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Use of benthic macroinvertebrates to assess the biological status of Pampean streams in Argentina

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Abstract

Macro-invertebrate communities and environmental variables were assessed seasonally for two years in seven streams in North-Eastern of Buenos Aires province (Argentina) in order to analyse changes in their structure and composition in relation with the quality of the water. The study includes pristine streams and others affected by urban and industrial effluents with high conductivity, nitrates, nitrites, phosphates and low oxygen content. Organisms with well-known pollution tolerance were identified to assess biological water quality, using a new Biotic Index (**IBPAMP**: **B**iotic **I**ndex for **PAMP**ean rivers and streams) in comparison with other existing biotic indices. The usefulness of principal component analysis (PCA) and correlation matrices were examined to evaluate the efficiency of the method to assess disturbances. In general IBPAMP did well correlate with several classical measures of biological water quality (taxon richness, diversity and several biotic indices). The El Gato stream was the most disturbed ecosystem among all studied sites. It was characterised by low dissolved oxygen levels, high turbidity in the middle course, high BOD5 ($>$30 mg l^{-1}) and COD ($>$40 mg l^{-1}) values. The Buñirigo stream has a bad quality in the industrial area, but varying according to the dry and wet periods. In general, in the mountainous areas the water quality of streams was good with the exception of the stations located downstream of cities like Ayacucho on the Tandileofú stream.

Introduction

The Pampean biogeographic province occupies a vast territory of South America, embracing the plains of Eastern Argentina from 30 to 39 deg South, Uruguay and half the state of Rio Grande do Sul in Brazil. Small streams and rivers of the plains have a low-gradient bed carved through cenozoic sedimentary deposits, sediments of loess-mud or clay rich in organic detritus, and running waters with slow-currents and a high-turbidity (Frengüelly, 1956; Ringuelet, 1962; Rodrigues Capítulo, 1999). In the Argentinian Pampean plains streams are usually of the semipermanent or temporary type, with waterflows having semi-desert characteristics. In relation with biological characteristics of the region, considering organisms living in Pampean streams and rivers, it has been noticed the almost total absence of typical elements of mountain rivers, except in some streams and rivers having headwaters at Sierras de Tandilia and Ventania. There, a few species of Trichoptera and Ephemeroptera but no Plecoptera can be found. All mentioned taxa, are common elements in rivers and streams of Patagonia (Andes), central and north-western Argentina (Albariño, 1997). There is a clear dominance of detritivores owing to the crumbles along the main arms of the largest rivers with the lowest transparency. This is complemented with the occurrence of carnivores when the abundance of macrophyte vegetation increases, leading to the development of the typical fauna at the regional level for this kind of rivers and streams.

The objective of this work was to analyse the changes in the structure and composition of the

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macro-zoobenthos and macro-invertebrates present on macrophytes in the same habitats in relation with the quality of the water in several streams affected to a different extent by urban and industrial perturbations, and compared with pristine streams of the region. Organisms with known pollution tolerance were identified to establish biological water quality (Hynes, 1971; Hart & Fuller, 1974; Rodrigues Capítulo, 1984a, b; Hakanson, 1999), using a new Biotic Index (**IBPAMP**: **B**iotic **I**ndex for **PAMP**ean rivers and streams) in comparison with other biotic indices.

Materials and methods

Study area and characteristics of sampling sites

In this paper only streams were considered which are located in two hydrographic areas of the Pampean biogeographic province according to Fregüelly (1956) (Figure 1): (a) Tributaries of the Río de la Plata river (mean length 36 km approximately): El Gato, El Pescado, Juan Blanco and Buñirigo; (b) Streams of Tandilia gills northeastern slope stream (mean length 60 km approximately): Tandileofú, Napaleofú and Vivoratá, which have artificial channels in the downstream section to facilitate drainage to the Samborombón Bay and the Atlantic Ocean. The study sites have been described by Rodrigues Capítulo (1999), the general hydrologic characteristics by Ringuelet (1962), Sala et al. (1983), Godz et al. (1983) and Kruse (1986).

Several streams are affected to a certain extent by urban and industrial effluents. Among these, El Gato and the middle section of Buñirigo are characterised by high contamination levels. The former is largely polluted by industrial production (paper mills, iron and steel, and textile) and domestic waste-waters. El Pescado is only moderately disturbed by agricultural and food processing practices. On the other hand, the Juan Blanco stream is located in the natural reserve of the UNESCO Biosfera. Only in the upstream part of this stream the quality of the water is affected by some agriculture.

The creeks of the Tandilia system in Buenos Aires province have stronger currents, with stony to stony-sandy or clayey (compacted clays) sediments and pools are frequently present. The majority of these are only impacted by agriculture. However, near the small cities as Tandileofú and Napaleofú, urban contamination was observed and the changes in the macro-invertebrates communities assessed.

Sampling techniques

Seasonally biological samples were taken from 1997 till 1999 with Ekman (100 cm^2) and Van Veen (470 cm^2) grabs in muddy and sandy sediments, and a Surber net in stony areas. Qualitative samples were always taken with sieves from the macrophytes to examine the presence of macro-invertebrates. Sampling stations were located in the upstream, mid-course and downstream sections of the streams. The macroinvertebrates were fixed with formaldehyde (5%).

