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Primary Research Paper

Response of the zoobenthos community along the dispersion plume of a highly polluted stream in the receiving waters of a large river (Rio de la Plata, Argentina)

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Abstract

The ingress of an urban stream carrying high contaminant loads into a large coastal river originates a "dispersion plume" subject to the hydrological conditions of a river affected by tidal influences. In the present study 21 sites within the "contaminant plume" of the Riachuelo River in the Rio de la Plata were analysed on the same date in order to evaluate the biological status of the area which receives this strong environmental impact, and to examine its effect on the zoobenthic communities. Diversity, taxonomic richness, abundance, physico-chemical parameters and a biological index (IMRP) were used to assess the responses of the macroinvertebrates. The correlation between exposure and effect was calculated by means of the exposure index (IEX). The relationship between the macroinvertebrate communities and environmental variables was examined using CCA analysis. Conductivity, Cr, BOD and COD, were most strongly correlated with Axis 1, suggesting the existence of a gradient of environmental degradation. The most severely contaminated sites (IMRP = 1.1–2.5; IEX = 100–78%) were all characterized by a reduced community dominated by Nematoda and Oligochaeta. A moderate response was observed between 1400 and 1600 m from the coast (IMRP = 2.6–3.9; IEX = 36%) largely owing to the physico-chemical characteristics of the recipient river which contributed to moderating the effect of the anthopogenic perturbation. For statistical validation, this area was compared with historical physico-chemical and biological data, where OD and COD showed the same tendency throughout the 10-year period.

Introduction

Most studies of contamination by industrial and urban wastes in hydrological systems close to important urban centres have relied on identification and valuation of the physical and chemical parameters of the receiving waters (Gagnon & Saulnier, 2003) quantifying water quality changes in terms of waste load reductions (Harrell & Hall, 1991). Biological communities are constantly responding to physical forces, chemical dynamics and ecosystem processes and thus the difficulty is to establish to what degree these changes affect an ecosystem (Nedeau et al., 2003). The biological communities, especially the benthos, certainly reflect this situation (Margalef, 1983), highlighting the extent of the real impact of the contaminants on the environment, which will determine their survival or extinction. Since the US Protection Agency (1973) recommended the use of macrobenthic communities as an indicator of water quality, changes in benthic community structure were widely used in pollution assessment studies (e.g. Warwick, 1993; Chapman & Wang, 2001; Harrell & Smith, 2002; Harkantra & Rodrigues, 2003).

The studies on the benthic community in the Rio de la Plata began in 1997 in order to know its faunistic composition and to be able to interpret different ecological variables (Rodrigues Capitulo et al., 1997a, 1998; Cesar et al., 2000). A later study (in Rodrigues Capitulo et al., 1997b), about the water quality of the Matanza–Riachuelo basin, allowed the elaboration of an Index for Macroinvertebrates of Pampean Rivers (IMRP) based on Armitage et al. (1983) and Alba-Tercedor & Sanchez Ortega (1988).

The assessments of water quality monitoring were focussed mainly along the South Coastal Fringe (SCF), which embraces the area up to 10,000 m from the coast, along the Superior and Median areas of the river (AGOSBA, OSN, SHN, 1994). Other studies carried out in this area were: Boschi (1988); SRN and AH (1995); AA, AGOSBA, ILPLA, SHN (1997).

The SCF is characterized by receiving high pollutant loads coming from rivers and streams which transport urban (375,000 m^3 day^{-1}) and industrial (125,000 m^3 day^{-1}) sewage and drainage from cultivated areas, deriving from the activities of the biggest urban conglomerate in Argentina. Anthropogenic discharges in shallow bays and harbours may cause severe effects on benthic communities (Danulat et al., 2002) but ecological effects at the community or ecosystem levels derived from varied sources of disturbance and the scales in responses and recovery are still poorly known (Wu, 1999).

Due to harbours are characterized by low values of hydrodynamism and oxygen in the water column and high concentrations of pollutants in sediments (Guerra-Garcia & Garcia-Gomez, 2005) this area is considered to be at high ecological risk due to the location of Buenos Aires Port where most of the shipping activity is concentrated.

The north coast of the Rio de la Plata estuary which receives pollutant loads at the Montevideo Bay through two severely contaminated streams have been recently studied by Muniz et al. (2004).

Intensive samplings were planned in the outlet of the Riachuelo River analysing the influence of pollutants along the "contaminant plume" in the Rio de la Plata as part of the surveys realized in the SCF.

The objective of this study was to determine the relationship exposure-effect on the zoobenthos community structure of this receptive area of high environmental impact into a large river affected by tidal influences by means of two biological indexes.

Study area

The Rio de la Plata receives water from the Paraná and Uruguay rivers, forming the great del Plata basin, which drains a surface area of 3.1 million square kilometres before flowing into the Atlantic Ocean. Three areas are recognized in the Rio de la Plata based on their fluvio-marine character: Superior, Median and Exterior, which differ in the extent and concentration of marine influence, which together cover a length of approximately 323 km, with a mean flow of 20,000 m^3 s^{-1}.

Material and methods

In March 2000 sampling was carried out from the Army ship ARA Cormoran of the Naval Hydrograph Service (SHN) at the deeper points, and on the Monte Blanco Cruise for the shallower points. The study area covered an approximate surface area of 25 km^2 located at 34° 38′ S and 58° 20′ W (Fig. 1).

