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Seasonal and spatial distribution of the microbenthic communities of the Rio de la Plata estuary (Argentina) and possible environmental controls

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ABSTRACT

The relationship between microbenthic communities, the habitat characteristics, and physical and chemical gradients was studied in the Rio de la Plata estuary. Five replicates of the surface layer were collected seasonally, in 10 sampling sites influenced by different land uses. The distribution of microbenthic communities was governed by two gradients, the first one determined by anthropic factors, related to pollution, and the second one to conductivity and turbidity. The higher densities of producers were observed in sites characterized by fine sediments. During winter, spring, and summer cyanophytes were abundant, while in autumn the diatoms, particularly birraphideans, dominated. The ciliates were the most abundant group among consumers, particularly in winter, and their spatial distribution was influenced by the turbidity. The whole study area has an eutrophic condition. Turbidity and the enrichment with nutrients and organic matter explained 50% of the variability in the species' distribution.

1. Introduction

The association of algae, bacteria and micro-fauna, along with inorganic particles embedded in a polysaccharide matrix, form a biofilm that coats different surfaces. This biofilm forms the base of local-scale food chains, governing the assimilation, retention and transformation of dissolved and particulate materials in the aquatic ecosystem (Pusch et al., 1998; Sekar et al., 2002). The microphytobenthos may contribute up to 50% of the total primary production, and play an important role in both the benthic and pelagic trophic web, constituting a substantial food source for sediment feeders (macro-meiobenthos) (Montagna et al., 1995; Perissinotto et al., 2002). Furthermore, microbenthic communities are critical for coastal bed dynamics through the stabilization of sediments by their extracelular polymeric substances (Underwood and Paterson, 1993), and oxygenation by algal photosynthesis is one important factor influencing most processes at the sediment surface (Glud et al., 1992). Despite the significant advances over the past few years about the biofilm's physiology and functioning, there is still a very patchy and unclear picture of what influences the species' composition of the biofilm (Graham et al., 2006).

Aesthetic and recreational values, as well as the provision of food resources, are clear examples of the importance of estuaries, but not less significant are influences on the transport and transformation of nutrients, sediments, pollutants, and on primary and secondary productivity. Human activities in watersheds have caused major changes in water quality, resulting in increased loading of nutrients, organic matter, and sediment to rivers and estuaries, and loss of productive habitats (Frink, 1991; Hopkinson and Vallino, 1995; Wulff et al., 1997; Paerl et al., 1998).

The Rio de la Plata is an extensive, shallow and microtidal coastal plain estuary on the eastern coast of South America. The study area analyzed here is located in the freshwater tidal zone ($<5000\ \mu S\ cm^{-1}$). This area is of great socio-economic importance, since industrial and urban areas around it (Buenos Aires and La Plata cities) affect the aquatic habitats. This water source is used for several purposes, including drinking water and recreational and navigational activities, and receives industrial and domestic effluent waste and agricultural runoff. Despite the importance of the biotic resources of this ecosystem, particularly in the freshwater sector, there is a lack of proper information that would allow the sustainable management of its fauna and flora (Gómez and Rodrigues Capítulo, 2000).

A number of studies of planktonic, epiphytic, and macroinvertebrate assemblages in the Rio de la Plata estuary, have been carried out to explore its diversity and structure (Gómez and Bauer, 1998a,b, 2000; Gómez et al., 2002; Rodrigues Capítulo et al., 2003; Gómez et al., 2004; Licursi et al., 2006; Paggi et al., 2006;

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Bauer et al., 2007; Cortelezzi et al., 2007; Ocón et al., 2007). Nevertheless, until now no studies of the biofilm that coats the sediments of the intertidal zone in this estuary have been carried out.

The main objectives in this study were to analyze: (1) the habitat characteristics, (2) the pattern of seasonal and spatial distribution of producers and consumers and their relationships with the main physico-chemical variables and (3) their trophic and saprobic preferences. This information is valuable for water quality monitoring and for future decisions on the measures required to improve the environmental quality in temperate estuar- ies.

2. Materials and methods

2.1. Study area

This study was carried out on the Argentinean coastline between coordinates 34°27′10″S 58°30′21″W and 35°16′45″S 57°13′19″W (Fig. 1). The tidal amplitude ranges from 30 to 100 cm and tidal waves complete their passage through the whole estuary in about 12 h. The dynamics of the Rio de la Plata estuary is controlled by tides, wind-driven waves and the continental runoff but are modified by topography and Coriolis force. Freshwater discharge (annual mean 22,000 m^3 s^{-1}) from the Paraná and Uruguay rivers into the estuary exhibits minimal seasonality, with a maximum mean of 26,000 m^3 s^{-1} in winter and a minimum mean of 19,000 m^3 s^{-1} in summer (Guerrero et al., 1997; Balay, 1961).

Ten sampling sites were placed along 155 km of shoreline, influenced by different land uses, anthropogenic impact levels, and degrees of exposition to breaking waves (Table 1).

The northernmost sites (S1, S2 and S3) are exposed directly to the impact of the city of Buenos Aires, where navigational and port activities take place, and where domestic, and industrial effluents discharge. Site S4 is located close to the sewage effluent of Buenos Aires city.

Site S5 is located on the natural reserve “Selva Marginal de Punta Lara”, and S6 is exposed mainly to recreational and fishing activities; however both sites are influenced by poor water quality caused by human activities upstream.

Site S7 is located on the surrounding area of La Plata’s city sewage effluent. Sites S8, S9 and S10 are exposed to small-scale recreational and fishing activities. S10 is the closest site to the maximum turbidity front (Fig. 1).

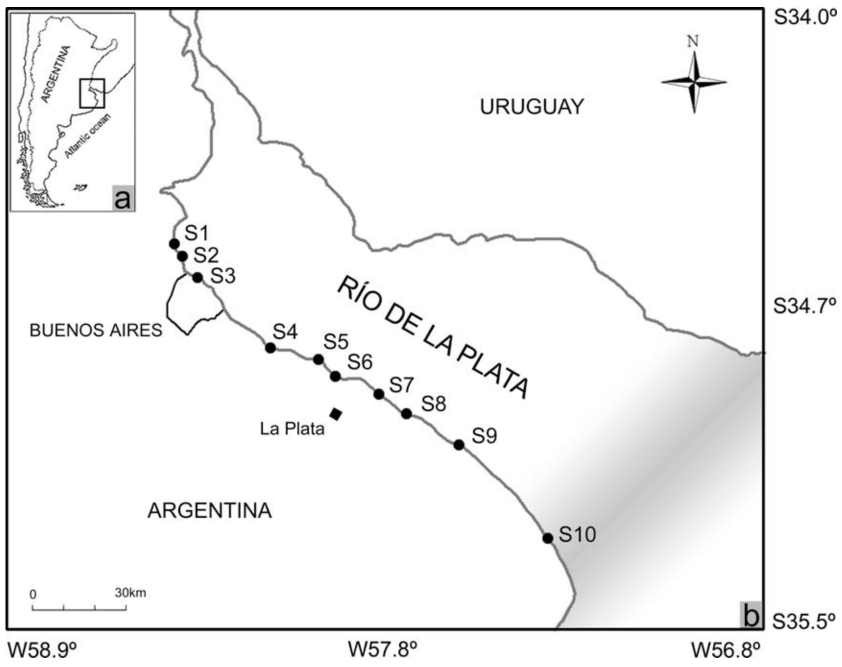

Fig. 1. Study area: location of the Rio de la Plata estuary (a) and sampling sites (b). Shaded area corresponds to the maximum turbidity front.