Temperature (°C), pH, conductivity (μS cm^{-1}), dissolved oxygen (DO mg l^{-1}) and turbidity (UNT) of the water were measured in the field by means of electrodes; transparency (cm) by means of a Secchi disk. The flow velocity (cm s^{-1}) was measured with a portable flow-meter (Cole Parmer). Water samples were collected for further chemical analysis in the lab according to standard methods (NO_3, NH_4, PO_4 in mg l^{-1}, BOD_5, COD) (Strickland & Parsons, 1968; APHA, 1985). The macro-invertebrates were sorted, identified (species, genus or families) and counted in the laboratory with a stereo or compound microscope.

Water quality assessment methods

Several existing biotic methods for water quality assessment were applied: the diversity index (H′) of Shannon and Weaver (1963); evenness (E) and taxon richness (Margalef (D) (1955); the biotic score of Chandler (1970) and the BMWP'(Biological Monitoring Working Party) score system (Alba Tercedor et al., 1988) adapted to local taxa of the Pampean area in the Neotropical Region (Rodrigues Capítulo, 1999). Besides two other indices were applied: the IMRP (**M**acroinvertebrate **I**ndex from **P**ampean **R**ivers) (Rodrigues Capítulo, 1999) and a new biotic index: the IBPAMP (**B**iotic **I**ndex for **PAMP**ean rivers and streams) which is based on the principles proposed by Tuffery & Vernaux (1967), De Pauw & Vanhooren (1983), Ghetti (1986), Prat et al. (1986, 1999) and Corigliano (1999), and adapted to locally occurring macro-invertebrates (Tables 1 and 2).

For the elaboration of the IBPAMP index seven classes of horizontal entry were used (Woodiwiss, 1978; Ghetti, 1986). The most sensitive taxa, according to measured physical and chemical parameters (Table 4) and other ecological characteristics observed in the habitats of the sampling sites, were Trichoptera with cases (Leptoceridae), Hydropsychidae, Lestidae, Elmidae and Gomphidae in the rhitron areas (Table 1) (Rodrigues Capítulo, 1999; Rodrigues Capitulo

Table 1. Standard table for calculating the IBPAMP index of rhitral zones

Faunistic groups			Total numbers of systematic units present						
			0–1	2–5	6–10	11–15	16–20	21–25	>26
			Biotic index						
1	Trichoptera with cases	> 1 S. U.	–	–	8	9	10	11	12
	(Leptoceridae)	Only 1 S.U.	–	–	7	8	9	10	11
2	Hydropsychidae Lestidae,	> 1 S. U.	–	6	7	8	9	10	11
	Elmidae, Gomphidae	Only 1 S.U.	–	5	6	7	8	9	10
3	Ancylidae, Decapoda,	> 1 S. U.	–	4	5	6	7	8	9
	Aeshnidae, Simuliidae, Other Trichoptera	Only 1 S.U.	–	3	4	5	6	7	8
4	Other Coleoptera Ephemeroptera (Caenidae excepted)	All S.U. above absent	–	3	4	5	6	7	–
5	Coenagrionidae, Caenidae, Heteroptera, Amphipoda	All S.U. above absent		2	3	4	5		
6	Tubificidae, red Chironomidae, Physidae, Culicidae	All S.U. above absent	1	1	2	3			
7	Syrphidae, Enchitreidae, Psychodidae	All S.U. above absent	–	0	1	2			

Table 2. Standard table for calculating the IBPAMP index of potamal zones

Faunistic groups			Total numbers of systematic units present						
			0–1	2–5	6–10	11–15	16–20	21–25	>26
			Biotic index						
1	Trichoptera with cases	> 1 S. U.	–	–	9	10	11	12	13
	(Leptoceridae)	Only 1 S.U.	–	–	8	9	10	11	12
2	Other Trichoptera Lestidae,	> 1 S. U.	–	6	7	8	9	10	11
	Elmidae, Gomphidae, Unionidae	Only 1 S.U.	–	5	6	7	8	9	10
3	Ancylidae, Decapoda,	> 1 S. U.	–	4	5	6	7	8	9
	Aeshnidae, Simuliidae	Only 1 S.U.	–	3	4	5	6	7	8
4	Other Coleoptera Ephemeroptera (Caenidae excepted), Libellulidae	All S.U. above absent	–	3	4	5	6	7	–
5	Coenagrionidae, Caenidae, Heteroptera, Amphipoda	All S.U. above absent		2	3	4	5		
6	Tubificidae, red Chironomidae, Physidae, Culicidae	All S.U. above absent	1	1	2	3			
7	Syrphidae, Enchitreidae, Psychodidae	All S.U. above absent	–	0	1	2			