The sampling strategy selected was 21 sampling sites, placed radial from the site E306 which was taken as the original point of the waste water discharge, according to the concept of a "contaminant plume", in which the pollutants enter from a discharge channel into a dynamic system (Arraga et al., 1997) such as the Rio de la Plata in the South Coastal Fringe.

The samples were extracted with Van Veen (470 cm^2) and Dietz-Lafond (Snapper) (173 cm^2) grabs. The material was fixed *in situ* with 5% formalin and the samples were taken to the laboratory and sorted with sieves (250 μm). For more details on the processing of the material see Rodrígues Capitulo et al. (1997a), Barbour et al. (1999).

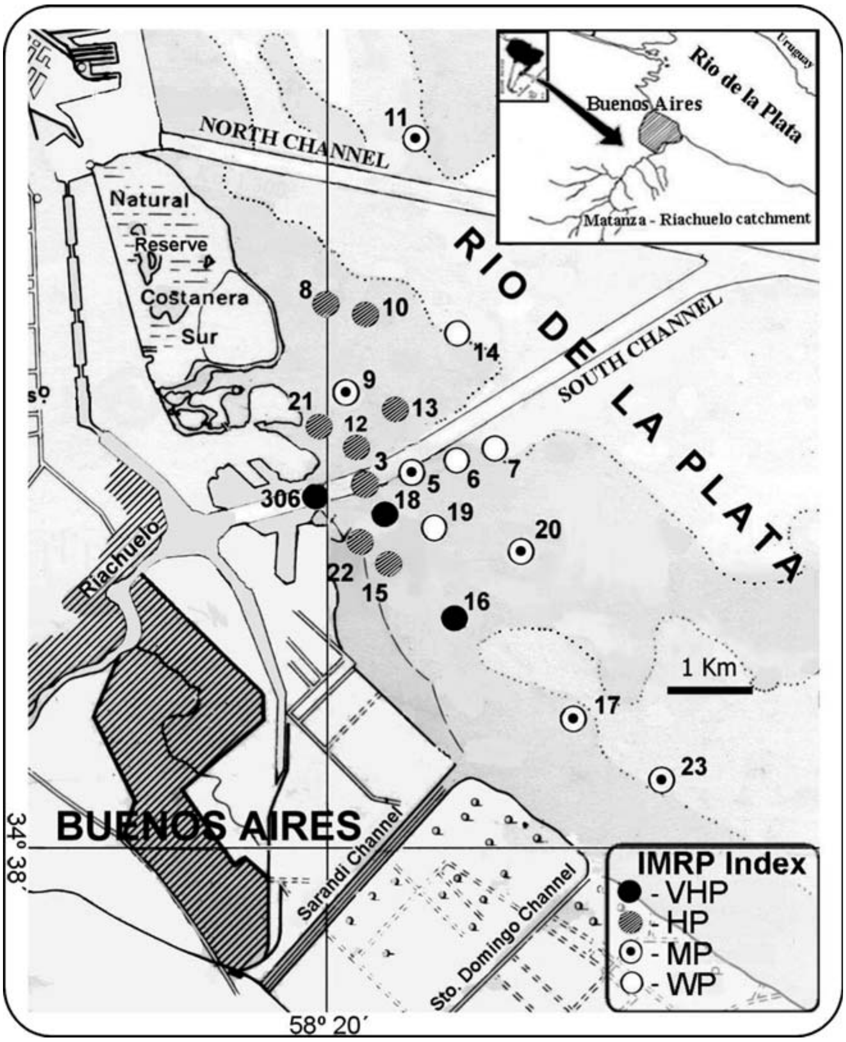

Figure 1. Map of the study area showing the sampling sites in the Rio de la Plata and the IMRP Index recorded along the dispersion plume of contaminants from the Riachuelo River. VHP = very heavy pollution. HP = heavy pollution. MP = moderate pollution. WP = weak pollution.

Organic matter (OM) was determined by the ignition method (LOI) at 500 °C during 4 h. The granulometric analysis was made following the Stokes principle, which applies the speed of particle sedimentation (Folk, 1959). The physico-chemical data were supplied by the Naval Hydrography Service (SHN) and determined by standard procedures (APHA, 1998).

Diversity was estimated according to Shannon & Wiener (*H′*) (1949) and Margalef (R) (1958); taxa richness (S) was also calculated. The Index of Macroinvertebrates for Pampean Rivers (IMRP) (Rodrígues Capítulo et al., 1997b; Gómez & Rodrígues Capítulo, 2001) was applied with the purpose of evaluating the biological status of the area studied and was calculated using the formula:

$$\mathrm{IMRP} \underset{\mathrm{sp1}}{\overset{\mathrm{n}}{=}} \sum Vx$$

where Vx is a value of ecological sensitivity assigned to each taxon that occurred in the study area. Each value of Vx is proportionally inverse to the pollution tolerance, varying from 0.1 for very tolerant to 3.0 for the most sensitive taxa. The scale of this index is provided in Results (*Biological Index IMRP*). Canonical correspondence analysis (CCA) was used (Ter Braak, 1986) to relate the physico-chemical, nutrient and biological variables.