Table 1
Sampling sites, geographical location, organic matter content, granulometry (average and SD in brackets), the main anthropic activity conducted in the area and the exposure degree to breaking waves.

	Coordinates	Organic matter (g m^{-2})	Coarse sand (%)	Medium sand (%)	Fine and very fine sand (%)	Silt (%)	Clay (%)	Main activity	Exposure to breaking waves
S1	34°27′10″S 58°30′21″W	242 (±168)	4.36 (±6.8)	24.12 (±38.4)	59.01 (±37.4)	7.59 (±8.1)	4.92 (±7.0)	Urban navigation	Low
S2	34°29′8″S 58°28′49″W	223 (±235)	5.16 (±2.0)	71.75 (±8.7)	19.79 (±11.3)	0.18 (±3.5)	3.12 (±0.3)	Urban recreational	Moderate
S3	34°32′57″S 58°25′35″W	348 (±261)	0.08 (±0.1)	1.49 (0.6)	91.77 (±9.2)	1.93 (±8.2)	4.74 (±1.8)	Urban recreational	Low
S4	34°44′38″S 58°10′42″W	208 (±59)	0.47 (±0.5)	1.87 (±1.6)	89.54 (±9.4)	1.27 (±10.9)	6.85 (±1.1)	Urban waste effluent	Moderate
S5	34°46′49″S 58°00′59″W	151 (±74)	0.10 (±0.0)	3.91 (±3.0)	92.07 (±3.7)	0.64 (±2.8)	3.28 (±0.4)	Fishing recreational	High
S6	34°49′29″S 57°57′35″W	142 (±51)	0.10 (±0.1)	4.17 (±5.9)	92.93 (±5.1)	0.26 (±3.4)	2.55 (±0.2)	Recreational	Moderate
S7	34°52′26″S 57°48′33″W	235 (±185)	0.06 (±0.1	0.23 (±0.1)	96.59 (±4.3)	0.26 (±3.9)	2.86 (±0.4)	Fishing waste effluent	Moderate
S8	34°55′44″S 57°42′56″W	130 (±79)	2.34 (±2.5)	2.90 (±2.5)	76.67 (±19.6)	7.27 (±9.7)	10.82 (±7.5)	Fishing recreational	Moderate
S9	35°0′49″S 57°32′7″W	176 (±105)	0.09 (±0.1)	0.47 (±0.5)	93.42 (±3.2)	4.77 (±1.2)	1.25 (±4.0)	Fishing recreational	Moderate
S10	35°16′45″S 57°13′19″W	153 (±39)	2.08 (±3.5)	29.25 (±13.9)	65.59 (±15.3)	1.01 (±1.6)	2.07 (±0.3)	Fishing recreational	High

2.2. Sampling and laboratory analysis

Conductivity (Lutron 4303-CD), dissolved oxygen (Oxymeter 600-ESD), turbidity (Turbidity meter 800-ESD), temperature and pH (Hanna HI 8633) were measured *in situ*. Water samples were collected to analyze $N{-}NH_4^+$, $N{-}NO_2^-$, $N{-}NO_3^-$, $P{-}PO_4^{-3}$, BOD_5 and COD (Mackareth et al., 1978; APHA, 1998).

Microbenthos samples were taken at low tide during spring 2005, autumn and winter 2006, and summer 2007. Five replicates of the surface layer (0.5 cm) were collected with a core (area 3.14 cm^2) at each site for the estimation of organic matter and another five were taken for taxonomic identifications and microbenthic organisms counts, the latter were preserved in formalin (final concentration 4%).

Organic matter, expressed as ash-free dry weight, was measured as the difference in weight between the dried mass at 60 °C for 24 h and combusted mass at 550 °C for 4 h (Bourasa and Cataneo, 1998; APHA, 1998).

A granulometry analysis was carried out recognizing the categories proposed by Folk (1974): clay ($\leqslant$3.9 μm), silt (3.9 to <62.5 μm), both fine and very fine sand (62.5 to <250 μm), medium sand (250 to <500 μm), and coarse sand ($\geqslant$500 μm).

Density of consumers and producers of the microbenthic community (size < 1 mm) was estimated using a Sedgwick–Rafter

Table 2
Physico-chemical parameters, average and SD in brackets.

	Conductivity ($\mu S\ cm^{-1}$)	pH	DO ($mg\ l^{-1}$)	TURB (NTU)	$N{-}NO_3^-$ ($mg\ l^{-1}$)	$N{-}NO_2^-$ ($mg\ l^{-1}$)	$N{-}NH_4^+$ ($mg\ l^{-1}$)	$P{-}PO_4^{-3}$ ($mg\ l^{-1}$)	BOD_5 ($mg\ l^{-1}$)	COD ($mg\ l^{-1}$)
S1	232.50 (±28.86)	7.64 (±0.92)	7.99 (±2.92)	62.20 (±30.10)	0.67 (±0.17)	0.04 (±0.01)	0.28 (±0.27)	0.33 (±0.40)	2.00 (±0.82)	10.25 (±6.65)
S2	290.75 (±41.40)	7.43 (±0.15)	7.14 (±0.84)	49.23 (±27.83)	1.08 (±0.24)	0.08 (±0.02)	0.26 (±0.16)	0.25 (±0.11)	3.50 (±2.38)	11.75 (±6.02)
S3	264.25 (±52.55)	7.25 (±0.10)	5.67 (±0.87)	47.15 (±18.36)	0.99 (±0.26)	0.07 (±0.03)	0.22 (±0.15)	0.13 (±0.02)	2.98 (±2.48)	10.25 (±5.66)
S4	499.50 (±69.70)	8.43 (±0.36)	10.76 (±1.31)	32.68 (±17.97)	0.96 (±0.22)	0.18 (±0.05)	0.86 (±0.76)	0.37 (±0.11)	6.00 (±3.92)	14.25 (±5.32)
S5	369.25 (±53.01)	8.43 (±0.68)	9.39 (±1.59)	43.25 (±0.75)	0.89 (±0.48)	0.04 (±0.02)	0.12 (±0.12)	0.22 (±0.06)	6.75 (±5.91)	21.25 (±8.62)
S6	351.75 (±122.19)	8.54 (±0.63)	11.20 (±4.08)	44.58 (±19.51)	0.99 (±0.63)	0.05 (±0.03)	0.27 (±0.28)	0.40 (±0.21)	9.00 (±2.94)	22.75 (±9.18)
S7	634.25 (±230.29)	7.81 (±0.24)	7.95 (±2.08)	52.65 (±37.07)	0.58 (±0.46)	0.11 (±0.15)	0.57 (±0.48)	0.72 (±0.48)	18.00 (±9.31)	39.50 (±32.71)
S8	362.00 (±108.48)	8.37 (±0.43)	9.22 (±1.94)	64.15 (±14.03)	0.36 (±0.36)	0.01 (±0.02)	0.03 (±0.03)	0.13 (±0.03)	6.75 (±0.96)	16.50 (±5.97)
S9	665.00 (±492.51)	8.22 (±0.16)	8.70 (±0.48)	99.88 (±43.76)	0.50 (±0.26)	0.01 (±0.01)	0.31 (±0.53)	0.13 (±0.06)	7.75 (±4.43)	20.50 (±9.68)
S10	2115.50 (±1789.29)	8.08 (±0.64)	8.40 (±1.47)	189.83 (±13.15)	0.23 (±0.21)	0.01 (±0.01)	0.05 (±0.05)	0.19 (±0.08)	6.00 (±3.65)	31.50 (±18.70)