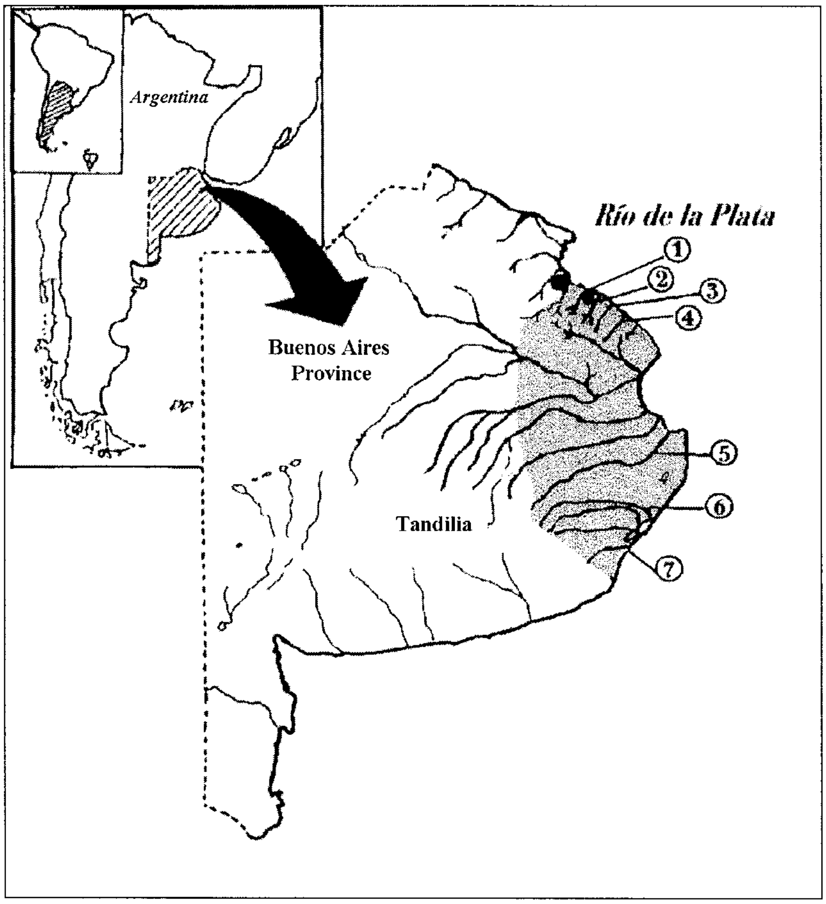

Figure 1. Geographical map with location of sampled streams. 1 – El Gato, 2 – El Pescado, 3 – Buñirigo, 4 – Juan Blanco, 5 – Tandileofú, 6 – Napaleofú, 7 – Vivoratá.

et al., in press) Tangorra et al. 1998, Tangorra et al., 1999). For the potamon were added Mollusca (Unionidae) at the first levels of water quality (Table 2). Furthermore the Pampean organisms are in accordance with the regional tolerance values for benthic macro-invertebrates of EPA (Barbour et al., 1999).

For this index five classes (I–V) of water quality, from unpolluted to very heavily contamination, were established according to the previously mentioned authors (Table 3).

Statistical analyses

For the statistical analyses a $\ln(x + 1)$ transformation was used for the values of biological, physical and chemical parameters in order to reduce the effect of seasonal variations. The correlation matrix was obtained including those parameters and the biotic index. Principal component analysis (PCA) was applied for the examination of multivariate data to evaluate the efficacy of the biotic indices and to assess the impact of human activity on the rivers and streams of Buenos Aires province (Zitko, 1994). Furthermore, the partial correlation ($p < 0.05$) between the biotic index (IBPAMP) and Factor 1 (which grouped physico-chemical parameters) was analysed (Pla, 1986).

Results

In general the effluent discharges caused an important decrease in dissolved oxygen levels of the stream waters, and a significant increase in nitrites, nitrates, phosphates, BOD5 and COD. The most affected sites were those of El Gato stream in all seasons of the year (DO <2 mg l^{-1}; high turbidity (>200 UNT in the middle part); high BOD5 (>30 mg l^{-1}) and COD (>40 mg l^{-1}). The Buñirigo stream only presented

Table 3. Classes of water quality based on IBPAMP index

Class	Biotic index IBPAMP	Significance	Colour
I	10–13	Unpolluted	Blue
II	8–9	Slightly polluted	Green
III	6–7	Moderately polluted	Yellow
IV	4–5	Heavily polluted	Orange
V	1–3	Very heavily polluted	Red

a bad quality in the industrial area, with changes according to the seasons.

In the mountainous part, in general the quality of the stream waters was good except for the stations located downstream of the cities. For example the Tandileofú stream showed, in general, a good physical, chemical and biological quality along its course except downstream of Ayacucho city.

A total of 118 invertebrate taxa including micro-crustaceans were recorded from the seven streams examined. The taxa found in the plain (potamon) area of El Gato, El Pescado, Buñirigo and Juan Blanco are described in Tangorra et al. (1999). In the present paper only the macro-invertebrate fauna was considered. The most abundant taxa registered during the study period in the potamon were the oligochaetes belonging to the family of the Naididae (*Dero* sp., *Pristina* sp., *Nais* sp., *Chaetogaster* sp. and *Stylaria* sp.) and the Tubificidae (*Limnodrilus hoffmeisteri*), the snails *Pomacea canaliculata, Biomphalaria peregrina* and *Heleobia parchappei* and the amphipod *Hyalella curvispina*. Among the insects the main taxa recorded were the chironomids *Chironomus* sp. and *Goeldichironomus* sp. followed by the coleopterans Hydrophilidae, Elmidae and Dytiscidae. The more sensitive species to antropogenic disturbances were registered in the Juan Blanco stream and in the upper sections of Buñirigo and El Pescado: *Palaemonetes argentinus* and *Macrobrachium borelli* (Decapoda Natantia), *Diplodon delodontus delodontus* (Pelecypoda), *Campsurus* sp. (Ephemeroptera), *Aeshna bonariensis* (Odonata), *Cyrnellus* sp. and *Oecetis* sp. (Trichoptera). In polluted areas these taxa disappear or their numbers are significantly reduced.