With the objective of analysing the response of the benthic community to the chemical contamination, the % effluent (Exposure Index) along the contaminant plume was estimated. Four variables (BOD, COD, Conductivity and Total Cr) were used as conservative parameters that flood into the Río de la Plata from the Riachuelo River. For each variable the maximum concentrations (100%), near to the mouth of the Riachuelo, and the minimum (0%) concentrations, at the farthest extent of influence of the contaminant plume were used. The % effluent resulted from the average of the four variables considered.

The relationships between the most representative chemical parameters and biological indices were analysed following Sokal & Rohlf (1994).

Results

Substratum characteristics

Sand was the predominant fraction at most of the sites in the area studied, except at site 9 where silt and sand were recorded in similar proportions (50%), and at site 11 where the highest percentage of gravel was registered (15%). The fraction of silt varied between 0.12 and 1.13%, while clay varied between 0.09 and 1.1% at the other sites.

The percentages of OM showed no great variation among the sites sampled (0.9–2.82%) with the exception of site 306, the outlet of the Riachuelo, with 8.32%.

Macrobenthic invertebrates composition and diversity indices (Table 1) (Fig. 1)

Excluding site 306, site E21 showed the lowest values of the diversity and taxa richness indices, with nematodes dominating over *Corbicula fluminea* and *Heleobia parchappei* (a decrease in the percentage of OM was also observed). Towards site E8 the number of faunistic groups increased while the density of nematodes decreased significantly, compared with the previous site.

The abundance of nematodes at site E10 caused a fall in the values of the diversity indices. Sites E16 and E18 were still considerably influenced by the Riachuelo inflow, with low index values even when the presence of nematodes and naidids was excluded.

At site E14 increases in the values of the indices were observed off the coast due to the presence and abundance of species such as *H. parchappei*, *Limnoperna fortunei*, *C. fluminea* as well as cladocerans (Chydoridae), harpacticoid copepods, chironomids and acarii. Similar results were observed at site E7 due to the appearance of *Claudicuma platensis*, ostracods and macrothricid cladocerans, the latter coinciding with a decrease of % OM. Site E19 also showed an increase in the indices with the presence of 11 taxa, but the number of faunistic groups declined again at site E20.

Biological index IMRP

If we consider the IMRP Index (Fig. 1), sites that showed *very heavy pollution* (IMRP: 0–1) were 306 (0.35) 18 (0.85) and 16 (0.5) the last two being located at 800 and 2100 m, respectively, from the first site. Sites 306 and 18 received the direct influence of the Riachuelo outlet. Site 16, however, was affected by the "contaminant plume" which had a north-southeast displacement at the time of sampling due to the effect of river dynamics. The maximum concentrations of nitrites (N/NO_2) (0.11–0.13 mg l^{-1}) and phosphates (P/PO_4) (0.18–0.20 mg l^{-1}) were recorded in all these sites. Sites with *heavy pollution* (IMRP: 1.1–2.5) were 3 (2.5), 8 (2.05), 10 (1.75), 12 (1.45), 13 (2.05), 15 (1.1), 21 (1.45) and 22 (1.75), covering a large area both north and south of the navigable channel, between 650 and 2100 m from point 306, influenced by the inflow. Here the nitrites showed a wide variation from 0.02 to 0.15 mg $l^{-1}$and the phosphates oscillated between 0.13 and 0.23 mg l^{-1}.

Sites with *moderate pollution* (IMRP: 2.6–3.9) were 5 (3.1), 9 (3.85), 11 (2.7), 17 (2.7), 20 (2.55), and 23 (3.8). Sites 11, 17 and 23 were the furthest from the Riachuelo mouth (4150; 3500 and 4700 m respectively). All the sites subject to this level of pollution were at very dissimilar distances from the reference site, 306, covering an undefined area, and therefore with great variation in the concentrations of nitrites (0.00–0.13 mg l^{-1}) and phosphates (0.10–0.16 mg l^{-1}).

Sites with *weak pollution* (IMRP: 4–7.9) were 6 (4.9), 7 (6.15), 14 (4.5) and 19 (4.55), located at 1650; 2100; 2500 and 1400 m, respectively, from the Riachuelo mouth, showed signs of recovery due to mixing and water replacement in this area. Here the nitrites were in the order of (0.02–0.12 mg l^{-1}) and phosphates (0.13–0.15 mg l^{-1}).

Remarkably, neither *slightly polluted* sites (IMRP: 8–12) nor *unpolluted* ones (IMRP: 12.1–20) were found due to the general conditions of the SCF area considered. Nevertheless, other sites in the Rio de la Plata outside the study area presented an IMRP: >12.

Exposure–effect relationship

The relationship between conductivity and DO showed a significant negative correlation ($r^2 = 0.7233$; $p = 0.00002$) where the maximum values (219–382 μS cm^{-1}) of conductivity were observed in sites 306, 3, 18, 22 and 16, close to the Riachuelo outlet, coinciding with the minimum values of DO (3.72–5.93 mg l^{-1}). In contrast, the minimum values of conductivity (151–179 μS cm^{-1}) were in sites 11, 8, 7 and 14 where the DO concentrations were between 6 and 7 and 7.7 mg l^{-1}, coinciding with the furthest distances from the discharge point.

In the present study area the maximum Cr concentrations were between 40 and 110 μg l^{-1} at sites 3, 22, 18 and 16. The Cr concentrations at the rest of the sampling sites were about 12 and 18 μg l^{-1}.