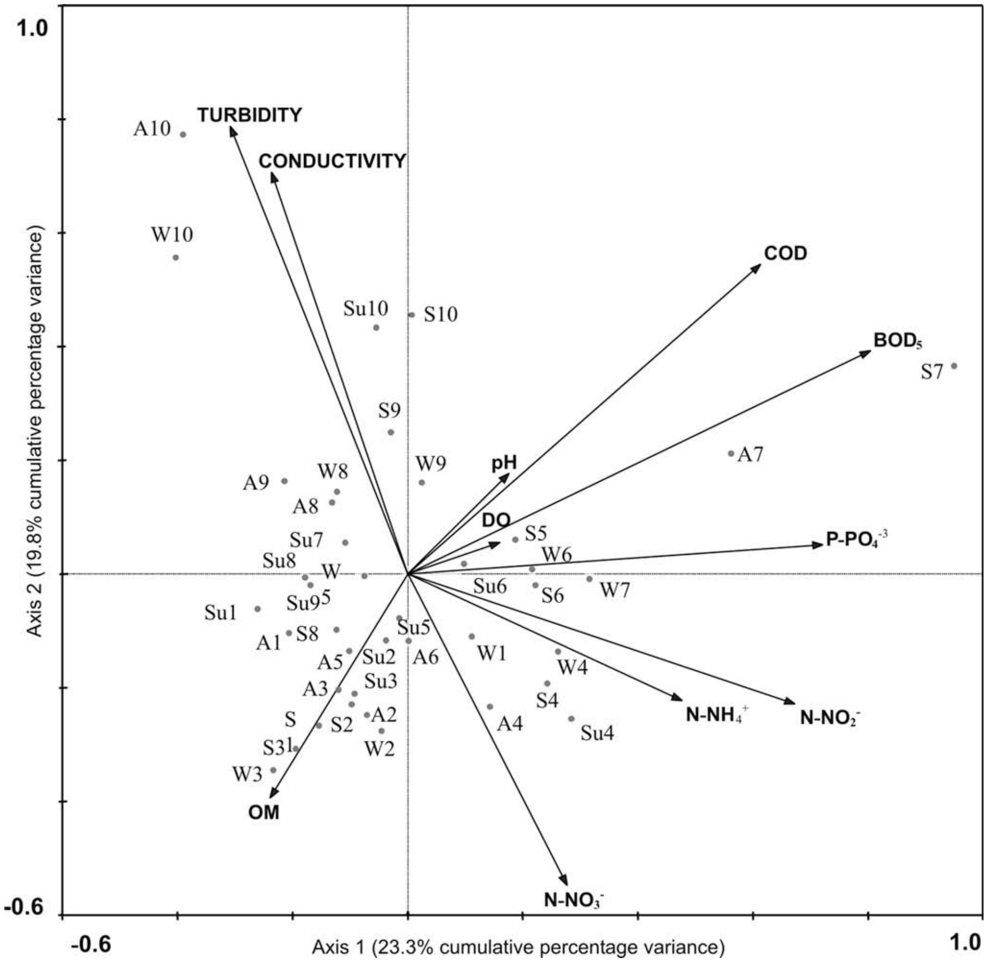

Fig. 2. Representation of the first two PCA factors showing the physical and chemical variables of the sampling sites.

chamber (APHA, 1998). Previous to counting, each sample was placed on a Shaker for 10 min to facilitate the homogenization of the sample, and the resuspension of the organisms. All ciliate species were grouped as Ciliates, because the fixer used to preserve the samples did not allow the detailed identification of different species in this group. Subsamples used for diatom identifications