El Gato stream presented a low diversity, mainly in the middle part where the industrial discharges are more important. In this section of the stream only *Dero* sp., *Limnodrilus claparedianus*, Colembola and Tardigrada were observed.

The streams of the Tandilia hills had in general the best water quality (flow >60 cm s^{-1} and high transparency and low turbidity) and enabled the establishment of populations of sensitive species; the more typical ones recorded were cased Trichoptera (Leptoceridae), Trichoptera without cases (Hydropsychidae: *Smicridea pampeana*), Ephemeroptera (*Callybaetis* sp.), Lestidae and other Zygoptera, Coleoptera (Elmidae), Molluscs (Ancylidae) and Gordioidea.

In Table 4 the major taxa recorded are listed as well as the mean and standard deviation of the physical and chemical parameters measured in sampling sites.

The taxonomic levels and the total number of systematic units (S.U.) that determine the vertical entry in the table for the IBPAMP index are shown in Table 5. Biotic index scores obtained for the different sampling sites are given in Table 6.

The distributions of the scores over the IBPAMP quality classes were the following: unpolluted (14.4%); slightly polluted (38.4%); moderately polluted (21.6%); heavily polluted (13.2%); and very heavily polluted (12%) (Table 6).

One can see that the low values correspond with a high degree of pollution of the El Gato stream from up to downstream in all the seasons. In the El Pescado stream the water quality was very bad in the upper part of the basin especially during summer and fall.

The IBPAMP score proved to be a very interesting tool for the assessment of the Pampean streams examined. The scores correlated well with all physico-chemical parameters (dissolved oxygen excepted) (Figure 2). The IBPAMP index had a good correlation with the diversity indices of Shannon & Weaver and Margalef, as well as the biotic indices BMWP', Chandler and the IMRP.

The correlation matrix was made up by 15 variables (the physico-chemical parameters and the biotic indices) and 52 valid cases. In the PCAs the first principal component explained 45.4% of the variance and the second 14.6%. In Figure 2 one can see three distinct groups. One group is formed by diversity and biotic indices at the left of the axis one; the second group on the other side of the axis is made up by the parameters indicating antropogenic disturbance (BOD_5, COD, conductivity); and the third group in the upper part of the axis two by NO_3, PO_4 and NH_4. For the DO, pH and E (evenness) the correlation coefficient is low. Only the calculated correlation between the IBPAMP index and the factor 1 only (physico-chemical parameters) had a good statistical significance ($r = -0.77$) (Figure 3; Table 7).

Table 4. Main taxa of macroinvertebrates recorded and corresponding mean and standard deviation of the physical-chemical parameters