The relationship between some conservative chemical variables (exposure) and the benthic community response (effect) was analyzed by plotting the biological index IMRP against BOD (r^2 = 0.7765; $p = 0.000003$), conductivity ($r^2 =$ 0.3597; $p = 0.0066$), COD ($r^2 = 0.0768$; $p = 0.3173$) and Total Cr ($r^2 = 0.27$; $p = 0.038$).

After statistical validation these four variables were used to calculate the exposure index (IEX) based on the averages of the variables considered. The areas were calculated from the previously defined ranges used for the chemical variables (Fig. 2). The percentage distribution of each variable and the resulting effluent averages (IEX) are shown in Table 2.

Statistical analysis

The first two axes of the ordination, which was carried out by Canonical correspondence analysis (CCA), explained 34.5% of the accumulated variance of macroinvertebrate abundance. The eigenvalues extracted were CCA1: 0.31 and CCA2: 0.18. The values of species–environment correlation for the first four axes were greater than 0.84 and the combined percentage of species–environment variance for the first two axes was 52%. The Monte Carlo Test showed a *p*-value <0.01 for the first axis and for all axes a *p*-value <0.03. It can be seen from Figure 3 that most of the sites were spread along axis 1 which represented a gradient of environmental deterioration. Conductivity ($r = -0.74$, $p < 0.005$), BOD ($r = -0.67$, $p < 0.83$), COD ($r = -0.47$, $p < 0.25$), Cr ($r = -0.50$, $p < 0.89$) and N (NO_2) ($r = -0.53$, $p < 0.055$) showed the strongest negative correlations with this axis. The sites associated with this condition were E306, E18, E3, E23, E22, E12, E21, E16 and E15, in which the following taxa were recorded (e.g. Nematoda: *Dorylaimus* sp. *Monhystera filiformis, M.* cf. *similis*; Naididae: *Homochaeta naidina*, Dero (Dero) digitata; Dugesiidae: *Girardia anceps* and Macrothricidae: *llyocryptus* sp.). In addition, the first axis was positively correlated with the amount of gravel ($r = 0.70$, $p < 0.005$) and with the reduced weighting of those variables associated with an increase of DO. The majority of the macroinvertebrate taxa were located over this part of the plot, such as: *Heleobia parchappei, Limnoperna fortunei, Urnatella gracilis, Claudicuma platensis, Corbicula fluminea*, Chironomidae (*Coelotanypus* sp.) Temnocephalidae (*Themnocephala digitata*), Harpacticoida (*Harpacticoida* sp.), Hirudinea (*Helobdella simplex, H. triserialis triserialis, Orchibdella pampeana*) and Acarina (*Unionicola (P.) sinuata*). The sites associated with this positive section of the first axis were E11, E19, E6, E10, E13, E14 and E7.

Axis 2 was most strongly correlated with NO_3 ($r = 0.72$, $p < 0.01$) and DO (0.69, $p < 0.66$). Sites E8, E9, E17, E5 and E20 were positively affected by NO_3 and DO with which Tubificidae (*Limnodrilus claparedianus, L. hoffmeisteri*)

Table 1. Macroinvertebrate density (ind m^{-2}), Taxa Richness (N), Diversity (H') and (R_1) percentages of OM and the IMRP index at the sampling sites in the Rio de la Plata

Taxa (ind./m^2)	E3	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E306
Cnidaria																					
Cordilophora caspia (Cord)																42			42		
Platyhelminta																					
Dugesiidae (Duges)	42	127		85					170					85	170						
Temnocephalidae (Temno)			170																		
Nematoda (Nemat)	9520	340	8150	6247	595	4760	66810	340	6290	4250	5142	2905	8500	6800	1530	1870	1062	8637	1445	15427	1020
Oligochaeta																					
Tubificidae (Tubif)	1360	42	1360	340	1500	552	850			1955	340	338	1530	1445		127	170	297			
Naididae (Naid)	1955	1232	1360	212	457	212	1700		1530	1190	127	160	595	2125	1190	297			297	7522	1020
Hirudinea (Hirud)		84	170	85		297					42					127				42	
Pelecypoda																					
Corbicula fluminea (Corbi)	255	1147	8500	3995	340	1317	5920	265		1020	1997			595		85	1615	42		2465	
Limnoperna fortunei (Limno)			5780	85	85	42		255			1062					1360					
Gasteropoda																					
Heleobia parchappei (Heleo)		255	510	425		212		450		255	595	170		255		85	255	42		255	
Endoprocta																					
Urnatella gracilis (Urnat)	42															637					
Copepoda																					
Harpacticoidea (Harp)			170	255							127										
Cyclopodea (Clyclop)				425	85	127	850									85				42	