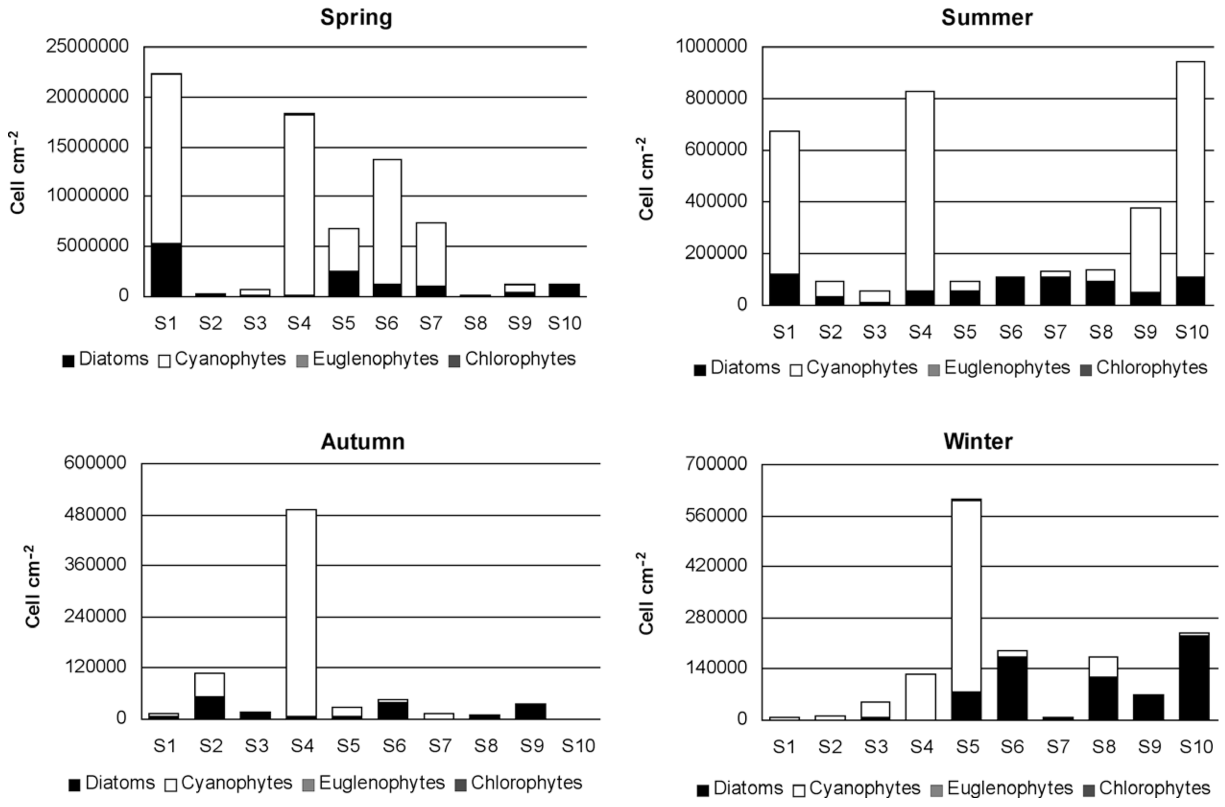

Fig. 3. Spatial and seasonal distribution of producers identified in the microbenthos.

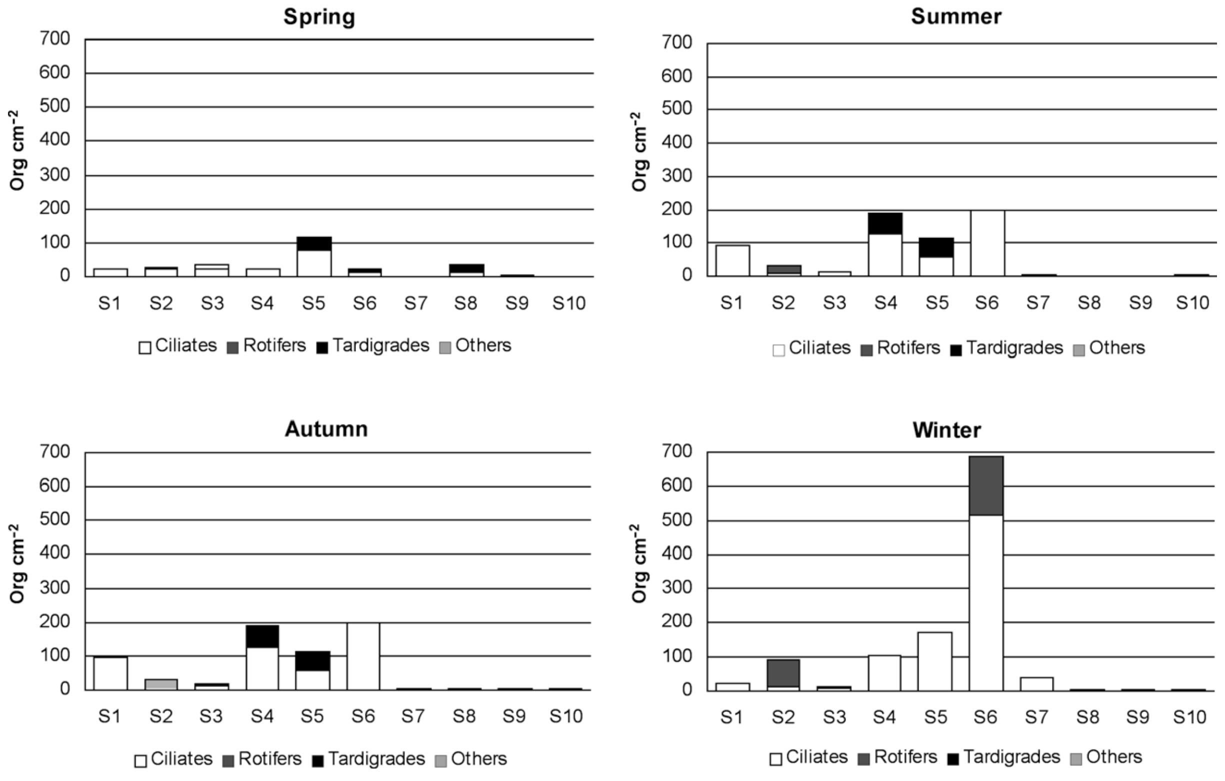

Fig. 4. Spatial and seasonal distribution of consumers identified in the microbenthos.

were cleaned with H_2O_2, washed thoroughly using distilled water, mounted on microscope slides with Naphrax® and then examined with an Olympus BX 51 microscope with phase contrast and Normarski DIC optics.

Species diversity was calculated using the Shannon and Wiener index ($x = \log_2(ni/N)$) according to Shannon and Weaver (1949); saprobic and trophic species preferences were established according to Sládecek (1973), Lowe (1974), Lange-Bertalot (1979), Van Dam et al. (1994), Gómez (1998), Gómez and Licursi (2001), and Licursi and Gómez (2002).

2.3. Statistical analysis

Sampling sites ordination in relation with the physico-chemical variables was explored through a principal component analysis (PCA). A canonical correspondence analysis (CCA) was performed to analyze the relation between species composition and the environmental variables measured. In this analysis, those species that had a frequency above 10% were included. According to the gradient length in standard deviation units obtained in a preliminary detrended correspondence analysis (>4), ordination techniques based on weighted averaging were more appropriate for data analysis. Species abundance were $\log_e(x + 1)$ transformed. Conductivity, BOD_5, $P—PO_4^{-3}$, $N—NO_2^-$, $N—NO_3^-$ and organic matter in sediment were selected in this analysis as environmental variables, since they were the only ones with a variance inflation factor <10; according to ter Braak and Verdonschot (1995) a greater value would indicate multicolinearity among variables. The overall significance of the ordination and the significance of the first two axes were tested with a Monte Carlo permutation test ($p < 0.01$) using restricted permutations.

The relationship between the biological variables and the physico-chemical parameters was analyzed using Pearson's correlation.

3. Results

3.1. Habitat characterization

Sediment composition consisted mainly of fine and very fine sand (62.5–250 μm). In site S2 the coast was anthropically modified by the addition of debris, leading to the predominance of coarser sand. The clay and silt fraction as well as the organic matter content were higher in those sites less exposed to breaking waves (Table 1).

3.2. Physical and chemical characteristics

Surface water temperature exhibited the typical seasonal pattern of temperate waters with the maximum temperature in summer (average 29.8 ± 2.7 °C) and the minimum in winter (average 16.3 ± 2.3 °C).