	DO (mg l^{-1})	Conductivity	BOD (mg l^{-1})	COD (mg l^{-1}	PO_4 (mg l^{-1})	NH_4 (mg l^{-1})
Oligochaeta						
Naididae	5.66 (2.91)	807.3 (83.2)	9.15 (7.72)	36.3 (37.1)	0.70 (0.75)	1.10 (2.79)
Tubificidae	5.77 (2.90)	873.09 (832.5)	9.21 (7.74)	36.6 (36.8)	0.59 (0.82)	1.10 (2.88)
Enchitraeidae	6.02 (2.55)	757.7 (1190.6)	7.18 (4.35)	50.2 (47.0)	0.22 (0.25)	0.18 (0.35)
Opistocystidae	4.66 (2.63)	658.9 (312.6)	11.70 (10.58)	34.6 (31.9)	1.08 (1.17)	1.60 (3.62)
Lumbriculus variegatus	1.99 (1.78)	750.8 (986.3)	14.50 (8.59)	28.8 (9.4)	1.58 (1.21)	2.87 (3.38)
Hirudinea						
Helobdella triserialis	6.43 (2.97)	846.2 (770.3)	8.66 (4.05)	6.2 (35.4)	0.55 (0.82)	0.98 (2.68)
Helobdella stagnalis	4.45 (2.05)	280.5 (98.9)	8.16 (3.60)	74.0 (79.7)	0.31 (0.14)	0.23 (0.34)
Mollusca, Bivalvia						
Limnoperna fortunei	6.06 (2.84)	583.8 (152.7)	9.50 (3.67)	45.6 (49.7)	0.36 (0.30)	0.25 (0.35)
Corbicuia flumínea	6.06 (2.84)	583.8 (152.7)	9.50 (3.67)	45.6 (49.7)	0.36 (0.30)	0.25 (0.35)
Diplodon delodontus	6.37 (2.57)	829.3 (1.292)	6.96 (4.71)	44.0 (36.4)	0.19 (0.26)	0.16 (0.35)
Gastropoda						
Heleobia parchappei	7.38 (2.58)	943.1 (842.8)	8.22 (7.16)	39.5 (39.5)	0.39 (0.73)	0.57 (1.94)
Gundlachia concentrica	6.30 (3.03)	834.1 (907.7)	13.90 (3.25)	35.4 (39.3)	0.31 (0.49)	0.44 (2.38)
Biomphalaria peregrina	7.17 (2.80)	994.7 (852.8)	8.06 (5.70)	38.9 (25.8)	0.35 (0.47)	0.67 (2.19)
Drepanotrema kermatoides	5.67 (2.46)	583.8 (152.7)	9.50 (3.67)	45.6 (49.7)	0.36 (0.30)	0.25 (0.35)
Stenophysa marmorata	3.60 (2.71)	707.5 (415.3)	13.16(9.70)	37.9 (40.1)	1.28 (1.07)	2.59 (4.20)
Pomacea canaliculata	4.37 (2.62)	877.3 (1094.1)	8.40 (8.50)	38.5 (33.0)	0.51 (0.94)	0.79 (2.54)
Lymnaeidae	6.05 (2.84)	583.8 (152.7)	9.50 (3.67)	45.6 (49.7)	0.36 (0.3)	0.25 (0.35)
Omalonyx sp.	4.15 (3.23)	432.3 (256.5)	10.58 (7.87)	27.2(15.7)	1.06 (1.02)	1.49 (2.69)
Chilina sp.	6.35 (1.90)	956.9 (247.0)	3.91 (3.09)	16.9 (15.7)	0.08 (0.05)	0.009 (0.016)
Crustacea						
Hyalella curvispina	6.15 (2.77)	786.9 (871.8)	7.50 (5.41)	35.9 (39.1)	0.32 (0.48)	0.39 (1.23)
Fritzianira exull	6.06 (2.84)	583.8 (152.7)	9.50 (3.67)	45.6 (49.7)	0.36 (0.30)	0.25 (0.35)
Palaemonetes argentinus	5.67 (2.46)	1221.8 (1499.7)	6.27 (4.70)	38.8 (33.6)	0.27 (0.29)	0.23 (0.43)
Macrobrachium borelli	5.84 (2.29)	463.8 (224.0)	6.24 (4.78)	26.2 (16.5)	0.31 (0.34)	0.11 (0.17)
Hydracarina	5.75 (3.00)	794.8 (877.3)	9.20 (7.76)	38.0 (32.2)	0.62 (0.90)	1.16 (3.00)
Insecta, Diptera						
Chironominae	6.43 (2.97)	846.3 (770.3)	8.66 (4.05)	6.2 (35.4)	0.55 (0.82)	0.98 (2.68)
Tanypodinae	6.05 (2.45)	349.1 (202.8)	7.66 (4.72)	46.7 (50.9)	0.25 (0.27)	0.12 (0.21)
Alluaodomyia sp.	5.43 (2.84)	757.7 (1190.6)	8.27 (5.80)	46.2 (43.7)	0.42 (0.69)	0.58 (1.58)
Athericidae	4.59 (3.49)	620.5 (397.6)	13.60 (12.13)	53.3 (59.1)	1.34 (1.35)	2.32 (4.30)
Stratyiomidae	6.49 (2.57)	811.3 (1258.0)	7.41 (4.60)	44.3 (38.2)	0.22 (0.27)	0.18 (0.22)
Tabanidae	5.52 (3.16)	470.2 (370.2)	11.57 (9.71)	37.6 (29.3)	0.97 (1.20)	1.61 (3.34)
Psychodidae	4.25 (3.18)	768.5 (458.4)	15.25 (9.84)	38.5 (30.4)	1.41 (1.18)	3.15 (4.60)
Blepharoceridae	5.36 (1.52)	495.3 (193.2)	5.83 (4.91)	26.6 (12.4)	0.10 (0.03)	0.07 (0.09)
Dolychopodidae	3.26 (2.48)	1145.9 (1642.6)	7.38 (5.11)	50.6 (42.4)	0.12 (0.13)	0.19 (0.42)
Tipulidae	6.35 (2.93)	1738.6 (1891.6)	5.99 (3.92)	53.3 (36.1)	0.14 (0.16)	0.30 (0.55)
Culicidae	6.55 (2.77)	484.4 (409.3)	12.31 (11.08)	44.5 (34.8)	0.91 (1.35)	1.68 (3.84)
Muscidae	5.14 (3.57)	672.4 (516.8)	13.60 (7.01)	44.6 (40.6)	0.84 (0.86)	2.62 (4.95)
Empididae	8.10 (2.67)	188.1 (27.4)	10.00 (5.25)	60.8 (53.3)	0.04 (0.05)	0.05 (0.06)
Ephydridae	5.52 (3.16)	470.2 (370.2)	11.57 (9.71)	37.6 (29.3)	0.97 (1.20)	1.61 (3.34)
Simuliidae	8.41 (1.80)	1033.1 (212.2)	3.89 (2.86)	16.9 (17.3)	0.09 (0.05)	0.007 (0.009)