Cladocera																					
Chidoridae											42										
Macrothricidae (Macro)	2507			85					170											42	
Ephipia	255			127					340		42									42	
Ostracoda (Ostr)				42																42	
Cumacea																					
Claudicuma platensis (Claud)			170													42					
Diptera																					
Chironomidae (Chiro)		42		297		42		85			85					42	42			85	
Ephydridae (Ephyd)			170																		
Acari	127		170	42		42	170				212										
S	9	8	12	15	6	10	6	5	5	5	12	4	3	6	3	11	6	4	3	10	2
R_1	0.83	0.86	1.08	1.48	0.62	1	0.44	0.55	0.33	0.44	1.09	0.37	0.21	0.53	0.25	1.18	0.62	0.33	0.4	0.79	0.13
H'	1.24	1.5	1.63	1.49	1.39	1.27	0.51	1.5	0.67	1.31	1.47	0.67	0.62	1.16	0.87	1.66	1.18	0.2	0.65	1	0.69
OM	2.13	2.27	1.2	0.95	2.82	0.97	1.07	2.52	2.49	1.17	2.51	2	1.38	_	0.9	1.13	1.08	1.13	_	1.7	8.32
IMRP	2.5	3.1	4.9	5.75	2.05	3.85	1.75	2.7	1.45	2.05	4.5	1.1	0.5	2.7	0.85	4.55	2.55	1.45	1.35	3.8	0.35

% EFFLUENT

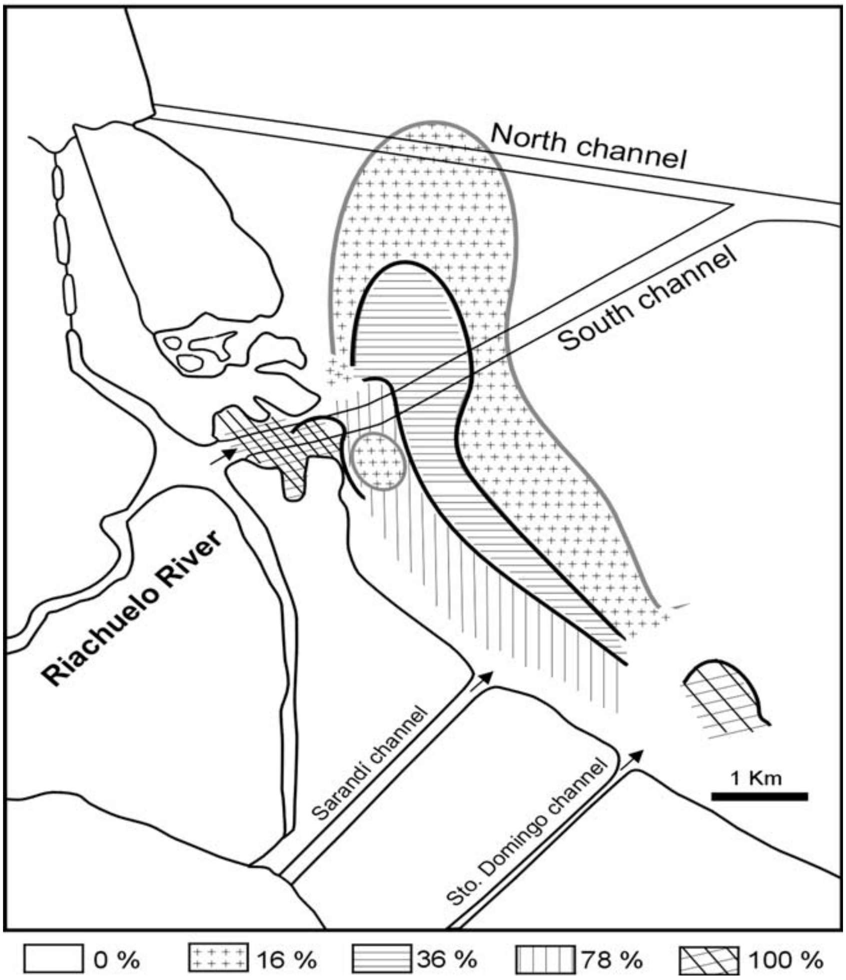

Figure 2. Distribution of the areas in the Rio de la Plata according to the % of effluent along the line of influence of the contaminant plume from the Riachuelo River.

and Cyclopoida (*Acanthocyclops robustus, A. michaelseni*) were most strongly correlated. Clay ($r = -0.43$, $p < 0.08$) and depth ($r = -0.14$, $p < 0.12$) were negatively correlated with this axis and were associated with the presence of the Ostracoda Cyprididae and Cnidaria (*Cordilophora caspia*).

Table 2. Percentage distribution of each variable and the resulting effluent averages (IEX). 0% Maximum and 100% Minimum levels of contamination

100% →	Effluent Gradient (%)	← 0%	
Cond	65	43	22
BOD	77	45	23
COD	97	22	8
Cr	73	33	10
IEX (Average)	78	36	16

Comparison with historical data

Historical physico-chemical data for nutrients (NO_2, NO_3), DO, BOD, COD, conductivity, total Cr and species tolerance, were used for the purpose of comparing the results of this study with those from the long-term period (1990–2000) of the Monitoring Program of the SCF of the Rio de la Plata. The selected points were E306, as the initial point of contamination (0 m),

