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The Pampean Diatom Index (IDP) for assessment of rivers and streams in Argentina

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Abstract

The rivers and streams of the Pampean plain are subjected to the impact of agriculture, cattle-raising and industrial activities. The largest urban center of Argentina is located here. The most important stresses on rivers and streams in the Pampean plain are organic enrichments (discharge of insufficiently treated sewage), nutrients, heavy metals, pathogenic agents, pesticides, herbicides and physical changes produced by dredging and canalisation. The epipelic community is suitable for biomonitoring purposes because it allows for comparing similar substrates along the rivers and streams. A total of 164 samples of epipelic diatoms were collected during 1995-1999 from Pampean rivers and streams. The analysis of these samples resulted in the development of a specific biotic index: the Pampean Diatom Index (IDP). The results were correlated with the main chemical water characteristics and with other biotic indices. This study suggests that the IDP is integrating organic pollution and eutrophication and can be applied for monitoring the biological quality of rivers and streams in the Pampean plain.

Introduction

Diatoms have been included in assessment of river water quality since the early Kolkwitz & Marsson (1908) studies and are known as reliable bioindicators of organic pollution and eutrophication (Descy & Ector, 1999). In this context, numerous studies dealing with water quality assessment have been focussing on the application of standardized methodologies based on diatom assemblages (Descy & Coste, 1990; Whitton et al., 1991; Whitton & Rott, 1996; Prygiel et al., 1999). Most of these studies were undertaken in the Northern Hemisphere, in particular in European countries.

The use of diatoms as indicators of water quality changes has few precedents in South America. Lobo et al. (1996. 1998) applied the saprobic system to assess the water quality of Southern-Brazil rivers, on epilithic diatom assemblages.

The water quality assessment of the Matanza-Riachuelo river basin (Gómez, 1998, 1999), based on epipelic diatom assemblages, represent the first precedent in Argentina. Hereafter the methodology applied in that study, including the use of both saprobity and diversity indices and multivariate analysis. was also considered for other Pampean lotic environments (Tangorra et al., 1998).

The Pampean plain represents around 87% of the total area of Buenos Aires Province. Its rivers and smaller streams present a semi desertic type of drainage with filtration and evaporation as predominant working processes (Sala et al., 1983). The slope ranges between 1.15 m km^{-1} in the more elevated areas (10% of the total area) and 0.25 m km^{-1} in the lower areas. Water input is mostly from precipitation and underground water.

The bottom substrate is mostly composed of slimeclay with low proportions of gravel and sand, except at the mouth of the rivers and streams, where sand can be dominant.

Hard stony substrates are found in streams with springs in the Sierra de Tandil and the Sierra de la Ventana. Limestone concretions can be found in mid or lower sections of certain streams.

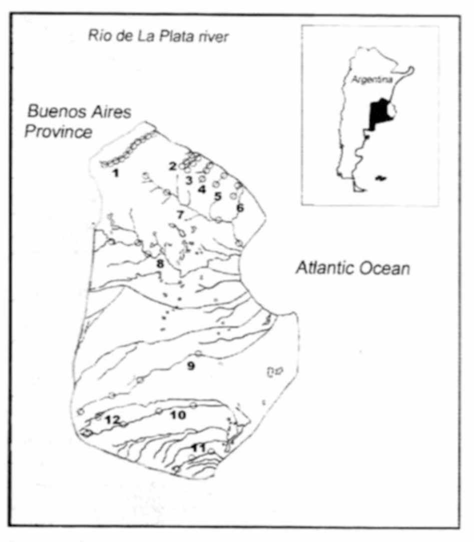

Figure 1. Study area and location of studied rivers and streams in the Pampean plain: 1. Matanza-Riachuelo river; 2. Rodríguez stream; 3. El Gato stream; 4. Pescado stream; 5. Buñirigo stream; 6. Juan Blanco stream; 7. Samborombón river: 8. Salado river; 9. Tandileofú stream: 10. Napaleofú stream; 11. Vivoratá stream; 12. Tandil stream

Lotic systems traversing the Pampean plain are affected by the activities and by-products of agriculture, cattle-raising, and industry. In addition, the most important urban centre in Argentina is located in this area. Water quality deterioration is mostly caused by organic enrichment, input of nutrients, heavy metals, pathogenic agents, pesticides, herbicides, and changes produced by dredging canalisations.

