



**HAL**  
open science

# REVIEW OF THE USE OF MICROALGAE IN SOUTH AMERICA FOR MONITORING RIVERS, WITH SPECIAL REFERENCE TO DIATOMS

E A Lobo, V L M Callegaro, G Hermany C, N Gómez, L Ector

► **To cite this version:**

E A Lobo, V L M Callegaro, G Hermany C, N Gómez, L Ector. REVIEW OF THE USE OF MICROALGAE IN SOUTH AMERICA FOR MONITORING RIVERS, WITH SPECIAL REFERENCE TO DIATOMS. *Vie et Milieu / Life & Environment*, 2004, pp.105-114. hal-03218105

**HAL Id: hal-03218105**

<https://hal.sorbonne-universite.fr/hal-03218105v1>

Submitted on 5 May 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## REVIEW OF THE USE OF MICROALGAE IN SOUTH AMERICA FOR MONITORING RIVERS, WITH SPECIAL REFERENCE TO DIATOMS

E. A. LOBO<sup>a\*</sup>, V. L. M. CALLEGARO<sup>b</sup>, G. HERMANY<sup>c</sup>, N. GÓMEZ<sup>d</sup>, L. ECTOR<sup>e</sup>

<sup>a</sup> Laboratory of Limnology, University of Santa Cruz do Sul (UNISC),  
Av. Independência, 2293 Santa Cruz do Sul, RS Brazil

<sup>b</sup> Natural Sciences Museum, Zoobotanical Foundation of Rio Grande do Sul (FZB),  
Av. Salvador França, 1427 Porto Alegre, RS Brazil

<sup>c</sup> Graduate Course on Ecology, Federal University of Rio Grande do Sul (UFRGS),  
Av. Bento Gonçalves, 9500, Campus do Vale, Porto Alegre RS Brazil

<sup>d</sup> Institute of Limnology Dr. Raúl A. Ringuelet (CONICET-UNLP),  
P. O. Box 712-1900 La Plata, Buenos Aires, Argentina

<sup>e</sup> Public Research Center - Gabriel Lippmann, CREBS, Avenue de la Faïencerie, 162a 1511 Luxembourg

\*Author to whom correspondence should be addressed: lobo@unisc.br

WATER QUALITY ASSESSMENT  
BIOMONITORING  
BIOTIC INDEX  
MICROALGAE  
EPILITHIC DIATOMS  
EPIPELIC DIATOMS  
ARGENTINA  
BRAZIL

**ABSTRACT.** – Microalgae communities have been used for monitoring continental freshwaters in South America, mainly in Argentina and Brazil. Considering that the epipellic diatom community dominates the sediments of running waters from the Argentinean Pampean plain, and index named Diatom Pampean Index (DPI) was formulated, aiming to assess organic pollution and eutrophication. Based on the tolerance of epilithic diatom species to water organic pollution and eutrophication in rivers and streams of Southern Brazil, the Biological Water Quality Index (BWQI) was formulated, integrating the effects of both stressors.

EVALUATION DE LA QUALITÉ DE  
L'EAU  
INDICE BIOTIQUE  
MICROALGUES  
DIATOMÉES ÉPILITHIQUES  
DIATOMÉES ÉPIPELIQUES  
ARGENTINE  
BRÉSIL

**RÉSUMÉ.** – Les communautés de microalgues ont été utilisées pour le monitoring des eaux douces continentales en Amérique du Sud, principalement en Argentine et au Brésil. Etant donné qu'en Argentine les eaux courantes de la plaine de la Pampa sont dominées par les Diatomées épipéliques, un indice appelé Indice Diatomique de la Pampa (Diatom Pampean Index DPI) a été mis au point dans le but d'estimer la pollution organique et l'eutrophisation. Basé sur la tolérance des espèces de Diatomées épilithiques vis-à-vis de la pollution organique et de l'eutrophisation dans les rivières et ruisseaux du Sud du Brésil, l'Indice Biologique de Qualité de l'Eau (Biological Water Quality Index BWQI) a été défini en tenant compte de l'effet de ces deux facteurs.

### Introduction

In South America, microalgal communities have been utilized for monitoring and evaluating water quality in continental waters. However, the first studies were published only in the second half of the 20<sup>th</sup> century and were restricted to research groups located, basically, in Argentina and Brazil.