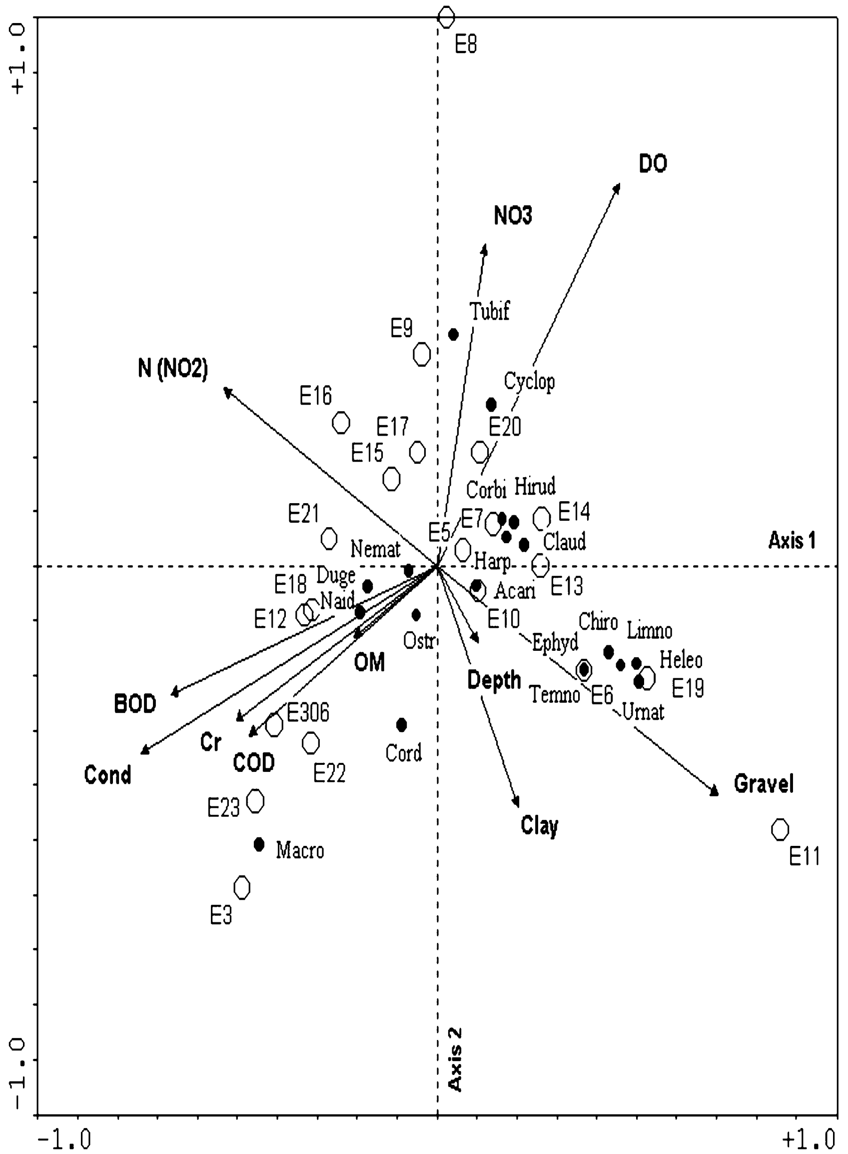

Figure 3. Triplot of the Rio de la Plata sampling sites, environmental variables and taxa abundance in relation to the two first ordination axes of the CCA. Abbreviations of taxa names in Table 1.

E3 at 500 m, E6 at 1650 m, E7 at 2100 m, E17 at 3500 m and E23 at 4700 m from the mouth of the effluent (Fig. 4a–j).

DO varied between 2 and 8 mg/l; the lowest values were at sites E306 and E3 500 m distant from the mouth of the Riachuelo and the beginning of the navigation channel of Buenos Aires Port, with the highest values at 2100 m distance. The curves showed the same tendency throughout the 10-year period (Fig. 4a). Tolerant species were always present and over 50% of the total benthic organisms occurred in all the sites analyzed. Sensitive species were only occasionally recorded in sites influenced by the contaminant plume, with a frequency slightly higher beyond 2100 m (Fig. 4b–d).

COD values were between 5 and 43 mg/l in all the sites analyzed, showing that the sites from the coast to 500 m had the highest values and the lowest were those beyond 1650 m (Fig. 4e).