Conductivity increased significantly in those sites nearer to the maximum turbidity front (S9 and S10), which also exhibited the highest turbidity values. The high values measured in sites S4 and S7 were related to sewage effluents. The average pH values were slightly alkaline in the sampling sites analyzed. Site S7 exhibited the highest BOD_5, COD and $P—PO_4^{-3}$ values, while the highest $N—NH_4^+$ and $N—NO_2^-$ values were found in S4 and $N—NO_3^-$ in site S2 (Table 2).

According to the PCA results (Fig. 2), the sampling stations were organized along an eutrophication and pollution gradient (axis 1 with 23.3% cumulative percentage variance) and also along a turbidity and conductivity gradient (axis 2 with 19.8% cumulative percentage variance). This last axis also grouped sampling sites in relation with the organic matter content in the sediments.

3.3. Characteristics of the microbenthic assemblages

3.3.1. Producers

Maximum cell density of producers occurred in spring (22×10^6 cell cm^{-2}) and minimum densities in autumn (600 cell cm^{-2}). Sites S1, S4, S5 and S10 exhibited higher density values in different occasions (Fig. 3).

During winter, spring, and summer the colonial cyanophyta *Microcrocis obvoluta* and the motile filamentous *Komvophoron constrictum*, both characteristic of benthic habitats, were abundant, and were present in more than 55% of the samples. Also, the planktonic cyanophyta *Pseudoanabaena catenata* was frequent in the biofilm (28% of presence in the samples). As a consequence of a bloom developed by the planktonic species *Microcystis aeruginosa*, in the

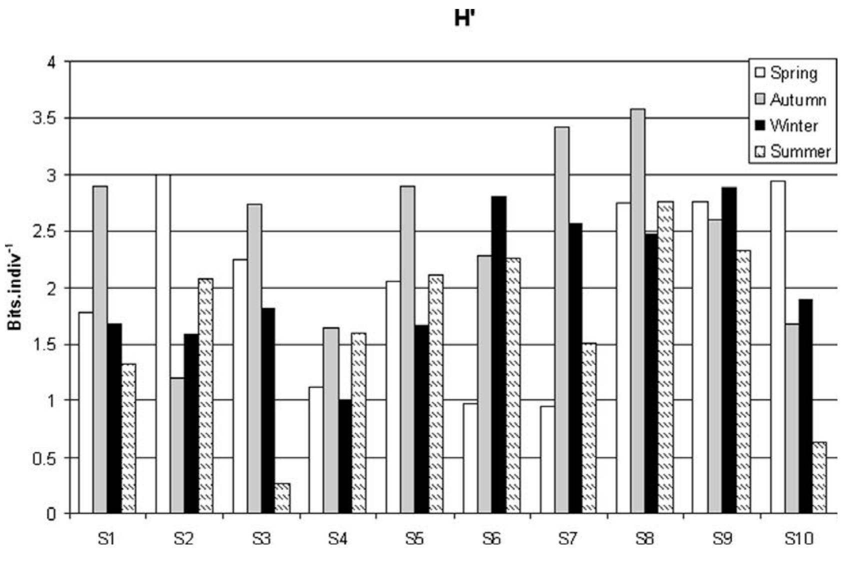

Fig. 5. Spatial and seasonal distribution of the diversity index (H') in the study area.

Table 3
List of identified species that had a frequency above 10% in the total sample set. The acronyms of the species included in the CCA are indicated.

Producers	
Cyanophyta	
Komvophoron constrictum (Szafer) Anagnostidis et Komárek	KOCO
Merismopedia sp. Meyen	MERI
Microcrocis obvoluta (Tiffany) Frank et Landman	MIOB
Oscillatoria sp. Vaucher ex Gomont	OSCI
Oscillatoria tenuis Agardh et Gomont	OSTE
Pseudoanabaena catenata Lauterborn	PSCA
Bacillariophyta	
Achnanthes delicatula (Kützing) Grun. ssp. *delicatula* Grunow	ADEL
Achnanthes minutissima Kützing v. *minutissima* Kützing (*Achnanthidium*)	AMIN
Actinocyclus normanii (Gregory) Hustedt morphotype *normanii*	ANMN
Actinocyclus normanii (Gregory) Hustedt morphotype *subsalsus*	ANSU
Amphora acutiuscula Kützing	AACU
Amphora libyca Ehrenberg	ALIB
Amphora montana Krasske	AMMO
Aulacoseira distans (Ehrenberg) Simonsen	AUDI
Cocconeis neodiminuta Krammer	CNDI
Craticula halophila (Grunow ex Van Heurck) Mann	CHAL
Cyclotella meneghiniana Kützing	CMEN
Fragilaria brevistriata Grunow (*Pseudostaurosira*)	FBRE
Fragilaria heidenii Oestrup	FHEI
Fragilaria pinnata Ehrenberg var. *pinnata* (*Staurosirella*)	FPIN
Gomphonema parvulum (Kützing) Kützing var. *parvulum* f. *parvulum*	GPAR
Hantzschia abundans Lange-Bertalot	HABU
Hippodonta hungarica (Grunow) Lange-Bertalot Metzeltin and Witkowski	HHUN
Luticola mutica (Kützing) D.G. Mann	LMUT
Luticola ventricosa (Kützing) D.G. Mann	LVEN
Navicula atomus (Kützing) Grunow var. *atomus*	NATO
Navicula decussis Oestrup	NDEC
Navicula erifuga Lange-Bertalot	NERI
Navicula gregaria Donkin	NGRE
Navicula laterostrata Hustedt	NLAT
Navicula monoculata Hustedt	NMOC
Navicula monoculata Hustedt var. *omissa* (Hustedt) Lange-Bertalot	NMOM
Navicula novaesiberica Lange-Bertalot	NNOV
Navicula pygmaea Kützing	NPYG
Navicula sanctaecrucis Ostrup	NSTC
Navicula schroeteri Meister var. *schroeteri*	NSHR
Navicula tenelloides Hustedt	NTEN
Navicula viridula (Kützing) Ehrenberg var. *rostellata* (Kützing) Cleve	NVRO
Neidium ampliatum (Ehrenberg) Krammer	NEAM
Neidium iridis (Ehrenberg) Cleve	NIRI
Nitzschia amphibia Grunow f. *amphibia*	NAMP
Nitzschia brevissima Grunow	NBRE
Nitzschia capitellata Hustedt	NCPL
Nitzschia inconspicua Grunow	NINC
Nitzschia lacunarum Hustedt	NLCR
Nitzschia levidensis (W. Smith) Grunow	NLEV
Nitzschia palea (Kützing) W. Smith	NPAL
Nitzschia paleacea (Grunow) Grunow	NPAE
Nitzschia sigma (Kützing) W.M. Smith	NSIG
Nitzschia umbonata (Ehrenberg) Lange-Bertalot	NUMB
Pinnularia gibba Ehrenberg	PGIB
Placoneis clementis (Grunow) Cox	PCLT
Placoneis placentula (Ehrenberg) Heinzerling	PPLC
Pleurosira laevis (Ehrenberg) Compere f. *laevis* Ehrenberg	PLEV
Sellaphora nyassensis (O. Muller) D.G. Mann	SNYA
Sellaphora pupula (Kützing) Mereschkowksy	SPUP
Stauroneis brasiliensis (Zimmerman) Compere	STBR
Stephanodiscus hantzschii Grunow	SHAN
Consumers	
Ciliates	CILI
Rotifers	ROTI
Tardigrads	
Dactilobyotus dispar Murray	DADI

downstream area during the summer, the microbenthos in sites S9 and S10 was largely dominated by this species (>88%).