Numerous studies in different countries about in-dices have been based on the analysis of epilithic diatom assemblages (Whitton et al., 1991. Prygiel et al., 1999; Whitton & Rott, 1996). The problem, however is that sampling stones in lowland lotic systems and slow flowing reaches is often difficult or impossible because they are simply not present.

The use of epiphytic diatom assemblages or artificial substrates is not a practical alternative either. According to Cazaubon (1991, 1996), monitoring of the epiphyton presents a number of methodological problems due to differences in composition and abundance of diatom species colonising the macrophytes, having an influence also on the sampled part of the plant (leaves,stems or roots). Artificial substrates are used to facilitate sampling procedures and replicability of samples, however the time to develop a climax periphyton is a matter of colonisation and growth velocity (quick in eutrophic, slow in oligotrophic systems) and in general the periphyton on artificial substrates does not reflect the complete natural community with respect to species diversity and/or quantitative relationships (Kann, 1978).

Table 1. Characterization of water quality classes based on NH_4-N, BOD_5 and PO_4-P (mg 1^{-1})

Water quality classes	BOD5	NH_4^+-N	PO_4^3-P
0	⩽3	⩽0.1	⩽0.05
I	>3-8	>O.1-0.5	>0.05-0.1
II	>8-15	>0.5-0.9	>0.1-0.5
III	> 15-25	>0.9-2	>0.5-1
IV	>25	>2	> 1

It is not very reliable to apply indices developed for other latitudes, the characteristic features of the Pampean plain need the development of suitable indices for biological monitoring of river water quality.

The purpose of this paper was develop an index at the regional scale, hereafter called the Pampean Diatom Index (IDP), directed towards the assessment of water quality of rivers and smaller streams of the Pampean plain. The index is based on the sensitivity of the epipelic diatom assemblages integrating the effect of organic enrichment and eutrophication, two phenomena which can hardly be separated.

Materials and methods

A total of 164 samples were collected in rivers and smaller streams throughout the Pampean plain (Fig-ure 1). In each river, 3-4 sampling stations distributed along the upper, middle, and lower parts of the river were selected and seasonally sampled during 1997-1999. In the case of the Matanza-Riachuelo river basin, 23 stations were selected and sampled during March, April, May, and July of 1995. In each sampling station a number of ten sub-samples were collected by pipetting (Stevenson, 1984; Lowe & Laliberte, 1996) a superficial layer of 5-10 mm of the sediment in different places, following Descy & Costes (1990) recommendations.

Table 2. Most frequently occuring diatoms in the epipelon of Pampean rivers and streams and ecological preferences according to water quality

Taxon	Water quality class	Specific index value I_{idp}
Achnanthes minutissima Kützing	0-II	1
Achnanthes lanceolata (Bréb.) Grunow	I-II	1.5
Achnanthes hungarica (Grun.) Grunow	II-III	2.5
Achnanthes delicatula ssp. *hauckiana* Lange-Bertalot & Rup	II	2
Amphora coffeaeformis (Ag.) Kützing	III-IV	3.75
Amphora libyca Ehrenberg	II-III	2.5
Amphora perpusilla Grunow	I-II	1.75
Amphora veneta Kützing	III-IV	3.5
Anomoeoneis sphaerophora (Ehr.), Pfitzer	III-IV	3.25
Bacillaria paradoxa Gmelin	I-II	1.75
Caloneis bacillum (Grunow) Cleve	I-II	1.5
Caloneis ventricosa Agardh	I-II	1.5
Cocconeis placentula Ehrenberg	I-III	2
Cocconeis placentula var. *euglypta* (Ehr.) Grunow	II-III	2.25
Cymbella affinis Kützing	I-II	1.75
Cymbella minuta Hilse ex Rabenhorst	0-I	0.75
Cymbella lanceolata (Ehr.) Kirchner	I-II	1.25
Cymbella silesiaca Bleisch in Rabenhorst	I-II	1.75
Denticula kuetzingii Grunow	I-II	1.5
Diatoma vulgaris Bory	I-II	1.5
Diploneis ovalis (Hilse) Cleve	I-II	1.25
Diploneis puella (Schumann)	I-II	1.25
Epithemia sorex Kützing	I-II	1.75
Eunotia bilunaris (Ehr.) Mills	I-II	1.25
Eunotia monodon Ehrenberg	I	1
Eunotia pectinalis (Dillwyn) Rabenhorst	I	1
Fragilaria capucina Desmazieres	0-I	0.5
Fragilaria ulna (Nitzsch.) Lange-Bertalot	I-III	2
Gomphonema angustum Agardh	0-II	1
Gomphonema clavatum Ehrenberg	I-II	1.25
Gomphonema parvulum Kützing	II-IV	3.25
Gomphonema truncatum Ehrenberg	I-II	1.25
Gyrosigma acuminatum Kütz. Rabenhorst	II	2
Hantzschia amphioxys (Ehr.) Grunow	I-III	2
Melosira varians Agardh	I-III	2
Meridion circulare (Greville) Agardh	0-I	0.25
Navicula accomoda Hustedt	III-IV	3.5
Navicula capitata Ehrenberg	I-III	2.75
Navicula capitatoradiata Germain	I-II	1.75
Navicula cryptocephala Kützing	II-IV	3
Navicula cuspidata Kützing	II-IV	3
Navicula gastrum (Ehr.) Kützing	I-II	1.25
Navicula goeppertiana (Bleisch) H.L. Smith	III-IV	3.75
Navicula pupula Kützing	II-IV	3
Navicula pygmaea Kützing	II-III	2.75
Navicula radiosa Kützing	I-II	1.25
Navicula subminuscula Manguin	III-IV	3.75
Navicula tripunctata (O.F. Mull.) Bory	I-III	2
Neidium iridis (Ehrenberg) Cleve	I	1