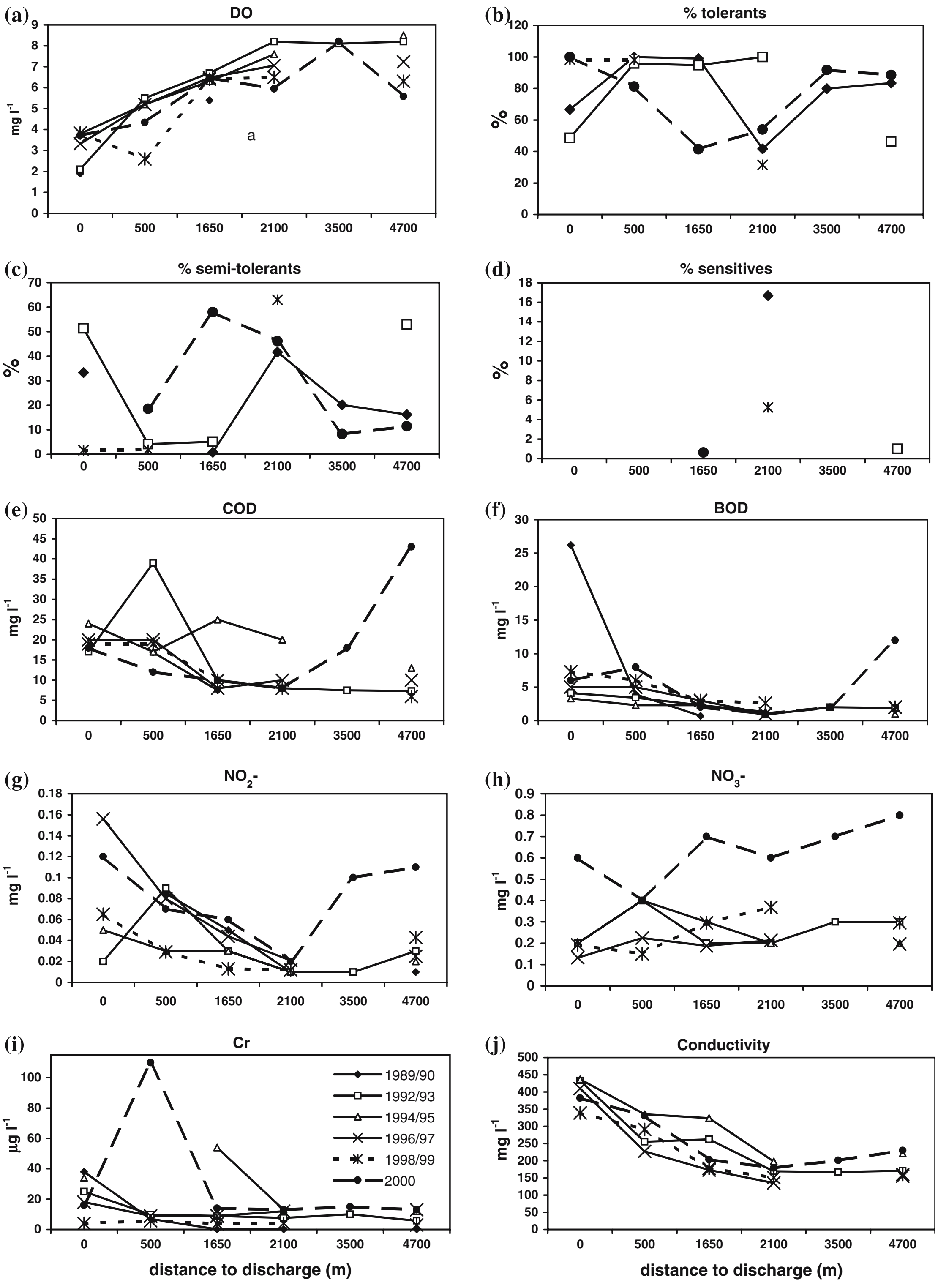

Figure 4. Physico-chemical and biological data at 0, 500; 1650; 2100; 3500 and 4700 m from the discharge effluent of the Riachuelo River in the area studied during 1990–2000 sampling period within the Monitoring Program of the SCF of the Rio de la Plata.

The values of BOD oscillated between 1 and 26 mg/l showing the same behaviour as COD along the contaminant plume and over the long-term period (Fig. 4f). Both these parameters showed a tendency to decrease in value at a greater distance from the effluent mouth, except site E23 in the year 2000 which increased its values when influenced by the discharges of other two highly polluted streams as a consequence of proximity to urban-industrial sectors.

The values of NO_2 were between 0.01 and 0.16 mg l^{-1} at the sites E306, E3 closest to the effluent discharge, while this parameter showed a major decrease beyond 2100 m from the discharge (E6, E7, E23). A minor fluctuation corresponded to site E7, one of the farthest points of the ''contaminant plume'' (Fig. 4g).

Meanwhile, the NO_3 showed greater variation over the area studied, with values between 0.1 and 0.6 mg l^{-1} at the initial point and values between 0.2 and 0.8 mg l^{-1} in more distant points, through the studied period (Fig. 4h).

The values of total Cr were between 5 and 40 μg l^{-1} at 500 m and also in the mouth of the Riachuelo. In contrast, beyond 1650 m from the effluent discharge, the concentration decreased to less than half, except for the years 1994/95 and 2000 when sites E3 and E6 showed an increase in Cr values (Fig. 4i).

The lowest values of conductivity (150–190 μS cm^{-1}) were observed at sites beyond 2100 m from the source. Those sites located near the effluent inflow (up to 500 m) always showed values around 350 μS cm^{-1} (Fig. 4j).

Discussion

Diversity and taxa richness indices for the whole of the area studied varied within a relatively short range. The minimum values were due to the dominance of nematodes and oligochaetes in most of the sampled sites, and not to a decrease in the number of taxa. A similar situation was stated by Harrel & Hall (1991) in Neches river. The dominance of these two taxa was controlled by soft sediments and available food resources. Although they are very tolerant to high concentrations of heavy metals (Winner et al., 1980), the substratum had a modifying influence (Gower et al., 1994). The percentages of OM stayed relatively constant in all the sites, with a notorious increment at the Riachuelo outlet indicating sewage as one of the origins of the contaminant inputs though was exceeded by industrial inputs being Cr one of the major contaminant. The natural Cr content in the surface waters is near 10 μg l^{-1} (WHO, 1984) and is strongly associated to the suspended particulate material. The Cr concentrations at the majority of the sampling stations in the SCF of the Rio de la Plata oscillated between 10 and 20 μg l^{-1} during the 1992–1995 sampling period, with the exception of maximum contaminant discharge points such as the Sarandí, Santo Domingo, and Riachuelo channels, with values of 1 mg l^{-1} (Lammel et al., 1997). Wilson (2003) highlighted the importance of determining the different origin of contaminants when compares water quality changes in two estuaries in Ireland.