In autumn the diatoms, particularly birraphideans, dominated (Fig. 3); species such as *Navicula novaesiberica*, *Navicula pygmaea*, *Nitzschia palea*, *Navicula erifuga*, *Amphora lybica*, and *Sellaphora pupula* were the most abundant and frequent taxa (>60%). The diatom assemblages were dominated by motile forms (>60%) with a size greater than 30 μm (>65%). In sites S5, S6, and S7 the facultative nitrogen-heterotrophic taxa (needing periodically elevated concentrations of organically-bound nitrogen) dominated (64–67%), while in sites S1, S2, S3, S8, S9, and S10 nitrogen-autotrophic taxa (tolerating elevated concentrations of organically-bound nitrogen) prevailed (53–69%). The greater proportion of obligately nitrogen-heterotrophic taxa (needing continuously elevated concentrations of organically-bound nitrogen) was observed in the S4 site (37%).

Both the chlorophytes and euglenophytes were poorly represented in the biofilm.

3.3.2. Consumers

The greater consumer density was observed in winter, with 685 org cm^{-2}, and the minimum in spring with 1 org cm^{-2} (Fig. 4). The highest densities throughout the sampling period were found in sites S4, S5, and S6.

Ciliates was the best represented group in the biofilm (47% of frequency) and particularly abundant in winter. Planktonic species, such as *Tintinnidium fluviatile* and *Codonella cratera*, were frequent in the microbenthos.

Tardigrads, mainly represented by *Dactylobiotus dispar* were present during the summer, autumn, and spring, while the rotifers, represented mainly by *Cephalodella*, *Notommata*, and *Lecane* genera, were more abundant in winter.

3.3.3. Diversity

Diversity values fluctuated between 0.2 and 3.5 bits indiv^{-1}. The lowest values were found in sites S1, S2, S3, S4, and S10, and the highest ones in sites S8 and S9. The community structure reached the highest diversity in autumn and the lowest in summer (Fig. 5).

3.4. Links between community composition, environmental variables and habitat

The canonical correspondence analysis included 61 taxa (Table 3) out of the 175 total identified. The first axis explained 36% and the second 24% of the sum of all canonical eigenvalues. These axes were selected for the graphical representation (Fig. 6). The results allowed us to distinguish two groups of species, the first one conformed by *Luticola ventricosa*, *Stauroneis brasiliensis*, *Navicula monoculata* var. *omissa*, *Oscillatoria* sp., *Microcroccis obvoluta*, and *P. catenata*, that was related with the highest nitrite (0.14 ± 0.10 mg l^{-1}) and ammonia values (0.30 ± 0.23 mg l^{-1}). The second group of species includes *Amphora acutiuscula*, *A. lybica*, *Pleurosira laevis*, *Actinocyclus normanii*, *Fragillaria pinnata*, *Hantzschia abundans*, *Hippodonta hungarica*, and *Navicula tenelloides*, associated with high conductivity (1657 ± 1597 μS cm^{-1}), and *Nitzschia lacunarum*, *Dactilobiotus dispar*, *K. constrictum*, and *Merismopedia* sp., linked to high concentrations of nitrates (0.94 ± 0.17 mg l^{-1}).

The higher total densities of consumers were found in sites S4, S5, and S6, whereas the higher densities of producers were found in sites S1, S4, and S6 (Fig. 7). While the density of producers increased with the rise in temperature ($r = 0.40$, $p < 0.05$) and nutrients, particularly nitrites ($r = 0.42$, $p < 0.05$), the density of consumers decreased with the increase in turbidity ($r = -0.58$, $p < 0.001$), particularly the ciliates ($r = -0.47$, $p < 0.01$). A significant correlation was also observed between density of producers and clay percentage ($r = 0.66$, $p < 0.01$), cyanophytes being the ones

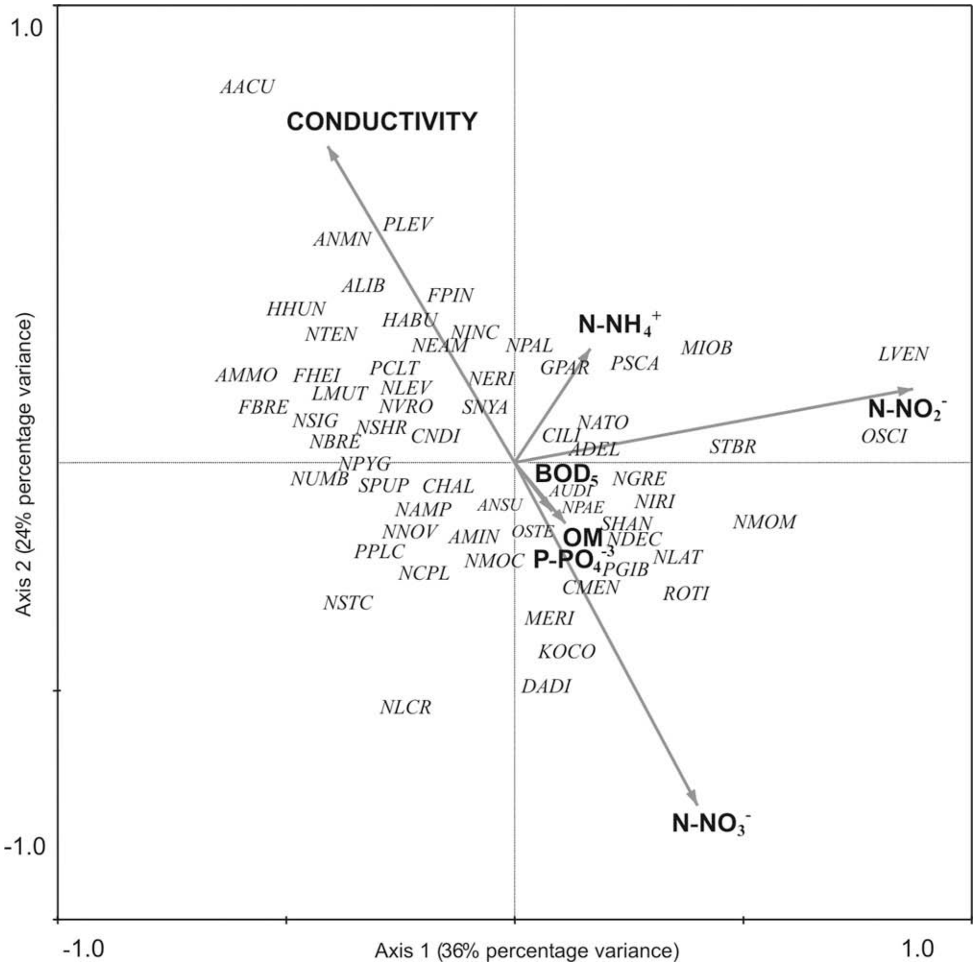

Fig. 6. Biplot of canonical correspondence analysis (CCA) showing the association between the different taxa and the environmental variables.