Table 2. Continued

Taxon	Water quality class	Specific index value I_{idp}
Nitzschia acicularis (Kütz) Smith	III-IV	3.75
Nitzschia amphibia Grunow	I-III	2.5
Nitzschia amphiboides Hustedt	I-III	2.5
Nitzschia angustata Grunow	II-III	2.5
Nitzschia brevíssima Grunow	II	2
Nitzschia constricta (Kütz) Ralfs	II-IV	3
Nitzschia dissipata (Kütz) Grunow	I-II	1.25
Nitzschia flexa Schumann	I-II	1.25
Nitzschia filiformis (W. M. Smith) Van Heurck	I-III	2.25
Nitzschia fonticola Grunow	I	1
Nitzschia frustulum Kutzing	I-II	1.75
Nitzschia gracilis Hantzch	I-II	1.5
Nitzschia heufleriana Grunow	I-II	1.25
Nitzschia hungarica Grunow	II-III	2.75
Nitzschia linearis (Ag.) W.M. Smith	II-III	2.5
Nitzschia palea (Kützing) W. Smith	II-IV	3.75
Nitzschia recta Hantzch ex Rabenhorst	I-II	I.75
Nitzschia sigma (Kützing) W. M. Smith	II-IV	3
Nitzschia umbonata (Ehr.) Lange-Bertalot	III-IV	3.75
Pinnularia gibba Ehrenberg	I-III	1.75
Pinnularia microstaurum (Ehr.) Cleve	II-III	2.75
Pleurosira laevis (Ehr.) Compere	I-II	1.75
Reimeria sinuata (Gregory) Kociolek & Stoermer	0-I	0.75
Rhoicosphenia abbreviata (Ag.) Lange-Bertalot	0-II	1.5
Rhopalodia musculus (Kütz.) O. Müler	I-II	1.75
Surirella angusta Kutzing	III-IV	2.25
Surirella tenera Gregory	I-II	1.5

Before being acid-treated and mounted in Naphrax, frustules were observed under the microscope for the examination of cytoplasm and condition of the chloroplasts. In each sample a total of 300 valves were examined under a magnification 1250 x to determine the relative abundance of each taxon. For species identification, the following keys were consulted: Husted (1930), Frenguelli (1941); Patrick & Reimer (1966, 1975). Krammer and Lange Bertalot (1986. 1991); Krammer & Lange-Bertalot (l987).

Temperature, pH, conductivity and dissolved oxygen were measured *in situ* with portable meters. Water samples were also collected in order to analyse the variables NH_4^+ -N , NO_3^- -N, NO_2^--N, PO_4^{3-}-P in 72 sampling stations, and COD and BOD_5 in all sampling stations. Soluble reactive phosphorus, nitrite and ammoniacal nitrogen were determined colorimetrically, nitrate was reduced to nitrite before colorimetric lecture (Mackereth et al.. 1978). BOD_5 was determined after 5 days incubation at 20 °C and COD by oxidation with potassium dichromate in acid medium (APHA, 1995).

Data variation was explored through a Principal Component Analysis based on a correlation matrix. Significance of the variation found for particular variables was evaluated applying Pearson's correlation (Johnson, 1998). Those variables which did not conform to the assumption of normality were transformed to logarithms (Johnson, 1998).