In Argentina, the first study to relate microalgae with contamination of lotic systems was carried out by Del Giorgio *et al.* (1991) in the Luján River. In a review of the use of microalgae for water quality assessment in Argentina, Loez & Topalián (1999) pointed out that the most recent studies were related mainly with the phytoplankton assemblages of the Pampean Plain. The singularities of these aquatic systems require a particular methodology for its monitoring with algae, and the use of

epilithon, frequently applied in biomonitoring elsewhere, had to be replaced by the use of epipelon in some lotic system of the Pampean Plain.

In Brazil, the research on phytoplankton ecology started in 1950's, even though limnological studies of sanitary emphasis took place since the thirties. Although the data obtained were empirical and qualitative, these studies are rather important, representing the studies carried out in hydrographic basins, reservoirs and water supplies (Rocha 1992). From the end of the nineties onwards, the number of studies in this area increased considerably; lotic systems, however, are still not thoroughly studied, despite the large hydrographical network in the country.

In Central America, Michels-Estrada (2003) working with the species composition and ecological requirements of benthic diatom assemblages

from various Costa Rica's streams and rivers, pointed out that baseline information on the ecology of aquatic systems is urgently needed in the tropics in order to develop new and effective biological methods of monitoring water quality. Limnological and ecological concepts developed for temperate zones have to be checked to see if they can be applied in tropical conditions.

### ***Microalgae and pollution: research in Argentina***

Argentina has extensive hydric networks, spread throughout its territory, with different preservation status. The most important stresses on rivers and streams are organic enrichment, nutrients, heavy metals, pesticides, herbicides and physical changes produced by dredging and canalisation.

The geographical area known as "Pampa" comprises the plains of the southern half of Rio Grande do Sul State (Brazil), Uruguay and East of Argentina, between the latitudes of 30 and 39° South. This zone is intensely exploited due to the fertility of its soil. The most important urban centre in Argentina is located in this area, with more than 14 million inhabitants. Agriculture and cattle-raising are the main activities in most parts of the area but urbanization has promoted industrial activity. The intensive exploitation of the area has impacted some of the aquatic systems with different intensities, leading to deterioration of water quality and destruction of habitats.

Streams and rivers in the Pampa originate in shallow depressions of the plain or on the hills that occupy a small area. Running waters have a slow current due to the low slope (0.25-1.3 m km<sup>-1</sup>). The headwaters lack riparian vegetation and the grasslands represent the characteristic biome. The bottom substrate is mostly composed of slime-clay with low proportions of gravel and sand.

In these lotic systems, phytoplankton is favored by low current velocities; epilithon develops in the rocky headwaters of some streams, while epipellic communities are very well represented along the watercourses. Epiphytic algae, on the other hand, develop on a diverse community of aquatic macrophytes (emergent, rooted and floating species), unequally distributed along the rivers.

Since 1997 a series of projects were implemented, funded by several Argentinean institutions (National Council of Scientific Research – CONICET, National University of La Plata – UNLP, National Agency for the Promotion of Science and Technology – ANPCyT), aiming to use different biological associations (phytoplankton, phytobenthos, macroinvertebrates, aquatic macrophytes and fish), for monitoring biological and ecological status of lotic systems of the Pampean Plain.

In order to achieve these aims, the response of phytoplanktonic and phytobenthic algae to different factors causing environmental stress was explored in an area of 50.000 km<sup>2</sup>, located in the Buenos Aires area and coastal zone of the La Plata River (34° 51'– 37° 59' S ; 57° 21'–59° 08' W). Both intensive and extensive studies were carried out (Table I).

Epipellic communities turned out to be a very useful alternative for biomonitoring lotic systems on these plains, whereas epilithic communities are virtually inexistent. Artificial substrata were not considered a practical alternative, since they were frequently stolen or destroyed. An index named *Diatom Pampean Index* (DPI) was formulated, aiming to evaluate the organic pollution and eutrophication in rivers and streams of the Pampa (Gomez & Licursi 2001). In this work, 164 seasonal epipellic samples were collected by pipetting from the superficial sediment layer, at 50 sampling sites along twelve lotic systems. Also conductivity, pH, temperature, dissolved oxygen, nitrate (NO<sub>3</sub><sup>-</sup>-N), nitrite (NO<sub>2</sub><sup>-</sup>-N), ammonium (NH<sub>4</sub><sup>+</sup>-N), phosphate (PO<sub>4</sub><sup>3-</sup>-P), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were measured. To formulate the index, 210 species were classified according to their sensitivity to organic pollution and eutrophication, taking into account their responses to the concentrations of PO<sub>4</sub><sup>3-</sup>-P, NH<sub>4</sub><sup>+</sup>-N and BOD (Table II). The IDP can be calculated as follows:

$$IDP = \frac{\sum(I_{IDP} \cdot A)}{\sum(A)}$$

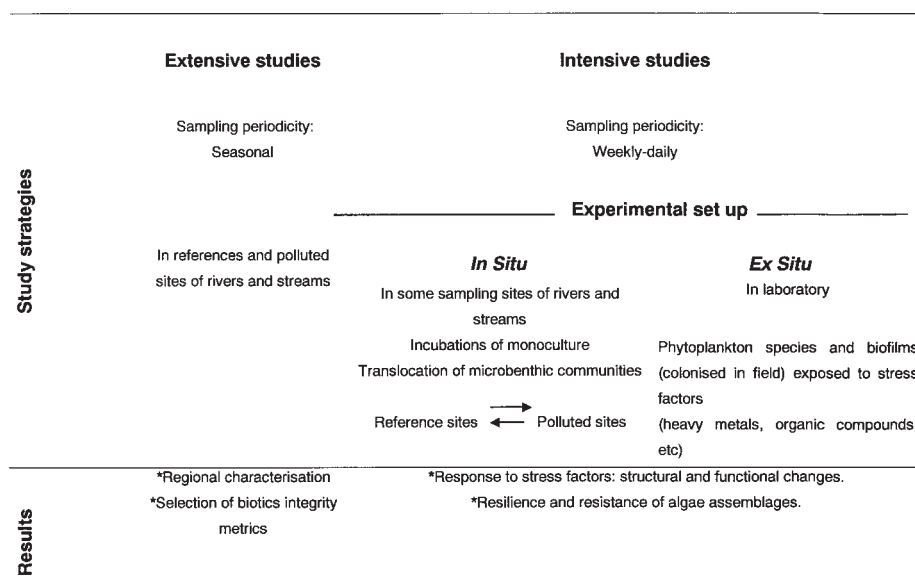
where I<sub>IDP</sub> is the specific index value, according to the classification of Gomez & Licursi (2001) and A the relative abundance of each species in the sample. This index ranges from 0 to 4 and determines 5 levels of water quality (Table III).

This regional index based on the use of epipellic community is an important tool for the study of rivers and streams of the Pampean Plain, where the use of indices developed for other latitudes not always gives adequate results in terms of water quality evaluation.

### ***Perspectives of the work with microalgae in Argentina***

Results of studies with microalgae have contributed to the diagnosis of water quality in some lotic systems (Gómez 1998, Gómez 1999, Gómez & Licursi 2001, Bauer *et al.* 2002a, Licursi & Gómez 2002, Tolcach & Gómez 2002). Their integration with a macroinvertebrate index (Rodrigues Capítulo *et al.* 2001) and physical-chemical variables allowed the first assessments of the ecological and biological status of some hydrographic basins on the Pampean Plain (Bauer *et al.* 2002b).

Tables I and II. – Top, study alternatives with phytoplankton and epipelic communities for monitoring rivers and streams in the Pampean Plain (Argentina). Bottom, characterisation of water quality classes in relation to BOD<sub>5</sub>, NH<sub>4</sub><sup>+</sup>-N, PO<sub>4</sub><sup>3-</sup>-P (mg l<sup>-1</sup>) and Interpretation of DPI (Diatom Pampean Index)