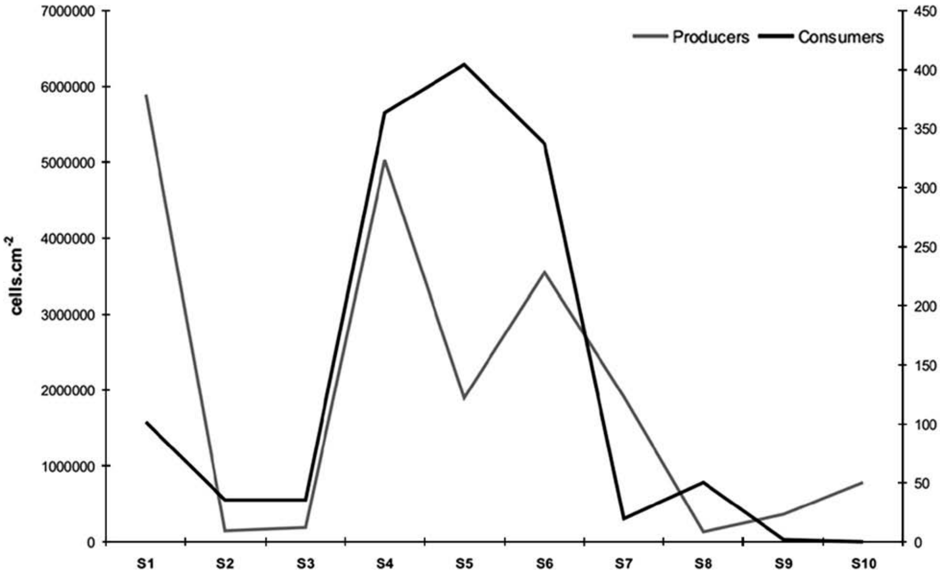

Fig. 7. Average densities of producers and consumers found in microbenthos.

most closely related with the predominance of this sediment type ($r = 0.44$, $p < 0.05$); the rotifers increased in sites with predominance of medium sand (250 to <500 μm) sediments ($r = 0.53$, $p < 0.01$).

3.5. Trophic and saprobic preferences

The higher proportion of α-mesosaprobic and polisaprobic species was found in sites S1–S7, while in sites S8–S10 the greater

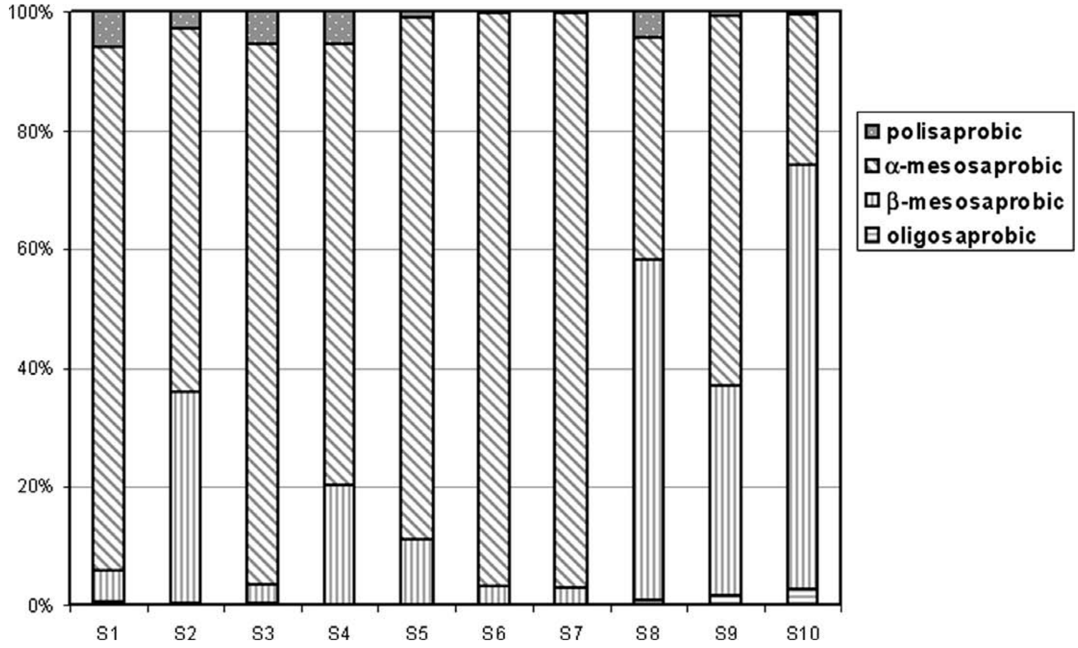

Fig. 8. Saprobic preferences of species found in the biofilms analyzed.

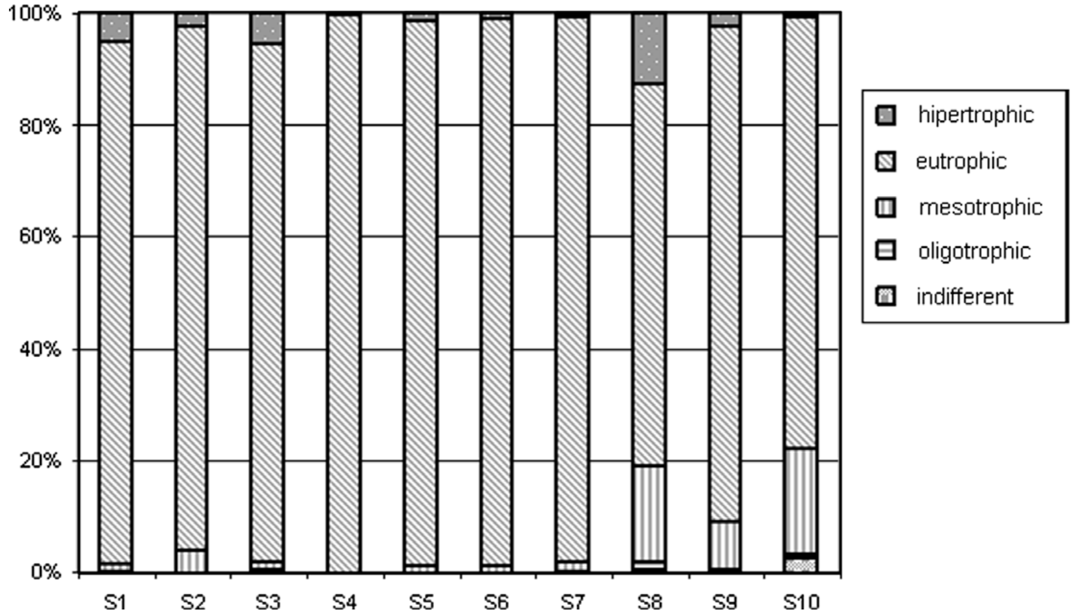

Fig. 9. Trophic preferences of species found in the biofilms analyzed.

percentage of β-mesosaprobic and oligosaprobic species was observed (Fig. 8).