For the elaboration of the index, 210 species were identified, quantified and categorised according to their sensitivity to organic enrichment and eutrophication, taking into account as the main variables BOD_5 NH_4^+ and PO_4^{3-}. Five classes of water quality were

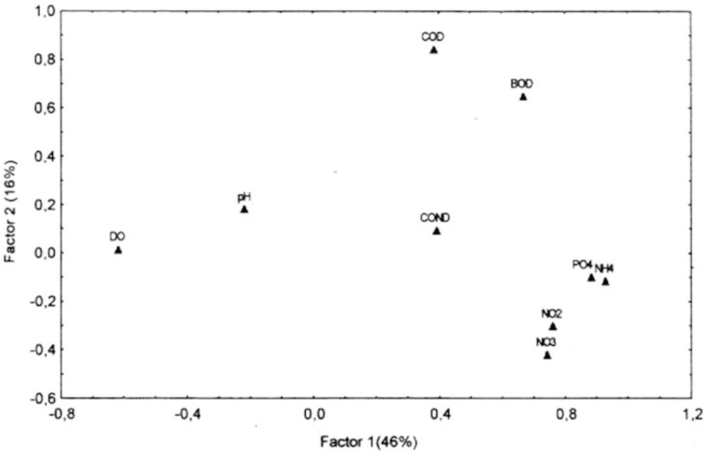

Figure 2. Representation of two first axes of the Principal Component Analysis using physical-chemical variables , performed on 72 samples

established (Table 1). The abundance of each species identified had been assessed in relation to those wa-ter quality classes, assigned a specific index value. In Table 2 are listed only the most frequendy occurring species.

The IDP was calculated by means of the following formula:

$$IDP = \frac{\sum_{j=1}^{N} I_{\text{idp}}j \cdot A_j}{\sum_{j=1}^{N} A_j}.$$

I_{idp} is the specific index value obtained for each species ranging between 0 and 4, and the water quality classes proposed for the IDP (0, I, II, III and IV) are according with Dell'Uomo (1991, 1995) criterion for monitoring rivers in Italy. If a certain species is found in two consecutive water quality classes and are equally distributed in both classes, lhe I_{idp} adopts values of 0.5, 1.5, 2.5, and 3.5. When the frequency of occurrence is higher in one of both classes, the value increases or decreases with 0.25. For example, a value of I_{idp} = 1.75 means that the species occurs in classes I and 11, but is more frequent and abundant in class 11 (Table 2). A is the relative abundance of each species.

The IDP was compared with lhe diatom indices IPS (Index Polluosensitivity Specific) ID Index Descy and Sladecek's index (Descy & Coste, 1990) and the macroinvertebrate index IBPAMP (Biotic Index for Pampean rivers) (Rodrigues Capítulo et al., 2001).

Table 3. Ranges for physico-chemical variables in the rivers and streams studied

	Average	Max.	Min.
Conductivity µS cm^{-1}	810.4	19150	105
pH	7.9	9.4	6.6
OD mg 1^{-1}	6.53	12.2	0.1
BOD_5 mg 1^{-1}	19	254	<1
COD mg 1^{-1}	57.74	655	3
PO_4^{3-} mg P 1^{-1}	0.46	6.92	<0.01
$N0_3$ mg N 1^{-1}	1.11	15.63	<0.01
NO_2^- mg N 1^{-1}	0.06	1.2	<0.01
NH_4^+ mg N 1^{-1}	0.53	45.9	<0.01

Results

Physical and chemical characteristics of rivers and streams

The main physical-chemical features of the rivers and streams studied are show in Table 3. The firts two factors PCA, carried out on water quality variables, accounted for 62% of the total variance (Figure 2). The first factor (46% of the variation of the selected variables) separated the following variables (factor loadings >.60): NH_4^+ -N , NO_3 -N, NO_2 -N, PO_4^{3-} -P and BOD_5 on the right hand side graph and dissolved oxygen on the left hand side. These variables are closely related to organic pollution and eutrophication. However, COD and Conductivity showed a lower relationship with the latter. Running waters can be enriched by organic matter or minerals, by natural

