were also observed in station A7 through A11 where low values of OM and also Chl a were measured. Furthermore, *Thalassiosira oestrupii*, *T. simonsenii*, *Triceratium reticulum*, *Fragilariopsis doliolus* and *Thalassionema pseudonitzschioides* are indicative of warm water regions (Table 2). Therefore, this species group is indicating a warm and marine water influence (Hasle and Syvertsen 1996; Méndez et al. 1998; Sar et al. 2001, 2007, 2010) which is evident as the higher temperature values recorded within this section (Figure 3), probably associated with the intrusion of the subtropical waters within the continental shelf related to a la Niña event that occurred during 2009 (Martínez and Ortega 2007; García-Rodríguez et al. 2014).

Group 2 did not show diatom species exclusively associated to this zone (Figure 3), but it was rather observed a mixture of freshwater, brackish and marine diatom species. Therefore, we inferred intermediate values in relation to the adjacent zones (ie groups 1 and 3). This zone indicates the transition between the continental and the marine influence, and it is associated with the position of the turbidity front as previously registered by Burone et al. (2013). The high turbidity inherent of this zone explains the dominance of planktonic species in group 2 and the highest values of benthic species observed in group 3. The latter is a consequence of the flocculation process of particulate matter in the turbidity zone (A5 and A6), which led to a highest light penetration in the external section (seaward), and allowed the development of benthic species, ie *Diploneis bombus*, *Triceratium reticulum* and *Fragilariopsis doliolus* (Calliari et al. 2009).

Final remarks

The diatom species distribution from superficial sediments is related to the continental input of freshwater into the RdlP and the marine intrusion. Three distinct diatom groups were identified along the main environmental gradients within the RdlP (evolved from the interaction between terrigenous continental input and oceanic water intrusion). Group 1 is associated with high productivity proxies and low salinity within the riverine and estuarine sections, and the related diatom species were mostly indicative of a freshwater and eutrophic system. On the other hand, group 3 is related to low productivity proxies and high salinity related to the marine domain and the associated diatom species are marine planktonic and benthic and some are indicative of subtropical waters. Group 2 presents a mixture of freshwater, brackish and marine diatom species. Thus presenting intermediate values respect to the adjacent zones (groups 1 and 3).These diatom groups are reliable modern analogues and can be used as proxies for paleoenvironmental studies of the continental versus the marine influence within the RdlP and adjacent continental shelf.

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