Water quality	Colour Code	BOD <sub>5</sub>	NH <sub>4</sub> <sup>+</sup> -N	PO <sub>4</sub> <sup>3-</sup> -P	IDP	Significance	Degree of disturbance
0	Blue	<3	<0.1	<0.05	0-0.5	<i>Very good:</i> without pollution	<i>Very slight</i>
I	Green	>3-8	>0.1-0.5	>0.05-0.1	>0.5-1.5	<i>Good:</i> slightly polluted	<i>Slight:</i> extensive cattle-raising and agriculture
II	Yellow	>8-15	>0.5-0.9	>0.1-0.5	>1.5-2	<i>Acceptable:</i> moderately polluted and eutrophicated <i>Bad:</i> strongly polluted and eutrophicated	<i>Moderate:</i> agricultural activity and/or intensive ranching.
III	Orange	>15-25	>0.9-2	>0.5-1	>2-3		<i>Strong:</i> intensive agriculture and cattle raising, moderate industrial activities, and population densities
IV	Red	>25	>2	>1	>3-4	<i>Very bad:</i> very strongly polluted and high concentration of organic matter	<i>Very strong:</i> intensive industrial activities and high population densities

Nevertheless, it is necessary to intensify phycological studies, particularly those with a functional approach, to obtain a better choice of biotic integrity measures, for an efficient diagnosis of water quality. Finally, the experience acquired in the Argentinean Pampa area should be integrated with that obtained by research groups in Brazil. This is an essential step towards the establishment of common protocols.

**Microalgae and pollution: research in Brazil**

In Brazil, the use of algae as pollution indicators started in the second half of last century (Rocha 1992), with several studies carried out in small

lakes and reservoirs. The main studies on phytoplankton related to pollution published in Brazil are listed in Table IV.

Work with biotic indices based on phytoplankton began in the mid eighties. At the Sanitation Technology Company of São Paulo State (CETESB), the Saprobic Index was used under the supervision of Dr Sládecek. This system, however, was abandoned in 1991, since studies about the ecological valences of diatom species to tropical climate were necessary. From 1983 the Trophic State Index was adopted in São Paulo State for use in reservoirs. At the same time, the Institute for the Environment of Paraná developed a water quality matrix, including parameters of phyto-

Table III. – Diatom species frequently found in the epipelon of Pampean streams and rivers and ecological preferences according to quality of the water (Gomez &amp; Licursi 2001).

TAXON	Water quality class	Specific index value ( <i>I<sub>wp</sub></i> )
<i>Achnanthydium minutissimum</i> (Kützing) Czarnecki	0-I	1
<i>Amphora coffeaeformis</i> (Agardh) Kützing	III-IV	3,75
<i>Amphora copulata</i> (Kützing) Schoeman & Archibald	II-III	2,5
<i>Amphora ovalis</i> (Kützing) Kützing	II-III	2,25
<i>Amphora perpusilla</i> (Grunow) Grunow	I-II	1,75
<i>Amphora veneta</i> Kützing	III-IV	3,5
<i>Anomoeoneis sphaerophora</i> (Ehrenberg) Pfitzer	III-IV	3,25
<i>Bacillaria paradoxa</i> Gmelin	I-II	1,75
<i>Caloneis amphisbaena</i> (Bory) Cleve	I-II	1,5
<i>Caloneis bacillum</i> (Grunow) Cleve	I-II	1,5
<i>Caloneis ventricosa</i> (Ehrenberg) Meister	I-II	1,5
<i>Cocconeis placentula</i> Ehrenberg	I-III	2
<i>Cocconeis placentula</i> Ehrenberg var. <i>euglypta</i> (Ehrenberg) Grunow	II-III	2,25
<i>Cocconeis placentula</i> Ehrenberg var. <i>lineata</i> (Ehrenberg) Van Heurck	I-III	2
<i>Craticula accomoda</i> (Hustedt) Mann	III-IV	3,5
<i>Craticula cuspidata</i> (Kützing) Mann	II-IV	3
<i>Craticula halophila</i> (Grunow ex Van Heurck) Mann	II	2
<i>Cymbella excisa</i> Kützing	I-II	1,75
<i>Cymbella neocistula</i> Krammer	I-II	1,25
<i>Cymbella lanceolata</i> (Ehrenberg) Van Heurck	I-II	1,25
<i>Denticula kuetzingii</i> Grunow var. <i>kuetzingii</i>	I-II	1,5
<i>Diadesmis confervacea</i> Kützing	II-III	2,75
<i>Diatoma vulgare</i> Bory	I-II	1,5
<i>Diploneis ovalis</i> (Hilse ex Rabenhorst) Cleve	I-II	1,25
<i>Diploneis puella</i> (Schumann) Cleve	I-II	1,25
<i>Encyonema minutum</i> (Hilse in Rabenhorst) D.G. Mann	0-I	0,5
<i>Encyonema silesiacum</i> (Bleisch in Rabenhorst) D.G. Mann	I-II	1,75
<i>Eolimna subminuscula</i> (Manguin) Moser Lange-Bertalot & Metzeltin	III-IV	3,75
<i>Epithemia adnata</i> (Kützing) Brébisson	I-II	1,25
<i>Epithemia sorex</i> Kützing	I-II	1,75
<i>Eunotia monodon</i> Ehrenberg	I	1
<i>Eunotia pectinalis</i> (Dyallwyn) Rabenhorst var. <i>pectinalis</i>	I	1
<i>Fallacia pygmaea</i> (Kützing) Stickle & Mann	II-III	2,75
<i>Fragilaria capucina</i> Desmazières	0-I	0,5
<i>Gomphonema angustum</i> Agardh	0-II	1
<i>Gomphonema clavatum</i> Ehrenberg	I-II	1,25
<i>Gomphonema parvulum</i> (Kützing) Kützing	II-IV	3,25
<i>Gomphonema truncatum</i> Ehrenberg	I-II	1,25
<i>Gyrosigma acuminatum</i> (Kützing) Rabenhorst	II	2
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow	I-III	2
<i>Hippodonta capitata</i> (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	I-III	2,75
<i>Hippodonta hungarica</i> (Grunow) Lange-Bertalot, Metzeltin & Witkowski	I-III	2
<i>Lemnicola hungarica</i> (Grunow) Round & Basson	II-III	2,5
<i>Luticola goeppertiana</i> (Bleisch in Rabenhorst) D.G. Mann	III-IV	3,75
<i>Melosira varians</i> Agardh	I-III	2
<i>Meridion circulare</i> (Greville) C.A. Agardh	0-I	0,25
<i>Navicula capitatoradiata</i> Germain	I-II	1,25
<i>Navicula cryptocephala</i> Kützing	I-IV	3
<i>Navicula gregaria</i> Donkin	II-III	2,75
<i>Navicula tripunctata</i> (O.F. Müller) Bory	I-III	2
<i>Nitzschia acicularis</i> (Kützing) Smith	III-IV	3,75