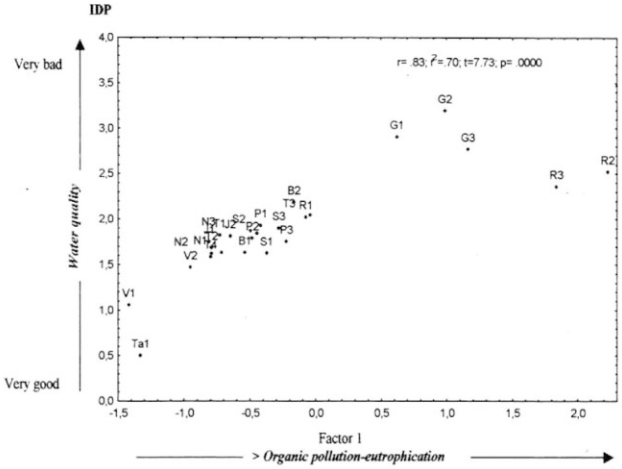

Figure 3. Linear regression of IDP average for each sampling station versus site scores average for axe. I. Symbols: R: Rodríguez stream; G: El Gato stream; P: Pescado stream; B: Buñirigo stream; J: Juan Blanco stream; S: Samboronbón river; T: Tandileofú stream; N: Napaleofú stream; V: Vivoratá stream; Ta: Tandil stream.

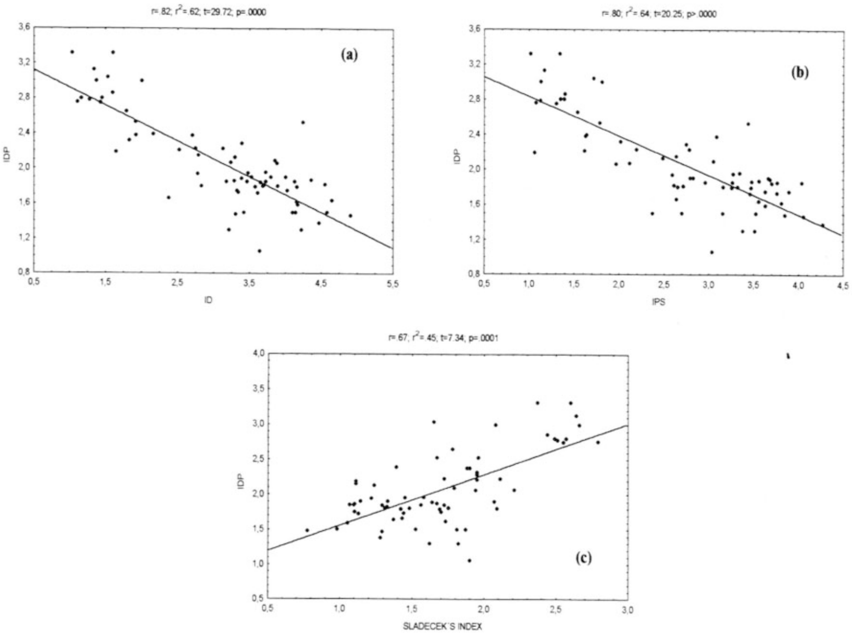

Figure 4. Relationship between IDP and (a) ID, (b) IPS and (c) Sládecek´s index.

Table 4: Interpretation of IDP (Pampean Diatom Index)

Water quality class	Colour code	IDP	Significance	Degree of disturbance
0	blue	0-0.5	*Very good:* without pollution, natural water, little nutrients and organic enrichment	Very slight: little humaninfluente
I	green	>0.5-1.5	*Good:* slightly polluted and eutrophicated, nutrients and organic matter levels stilllow	Slight: extensive cattle-raising and agriculture
II	yellow	> 1.5-2	*Acceptable:* moderately polluted and eutrophicated: high concentrations ofnutrients and organic matter	Moderate agricultural activity and/or intensive ranching
III	orange	>2-3	*Bad:* strongly polluted and eutrophicated, presence of partly degraded organic matter, nitrite, ammonia and aminoacids	Strong: intensive agriculture and cattle-raising, moderate industrial activities and population densities
IV	red	>3-4	*Very bad:* ven· strongly polluted high concentrations of organic matter, predominance of reductive processes and presence of industrial products	Very strong : intensive industrial activities and high population densities

means, and/or by contamination of some rivers and streams. In many sites the high organic matter concentration coming from macrophyte detritus and humic compounds can increase the COD values, e.g., upstream Pescado stream, Juan Blanco stream, Buñirigo stream. There are also many sites where pollution is associated with a high natural mineral content, e.g., Matanza-Riachuelo river.

IDP vs water quality

The IDP values ranging between 0 and <4 and the associated disturbance degree are explained in Table 4.