Considering the biological index IMRP, the study area presented a zone with very heavy pollution, from the entry point with a high pollutant discharge, as far as 2100 m, showing this area only a south easterly displacement to the Rio de la Plata downstream, according to the higher conductivity values. Nedeau et al. (2003) demonstrated that concentrations of most ions were greater in the effluent and this was reflected in conductivity values. The higher average values of conductivity along the SCF, according to AA-AGOSBA-IL-PLA-SHN (1997), were also evidence of this tendency along the coast, which extended downstream (20 km southeast). Two sectors with heavy pollution were observed inside the study area. One of them was located towards the north of the South Channel (sites 12, 13, 21, 8 and 10) between 650 and 2100 m from point 306. The other sector was situated to the south of the South Channel (sites 3, 15 and 22) between 500 and 1100 m from site 306; both sectors were dominated by nematodes and oligochaetes.

The most distant sites with moderate pollution were located between 3500 and 4700 m from the Riachuelo outlet, towards the southeast, where they formed an undefined area with wide variations in nutrient values. Gagnon & Saulnier (2003) considered that the variation in concentrations of nutrients, such as nitrites and phosphates, reflected the dilution taking place in the dispersion plume and highlighted the relative enrichment of the urban effluent, when compared with the receiving waters. Between 1050 and 2400 m similar characteristics were presented by sites 5, 9 and 20, where the relatively high DO values would be decisive for a better diversity of taxa.

The weak pollution was recorded in the central area, between 1400 and 2500 m inside the river, related to a rapid replacement of water and was associated with the maximum values of DO in the studied area. Harrel & Hall (1991) observed that DO concentrations, reduction of waste loads and deepening of the navigation channel were determinant of the changes in community structure of the macrobenthos in Neches River estuary along time period. The characteristic width of the Rio de la Plata showed that similar conditions played an important role in the changes of community structure in a transversal and longitudinal sense, so the response of the community was also spatial.

In order to explain the shape of the ‘‘contaminant plume’’ we could observed that the most polluted areas (78–100% IEX) showed only a low trend to the north respect to the moderate and weak polluted areas which presented a higher displacement towards the north and a posterior lengthening towards the southeast, due to the marine and meteorological conditions on the sampling date. This direction corresponded to an average tide height of 44 cm (referred to the zero of Riachuelo) on the sampling date and a predominant north wind of 15 km h^{-1}, varying to northeast towards the afternoon. These conditions were taken into consideration, according to Arraga et al. (1997). Nevertheless, these conditions are frequent throughout the year. A similar plume was recorded by Colombo et al. (1994) in La Plata Port and Access Channel at 60 km southeast.

The distribution of the organisms in relation with the environmental variables showed that the xenobiotic variables, indicative of a major gradient of environmental degradation, were plotted towards the left sector of the CCA, related to the presence of Naididae and Nematoda, and also to the sites with the lowest water quality indices. On the other hand, on the right sector of the plot, which was determined by the smallest weight of those variables, were the most sensitive organisms, indicators of good environmental quality (e.g. *Claudicuma platensis*, *Corbicula fluminea*, Copepoda Cyclopoidea), where sites with moderate to slight pollution indices were located. The gravel showed a strong influence associated with one of the sites where *Limnoperna fortunei* and *Heleobia parchappei*, characteristic taxa of this type of grain size and of relative ecological importance, showed higher abundances. Danulat et al. (2002) observed in Montevideo Harbour that some species tolerate high organic content of the sediments, however, its density was not correlated with this single variable, suggesting that additional factors such as organic and inorganic pollutants affect its distribution in the harbour. The study in Buenos Aires Port has demonstrated that the distribution of the benthic organisms were directly influenced by the combination of organic and inorganic pollutans.

Studies of contamination by heavy metals and petroleum hydrocarbons in Montevideo Harbour concluded that the study area can be divided into three regions with different degree of environmental pollution in an attempt to estimate adverse effects of contaminants on the benthic fauna (Muniz et al., 2004). Similar situation was analysed in Buenos Aires Port where four areas with different degree of exposure were recognized which determined the different responses of benthic community.

We can conclude that the area most impacted by the Riachuelo outlet was between 650 and 2100 m from the discharge and between the coast line and 1100 m according to Arraga et al. (op. cit). A moderate response was observed at 1400 m from the outlet and at 1600 m from the coastline. This would largely be owing to the physicochemical and hydrological characteristics of the river which would contribute to diluting the effect of the anthropogenic perturbation. The prevalence of coastal sandy substrate implies a low retention of pollutants in the bottom sediments of the most exposed areas, as well as the high river flow and the hardness and alkalinity of its right riverbank. The great dilution and transport capacity of the river leads to the displacement of a great part of the xenobionts downstream, lowering the impact of the pollution on the biota, due to the presence of fewer biodegradable chemical compounds (Tudino, 2001).

The analysis of 10 years of monitoring in the SCF of the Rio de la Plata allowed us to confirm that the behaviour of the variables in the present study was similar to that recorded throughout the long-term studies. The almost exclusive presence of tolerant species, and the occasional appearance of more sensitive ones, allowed us to see the accurate response of the benthic community both inside and outside the influence of the contaminant plume. However, long-term studies should be continued under different hydrological river conditions in order to assess changes in the zoobenthic communities of this highly polluted area, with the purpose of having more base-line studies for future restoration projects.

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