Table III. – *Continued.*

<i>Nitzschia amphibia</i> Grunow	I-III	2,5
<i>Nitzschia semirobusta</i> Lange-Bertalot	I-III	2,5
<i>Nitzschia angustata</i> (W. Smith) Grunow	II-III	2,5
<i>Nitzschia brevissima</i> Grunow	II	2
<i>Nitzschia dissipata</i> (Kützing) Grunow	I-II	1,25
<i>Nitzschia draveillensis</i> Coste & Ricard	I-II	2
<i>Nitzschia filiformis</i> var. <i>conferta</i> (Richter) Lange-Bertalot	I-III	2,25
<i>Nitzschia fonticola</i> Grunow	I	1
<i>Nitzschia frustulum</i> (Kützing) Grunow	I-II	1,75
<i>Nitzschia gracilis</i> Hantzsch ex. Rabenhorst	I-II	1,5
<i>Nitzschia heufferiana</i> Grunow	I-II	1,25
<i>Nitzschia linearis</i> (Agardh) W.M. Smith	II-III	2,5
<i>Nitzschia palea</i> (Kützing) W. Smith	II-IV	3,75
<i>Nitzschia recta</i> Hantzsch ex Rabenhorst	I-II	1,75
<i>Nitzschia sigma</i> (Kützing) W. M. Smith	II-IV	3
<i>Nitzschia sigmoidea</i> (Nitzsch.) W.M. Smith	II-IV	3
<i>Nitzschia umbonata</i> (Ehr.) Lange-Bertalot	III-IV	3,75
<i>Pinnularia gibba</i> Ehrenberg	I-III	2,75
<i>Pinnularia microstauron</i> (Ehrenberg) Cleve	I-III	2,5
<i>Pinnularia subcapitata</i> Gregory	I-II	1,75
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg	I-II	1,75
<i>Planothidium hauckianum</i> (Grunow) Round & Bukhtiyarova	II	2
<i>Planothidium lanceolatum</i> (Brébisson) Round & Bukhtiyarova	I-II	1,5
<i>Pleurostra laevis</i> (Ehrenberg) Compere	I-II	1,75
<i>Rhopalodia gibba</i> (Ehrenberg) O. Müller	I-II	1,25
<i>Rhopalodia musculus</i> (Kützing) O. Müller	I-II	1,5
<i>Sellaphora pupula</i> (Kützing) Mereschkowsky	II-IV	3
<i>Stauroneis phoenicenteron</i> (Nitzsch) Ehrenberg	II-III	2,25
<i>Surirella angusta</i> Kützing	II-III	2,5
<i>Surirella biseriata</i> Brébisson	I-II	1,25
<i>Surirella brebissonii</i> Krammer & Lange-Bertalot	I-III	2
<i>Surirella ovalis</i> Brébisson	II-III	2,5
<i>Surirella tenera</i> Gregory	I-II	1,75
<i>Tryblionella apiculata</i> Gregory	I-IV	3
<i>Tryblionella hungarica</i> (Grunow) D.G. Mann	II-III	2,75
<i>Ulnaria ulna</i> (Nitzsch) Compère	I-III	2