Table 4. Continued

	DO (mg l^{-1})	Conductivity	BOD (mg l^{-1})	COD (mg l^{-1}	PO_4 (mg l^{-1})	NH_4 (mg l^{-1})
Ephemeroptera						
Callybaetis sp.	7.08 (2.59)	873.1 (832.5)	6.12 (4.31)	30.6 (32.8)	0.15 (0.21)	0.10 (0.16)
Caenis sp.	6.39 (2.50)	976.6 (1433.3)	7.04 (4.72)	49.1 (38.4)	0.102 (0.12)	0.17 (0.38)
Campsurus sp.	6.36 (1.52)	495.33 (193.2)	5.83 (4.91)	26.6 (12.4)	0.096 (0.03)	0.07 (0.09)
Colembola	5.37 (2.98)	794.8 (932.8)	9.95 (8.04)	40.8 (39.2)	0.68 (0.94)	1.32 (3.22)
Odonata						
Homeoura chelifera	6.39 (2.57)	716.1 (650.3)	7.62 (6.30)	32.3 (47.3)	0.44 (0.51)	0.83 (0.97)
Aeshna bonariensis	6.66 (2.69)	710.1 (680.6)	7.66 (9.30)	39.3 (46.3)	0.44 (0.56)	0.81 (0.92)
Orthemis nodiplaga	5.36 (1.52)	495.3 (139.2)	5.83 (4.91)	26.6 (12.4)	0.096 (0.03)	0.07 (0.09)
Micratbyria didyma	6.39 (2.52)	976.6 (1436.3)	7.04 (4.72)	49.1 (38.4)	0.102 (0.12)	0.17 (0.38)
Coleoptera Elmidae	6.87 (3.06)	1031.6(1160.1)	10.17 (7.20)	41.8 (32.7)	0.63 (0.68)	1.55 (3.41)
Tyloderma sp.	5.76 (3.07)	520.16 (268.8)	6.16 (5.30)	25.5 (20.8)	0.42 (0.43)	0.15 (0.23)
Noteridae	6.00 (2.53)	749.7 (1173.9)	7.14 (4.44)	48.9 (45.4)	0.24 (0.26)	0.21 (0.31)
Suphisellus sp.	6.39 (2.52)	976.6 (1436.3)	7.04 (4.72)	49.1 (38.4)	0.102 (0.12)	0.17 (0.38)
Hydrophilidae Berosus sp.	6.58 (2.72)	1427.2 (1000.8)	8.04 (4.47)	54.2 (43.1)	0.17 (0.21)	0.22 (0.41)
Tropisternus sp.	6.39 (2.52)	976.6 (1436.3)	7.04 (4.72)	49.1 (38.4)	0.102 (0.12)	0.17 (0.38)
Dytiscidae	7.95 (13.35)	830.3 (1039.3)	9.64 (8.25)	48.4 (49.3)	0.66 (0.99)	1.08 (2.69)
Gyrinidae	6.02 (2.55)	757.7(1190.6)	7.18 (4.35)	50.2 (47.1)	0.21 (0.25)	0.18 (0.35)
Dryopidae	8.11 (2.13)	874.7 (125.6)	3.60 (4.72)	14.8 (9.6)	0.04 (0.032)	0.008 (0.005)
Heteroptera						
Ranatridae	6.71 (2.79)	1471.3 (1820.6)	8.16 (5.24)	62.6 (47.3)	0.13 (0.15)	0.25 (0.51)
Mesovelidae	6.26 (2.48)	1145.9 (1542.6)	7.38 (5.11)	50.6 (42.4)	0.117 (0.13)	0.19 (0.42)
Plea sp.	6.39 (2.52)	976.6 (1436.3)	7.04 (4.72)	49.1 (38.4)	0.102 (0.12)	0.17 (0.38)
Trichoptera						
Cyrnellus sp.	5.71 (2.21)	539.5 (172.4)	7.66 (4.56)	36.2 (35.9)	0.23 (0.25)	0.16 (0.26)
Oxyethira sp.	5.6 (2.97)	2754.5 (1827.3)	6.33 (4.96)	64.3 (45.7)	0.21 (0.18)	0.461 (0.68)
Oecetis sp.	8.10 (2.67)	188.2(27.4)	10.3 (5.25)	60.8 (53.3)	0.04 (0.05)	0.09 (0.06)
Smicridea sp.	8.09 (2.32)	923.9 (236.1)	3.72 (2.98)	15.6 (17.3)	0.07 (0.04)	0.001 (0.016)