Correlations between the Fl scores (related to the eutrophication and organic pollution variables) and the mean IDP of the sampling sites show the relationships between the index and the water quality (Figure 3). It can be seen that the IDP values increase with an increase in organic pollution and eutrophication. The sampling sites on the right hand side of the graph are those located in urban centers and exposed to waste water discharges from industrial activities and important human populations. The sampling sites on the left hand side of the graph are much less submitted to disturbance from human activities.

The analysis of the correlation between IDP values and physical-chemical features of the rivers and steams showed significant values ($p < 0.000$) for NH_4^+ -N ($r = 0.70$, $n = 72$), DO ($r = -0.57$, $n = 72$), $P0_4^{3-}$P ($r = 0.62$, $n = 72$), BOD_5 ($r = 0.58$, $n = 164$), COD ($r = 0.47$, $n = 164$), NO_2^- -N ($r = 0.45$, $n = 72$), conductivity ($r = 0.56$, $n = 174$), and NO_3^- -N ($r = 0.61$, $n = 72$).

IDP vs other biotic indices

The correlation between factor 1 and the diatom indices yields indeed a better relationship of IDP ($r = 0.86$, $p = 0.0000$) than with IPS ($r = -0.76$, $p = 0.0000$), ID ($r = -0.74$, $p = 0000$) and Sladeck´s index ($r = 0.44$, $p = 0.0001$). Also the relation between IDP with ID and IPS respectively was better than with the saprobic index (Figure 4a-c).

The relationship between IDP and IBPAMP (Biotic Index for PAMPean rivers), a regional index based on macroinvertebrate data, also showed a significant correlation (Figure 5). The IBPAMP values range from I (unpolluted water) to V (very heavily polluted water) and increase with decreasing IDP values, indicating a better ecological status of the streams and a better water quality.

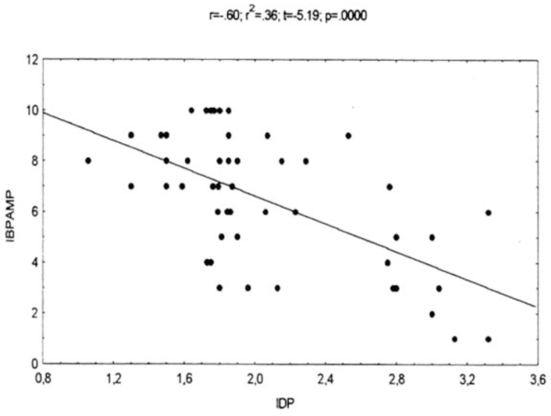

Figure 5. Relationship between IDP and the macroinvertebrate index IBPAMP

Discussion and conclusions

It is generally accepted that stony substrates are the most appropiate for diatom-based monitoring. Stones are however not always present along all river sections, and when present, they may not be the predominant kind of substrate for colonization by diatoms (Kelly, 1995).

Monitoring studies using epiphytic diatoms, for comparative purposes and water quality assessment, are difficult in lotic systems of the Pampean plain due to the intrinsic characteristics of these systems such as the heterogeneity in species composition of the aquatic macrophytes and their discontinuous distribution throughout the basin. The use of artificial substrates is not a practical alternative when the rivers run across densely populated areas where damage and losses of substrates are frequent, being exposed to theft and partial or total destruction.

On the base of the results of this study and these obtained by Gómez (1998, 1999) and Tangorra et al. (1998), the use of the epipelon is the most appropriate community for monitoring studies in the lotic system of the Pampean plain.

Organic pollution is usually closely related with enhanced nutrient concentrations. Based on the significant correlation with nutrients and organic pollution variables this study suggests that the IDP is integrating the effects of enrichment of organic pollution and eutrophication. As a consequence the results obtained lead to the use of the IDP for biomonitoring rivers and streams in the Pampean plain and possibly as well in other lotics systems with peculiar characteristics related to a very low slope.

In comparison with other diatom indices the IDP described better the changes in water quality than the ID, IPS and Sladeck's index. The latter was the least sensitive of all. According to Descy (1980) the saprobic index is ambiguous because it does not distinguish pollution from natural eutrophication phenomena. Also Gómez (1999) showed that Sládecek's index was relatively weak with respect to diagnosing changes in water quality in the Matanza-Riachuelo river.

The IDP is a good complement to the IBPAMP. According to Descy & Ector (1999) macroinvertebrates are more sensitive to changes in habitat diversity and quality than to changes in water quality, to which diatoms respond in a better way. Also the different generational time of diatoms and macroinvertebrates can show differences relevant for biomonitoring. Therefore biological assessments based on both communities are useful for describing the ecological status of these lotic systems.

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