Table IV. Most important Brazilian publications on phytoplankton and their relation to pollution, classified by Brazilian region.

Region	Authors
North	Sioli (1965)
Northeast	Wright (1935)
Middle-West	Palmer (1960, 1969); Oliveira & Krau (1970)
Southeast	Kleerekoper (1944); Branco (1964); Azevedo <i>et. al.</i> (1967); Bicudo & Bicudo (1967); Rocha & Branco (1970)
South	Souza (1970); Kleerekoper (1944); Pellin & Zini (1971)

plankton community structure. In the last ten years there was a significant increase in the number of studies using periphytic communities for water quality evaluation, mainly in urban reservoirs of São Paulo.

In a review of Brazilian phytoplankton research, Huszar & Silva (1999) pointed out the small number of studies on lotic environments, despite the large hydrographic network of the country. They also mentioned the proliferation of studies on

Table V. Saprobic values (s) and differential groups for epilithic diatoms in the Guaíba Hydrographic Basin, RS, according to Lobo *et al.* (2002). A (most pollution tolerant species), B (pollution tolerant species), C (less pollution tolerant species).

Species	s	Group
<i>Achnantheidium minutissimum</i> (Kützing) Czarnecki	4.0	A
<i>Adlafia bryophila</i> (Petersen) Moser. Lange-Bertalot & Metzeltin	4.0	A
<i>Amphipleura lindheimeri</i> Grunow	4.0	A
<i>Fragilaria ulna</i> (Nitzsch.) Lange-Bertalot var. <i>ulna</i>	4.0	A
<i>Gomphonema cf. clevei</i> Fricke	4.0	A
<i>Gomphonema pseudoaugur</i> Lange-Bertalot	4.0	A
<i>Gyrosigma scalproides</i> (Rabenhorst) Cleve	4.0	A
<i>Luticola goeppertiana</i> (Bleisch) D.G. Mann	4.0	A
<i>Melosira varians</i> Agardh	4.0	A
<i>Navicula cryptotenella</i> Lange-Bertalot	4.0	A
<i>Navicula schroeterii</i> Meister	4.0	A
<i>Nitzschia amphibia</i> Grunow	4.0	A
<i>Nitzschia linearis</i> (Agardh) W. Smith var. <i>linearis</i>	4.0	A
<i>Nitzschia nana</i> Grunow in Van Heurck	4.0	A
<i>Nitzschia palea</i> (Kützing) W. Smith	4.0	A
<i>Pinnularia gibba</i> Ehrenberg	4.0	A
<i>Pinnularia mayeri</i> Krammer	4.0	A
<i>Planothidium rostratum</i> (Oestrup) Lange-Bertalot	4.0	A
<i>Sellaphora pupula</i> (Kützing) Mereschkowsky	4.0	A
<i>Sellaphora rectangularis</i> (Gregory) Lange-Bertalot & Metzeltin	4.0	A
<i>Surirella ovata</i> (Kützing) Cleve var. <i>smithii</i> Cleve-Euler	4.0	A
<i>Achnanthes exigua</i> Grunow var. <i>exigua</i>	2.5	B
<i>Achnanthes inflata</i> (Kützing) Grunow	2.5	B
<i>Amphora montana</i> Krasske	2.5	B
<i>Cocconeis placentula</i> Ehrenberg var. <i>euglypta</i> (Ehrenberg) Grunow	2.5	B
<i>Cocconeis placentula</i> Ehrenberg var. <i>placentula</i>	2.5	B
<i>Cyclotella meneghiniana</i> Kützing	2.5	B
<i>Cymbella aff. hustedii</i> Krasske	2.5	B
<i>Cymbella affinis</i> Kützing	2.5	B
<i>Cymbella tumida</i> (Brébisson) Van Heurck	2.5	B