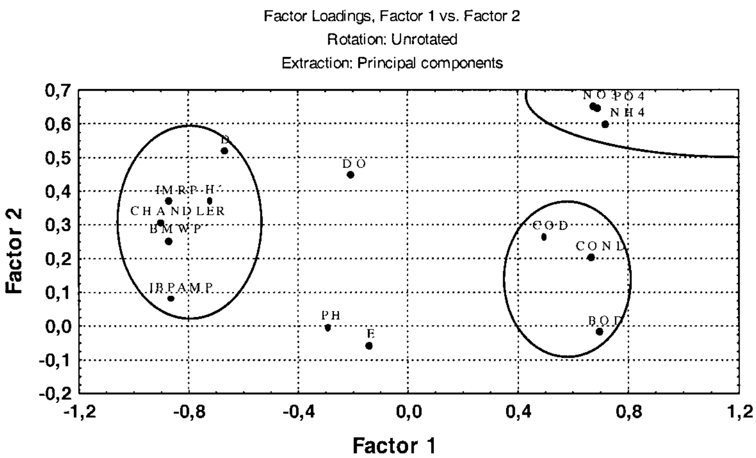

Figure 2. Principal component analyses (PCAs). At the left of axis 1 are grouped the biologic indices (IBPAMP, diversity, Chandler, IMRP, BMWP′); at the right are grouped the physical and chemical parameters used to assess the water quality (conductivity, BOD_5, PO_4, NO_3, and NH_4).

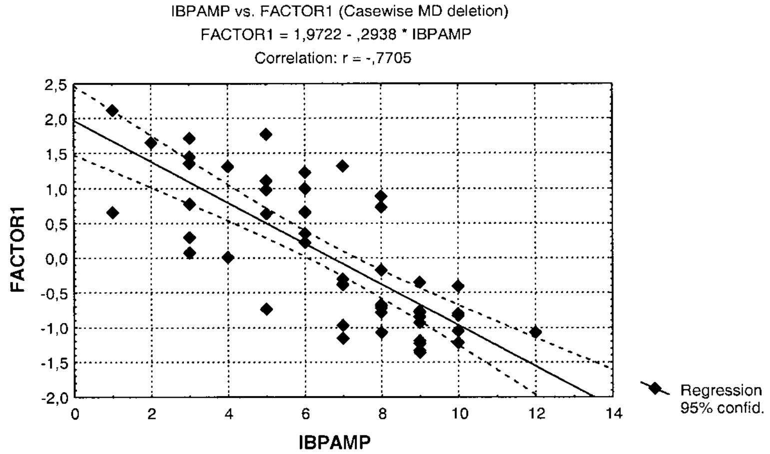

Figure 3. Relation between IBPAMP index and Factor 1 grouping the physico-chemical parameters.

Table 5. Taxonomic levels to define the systematic units (S.U.) for the IBPAMP index. Columns 3 and 4 show the most common numbers recorded in the rhitral and potamal zones of Pampean streams

Taxa	(Level) Systematic Unity (S.U.)	Total No. (S.U.)	Rithral (S.U.)	Potamal (S.U.)
Trichoptera	Family	5	4	3
Ephemeroptera	Genus	3	2	3
Odonata	Genus	6	3	5
Coleoptera	Family	5	2	4
Mollusca	Genus	10	4	7
Crustacea	Genus	7	3	5
Heteroptera	Genus	7	4	7
Diptera	Family	12	4	12
Tricladida	Family	1	1	1
Hirudinea	Family	3	2	2
Oligochaeta	Family	5	2	4
Hydracarina	Presence	+	+	+
Nematoda	Presence	+	+	+
Tardigrada	Presence	+	+	+
Coelenterata	Presence	+	+	+
Porifera	Presence	+	+	+
Bryozoa	Presence	+	+	+
Temnocephala	Presence	+	+	+

Discussion

The studied environments presented different variations in their watercourses owing to seasonal changes in precipitation and, in the lower sector, to the action of tidal waves from the Río de la Plata river, connected to the Atlantic Ocean. Under natural conditions the sources of some streams such as Juan Blanco, Buñirigo and Pescado do not frequently present water flow during the dry period (mainly in summer), forming pools where the fauna must adapt to the lentic conditions of the environment. However other streams which receive urban and industrial effluents, as is the case of El Gato stream, during dry periods, have certain continuity due to this influence, producing a strategic change in the life cycles of the inhabitant species. This aspect was previously considered by Williams (1987), Morais (1995) and lately by Coimbra et al. (1996) for European rivers in the Mediterranean area. The species which remain in these disturbed systems are more tolerant in general, to adverse conditions, as is the case for some Gastropods (Physidae), Oligochaeta (Tubifícidae) and Hirudinea.

In general the registered values of the dissolved oxygen in the water were lowest in polluted sectors of the studied streams. However, remarkable are the changes in the values of the DO observed in the sectors with high contents of nutrients, low content of suspended solids, and high densities of algal masses. These recorded variations are probably the reason of the low correlation with the IBPAMP index. On the other hand pH values are relatively uniform in all studied streams related with neutral or slightly alkaline soils (pH $= 7.0 - 8.5$) of the region, independent of the biotic communities.

Férnández and Schnack (1977) worked out a first list of invertebrates tolerant to some pollution factors in the Rodriguez and Carnaval streams (in the sampling area studied), the former being related to the effluents coming from a meat processing plant.