In relation to trophic preferences, the predominance of eutrophic species in all the sites was observed, reaching more than 90% in sites S1–S7 (Fig. 9).

4. Discussion and conclusions

In the studied area we recognized two gradients, the first one determined by anthropic factors, related to pollution and eutrophication (decreasing from the inner to the outer area), and the second one to conductivity and turbidity (increasing from the inner to the outer area), associated mainly to the dynamic of the estuary. According to Underwood and Kromkamp (1999) and Thornton et al. (2002), within estuaries the gradient is usually characterized by a decrease in nutrient concentration and an increase in salinity. Whereas in the study area the results agree with this pattern, those sites placed near sewage effluents diverted from it, showing higher conductivity values than expected.

In estuaries with a tidal range less than 2 m, as in the Rio de la Plata estuary, the dominant physical processes are generated by wind and wave effects. In our study the microbenthic habitat characteristics were influenced by the exposure degree of the sampling sites to breaking waves. Similar results were observed by Gómez et al. (2003) in epiphytic communities in the coast of de Rio de la Plata estuary.

The producers' density values obtained are similar to those reported for intertidal zones of other temperate estuaries (Cibic et al., 2007). The higher densities of producers were observed in sites characterized by fine sediments and with high amounts of dissolved nutrients. Brotas et al. (1995) points out that sediment type is one of the factors that account for the variability in the intertidal zones of the Tagus estuary (Portugal), determining the stability and cohesion of the surface layer and deposition of inorganic and organic particles. Furthermore, Herman et al. (2001) points out that algal biomass accumulates more easily with the increasing mud content of the sediment, and nutrient resources for growth can be expected to be higher in muddy areas, as mineralization rates are higher.

The cyanophytes and diatoms were the best represented groups of producers in the analyzed microbenthos; while the former dominated in the inner zone, the latter did in the outer zone of the study area. According to Cahoon et al. (1999) diatoms are ubiquitous and are usually dominant in terms of biomass, but there are situations when other photosynthetic microorganisms are more abundant.

The ciliates were the most abundant group among consumers, and their spatial distribution in the microbenthos of the Rio de la Plata estuary was influenced by the turbidity. Rotifers showed a preference for sandier sediments; among the identified species we found *Lecane* and *Notommata*, recognized in the bibliography as bacterivores and algivores, respectively (Pourriot, 1977). According to Bott (1996), the relative importance of the microconsumers is related to the densities and species composition of both microconsumers and algae, as well as macrograzer densities, nutrients and physical factors such as light, temperature, sediments properties and disturbances (e.g., tides and storms).

Seasonal variability was influenced by temperature and light availability for the community, being more noticeable in the producers' density fluctuations. Photoperiod and light intensity are recognized as elements that influence the species' seasonality (Sherman and Phinney, 1971; Hill, 1996). According to Cartaxana et al. (2006) benthic microalgae of intertidal sediments show a high degree of spatial and seasonal variability, and factors such as resuspension, nutrient and light availability, grazing, and desiccation have been suggested to control microphytobenthic biomass. Brotas et al. (1995) recognized in a mesotidal estuary that the tide plays an important role in the spatial distribution of the microphytobenthos, and that tidal height integrates a set of different variables, such as the effects of desiccation, available irradiation, temperature, algae resuspension, sediment particles and the immersion/emersion rhythm of vertical migration and grazing. In our case, the desiccation effect might be attenuated since it is a microtidal estuary.

The community structure varied along the study area, and the abundance of opportunistic and tolerant species offered the possibility to distinguish the anthropic pressure on the ecosystem. The biofilm consisted of taxa that preferred environments with high concentrations of nutrients and organic matter. The whole study area has an eutrophic condition, showing no significant differences between the sites. The highest proportion of α-mesosaprobic and polisaprobic species was observed among sites S1–S7. Also, the highest proportions of benthic cyanophytes and ciliates were found in those sites exposed to a higher anthropic impact, and particularly in those sites where sewage effluents are located. Vis et al. (1998) and Bauer et al. (2007) noted an increase in the relative abundance of filamentous cyanophytes with the increase in the amount of urban wastewater.

P. catenata along with *M. obvoluta*, *Oscillatoria* sp., *L. ventricosa*, and *S. brasiliensis* were more abundant in nitrite and ammonium enriched sediments. Ammonium concentration may play an important role in determining species composition due to the toxic effects of ammonia; this ion is usually found in high concentrations in organically-enriched sediments. A series of nutrient enrichment experiments carried out on saltmarshes found shifts in species composition due to nitrogen enrichment (Sullivan, 1999). Within the assemblage analyzed in the intertidal sediments in the Rio de la Plata estuary, *Nitzchia* spp. and *Navicula* spp. were the best represented diatoms; the dominance of these genera was related to the increase in nutrient availability by Watt (1998) and Agatz et al. (1999).

According to Porter (2008) nitrogen-heterotrophic algae have the ability to use simple organic compounds such as amino acids for nutrition and as an energy source to supplement photosynthesis. Thus, the relative abundance of nitrogen heterotrophs can be used as an indicator of organic nitrogen compounds and/or reduced light availability. In our case, the sites where this type of taxa was more abundant corresponded to those exposed to an important input of organic compounds, which originate from anthropogenic activity (sewage and industrial effluents).

According to the conductivity gradient, the species were also arranged by their preference to the mineralization degree of the water. Despite the fact that the study area is within the freshwater tidal zone of the Rio de la Plata, it was possible to notice the presence of diatom species that are more tolerant to a higher conductivity, such as *A. acutiuscula*, *P. laevis*, and *N. erifuga*, frequently in those sites closer to the maximum turbidity front where the conductivity is higher.

In our study, conductivity, turbidity, and the enrichment with nutrients and organic matter explained 50% of the variability in the species' distribution. According to Graham et al. (2006), while more descriptive studies on spatial and seasonal patterns in species composition are useful, manipulative studies are also needed to determine species-specific responses to environmental variables. A combination of these data will allow a more accurate understanding of what determines species composition in estuarine biofilms.

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