Table 6. Biotic index (IBPAMP) scores of sampled streams

Streams		Summer	Autumn	Winter	Spring
El Gato	Upstream	3	5	3	5
	Midstream	6	1	2	1
	Downstream	3	4	7	6
El Pescado	Upstream	6	6	5	4
	Midstream	8	6	6	8
	Downstream	5	3	8	7
Buñirigo	Upstream	dry stream	4	7	9
	Downstream	8	9	5	5
Juan Blanco	Upstream	7	9	9	9
	Downstream	10	9	9	10
Tandileofú	Upstream	8	9	7	7
	Midstream 1	10	10	10	9
	Midstream 2	3	4	3	3
	Downstream	7	8	8	9
Napaleofú	Upstream	9	9	10	7
	Midstream 1	9	10	9	9
	Midstream 2	8	7	8	9
	Downstream	5	6	6	5
Vivoratá	Upstream	9	9	8	9
	Midstream	10	10	9	10
	Downstream	10	10	8	9

These authors observed significant differences in the bacteriological contamination of the stream sections, which are directly connected to the cattle plant wastes. The invertebrates mentioned in this study are relatively coincident to the ones found in the samples from the potamal zone where the described biotic indices were applied. Modenutti (1987) studied the zooplankton of the Rodriguez stream in order to determine spatial variation of the species composition of this community. They reported in polluted sections a considerable increase in the proportion of Ciliata and Rotifera Bdelloidea, and a decrease in species and individual numbers of Rotifera Monogononta and Rhizopoda Testacea. The unpolluted sections and polluted ones of this stream were coincident with the mentioned results of Fernández and Schnack (1977) based on Sladecek (1973).

However, in the mountainous environments the conditions are different with a constant water flow coming from spring and flows. Although agriculture and cattle raising are present in the region, the alteration in the source areas (rhitron) and middle part is not significant. This is proved by the presence of high densities of sensitive species belonging to the Hydropsychidae, Hydroptilidae, Leptoceridae, Simuliidae, etc. Nevertheless in downstream direction the field slope decreases but the supply of pesticides, the nutrients coming from agriculture and urban sewage increases. In several streams and canals from this area the fauna becomes poor in favour of tolerant species belonging to the Chironomidae and Oligochaeta.

With regard to the index values itself, unpublished information about invertebrate samples of preliminary studies on rithral zones from Ventania Hills rivers (Sauce Grande River) allowed observing scores of the IBPAMP index between 10 to 13. In the Tandil Hills, however none of the analysed streams reached an index > than 10.

Gómez (1999) and Gómez and Licursi (2001), used an index based on benthic diatoms (with classes 0-IV following the Dell'Uomo (1991) criterion, in accordance with Sládecek (1973), that correlated significantly with the data of the aquatic invertebrates, which supports the validity of the applied indices in the present work.

This coincides with the opinion and considerations of De Pauw and Hawkes (1993), Ravera (1998), Corigliano (1999) and Prat et al. (1999) about the advantages of biological monitoring to obtain information on the global situation of the environment

Table 7. Factor Loadings (Unrotated) of the principal component analysis (PCA) for physico-chemical parameters only

Extraction: Principal components		
(Marked loadings (*) are > 0.70)		
	Factor	Factor
	1	2
DO	0.023064	0.108866
COD	0.630023	0.612948
BOD	0.637258	0.620653
COND	0.684489	0.409631
PH	−0.262087	0.126726
PO4	0.910036	−0.370762*
NO3	0.893231	−0.398242*
NH4	0.910583	−0.371459*
Expl.Var	3.795960	1.39066
%	47.4495	17.3833
Cumul. %	47.4495	64.8328

integrated over time. The community characteristics are the result of various environment factors influencing the community structure. The anomalies recorded by biological monitoring, indicate that stress conditions occurred in the past which appear not to be evidenced by chemical monitoring. However, these biological methods may not be applied in all situations, and chemical monitoring is important to identify and quantify the potential causes of biological effects. Both, biological and chemical monitoring are thus complementary to each other.

Conclusions

(1) The use of the biotic indices allowed to differentiate between sections of streams which are more or less affected by urban and industrial disturbance. The polluted El Gato stream is characterised by the following tolerant taxa: *Limnodrilus hoffmeisteri*, *Lumbriculus variegatus*, *Helobdela triserialis*, *Biomphalaria peregrina*, *Stenophysa marmorata*, *Pomacea canaliculata*, *Chironomus* sp. *Goeldichironomus* sp., etc.; the middle course of the Tandileofú stream is dominated by Nematoda and *Parachironomus* sp. In other sections with better environmental conditions the following sensitive species were found in the potamal zone: the dragonflies *Aeshna bonariensis*, *Micrathyria didyma*, the mayflies *Callybaetis* sp. and *Campsurus* sp., the caddisfly *Oecetys* sp., the shrimps *Palaemonetes argentinus* and *Macrobrachium borelli* and the bivalve *Diplodon delodontus delodontus.* In the rhitral zone other sensitive taxa are Hydropsychidae, Hydroptilidae, Leptoceridae, Simuliidae.

(2) The IBPAMP showed a positive highly significant correlation with the other biotic and diversity indices, except eveness, and a negative one equally significant with most of the physical-chemical water quality parameters that were considered (conductivity, BOD_5, PO_4, NO_3, NO_2 and NH_4), however not dissolved oxygen and pH.

(3) The correlation between factor 1 in which only physico-chemical parameters were considered, and the IBPAMP index was highly significant.

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