<i>Diadesmis confervacea</i> Kützing	2.5	B
<i>Diadesmis contenta</i> (Grunow ex Van Heurck) D. G. Mann	2.5	B
<i>Encyonema silesiacum</i> (Bleisch ex Rabenhorst) D.G.Mann	2.5	B
<i>Fragilaria capucina</i> Desmazières var. <i>rumpens</i> (Kützing) Lange-Bertalot	2.5	B
<i>Geissleria aikenensis</i> (Patrick) Torgan & Oliveira	2.5	B
<i>Gomphonema angustatum</i> (Kützing) Rabenhorst	2.5	B
<i>Gomphonema gracile</i> Ehrenberg	2.5	B
<i>Gomphonema parvulum</i> (Kützing) Kützing v. <i>parvulum</i>	2.5	B
<i>Gyrosigma acuminatum</i> Ehrenberg	2.5	B
<i>Mayamea atomus</i> (Kützing) Lange-Bertalot	2.5	B
<i>Navicula rostellata</i> Kützing var. <i>rostellata</i> (Kützing) Cleve	2.5	B
<i>Navicula cryptocephala</i> Kützing	2.5	B
<i>Navicula gregaria</i> Donkin	2.5	B
<i>Nitzschia sigma</i> (Kützing) W. Smith	2.5	B
<i>Planothidium lanceolatum</i> (Brébisson) Round & Bukhtiyarova	2.5	B
<i>Sellaphora seminulum</i> (Grunow) D. G. Mann	2.5	B
<i>Surirella angusta</i> Kützing	2.5	B
<i>Surirella linearis</i> W. Smith	2.5	B
<i>Ulnaria ulna</i> (Nitzsch) Compère	2.5	B
<i>Frustulia rhomboides</i> (Ehrenberg) De Toni	1.0	C
<i>Gomphonema angustum</i> Agardh	1.0	C
<i>Gomphonema neonasutum</i> Lange-Bertalot & Rechart	1.0	C

phytoplankton ecology in the nineties, with 111 studies published until December 1998, and the increasing occurrence of toxic cyanobacteria in Brazilian waters. Hence, the Ministry of Health issued an edict in 2000, determining that cyanotoxin

analyses will be necessary every time cyanobacterial densities become higher than 20.000 cells mL<sup>-1</sup> at water treatment stations.

Regarding to the use of epilithic diatom communities for water quality evaluation in continental

Table VI. TWINSPAN groups with respective abundant species and indicative values related to eutrophication, according to Lobo *et al.* (2004).

Species	Twinspan Group	Tolerance to Eutrophication	Indicative Value			
<i>Amphora montana</i> Grunow	C	Very Low	1			
<i>Frustulia</i> cf. <i>weinholdii</i> Hustedt						
<i>Luticola goeppertiana</i> (Bleisch in Rabenhorst) D. G. Mann						
<i>Geissleria aikenensis</i> (Patrick) Torgan & Oliveira						
<i>Rhopalodia gibberula</i> (Ehrenberg) O. Muller						
<i>Surirella angusta</i> Kützing						
<i>Ulnaria ulna</i> (Nitzsch) Compère						
<i>Cocconeis placentula</i> Ehrenberg var. <i>placentula</i>				D	Low	2
<i>Encyonema silesiacum</i> (Bleisch) D. G. Mann						
<i>Gomphonema angustum</i> Agardh						
<i>Nitzschia amphibia</i> Grunow						
<i>Planothidium rostratum</i> (Oestrup) Lange-Bertalot	A	Medium	3			
<i>Adlafia bryophila</i> (Petersen) Moser. Lange-Bertalot & Metzeltin						
<i>Amphipleura lindheimeri</i> Grunow						
<i>Cocconeis placentula</i> Ehrenberg var. <i>euglypta</i> (Ehrenberg) Grunow						
<i>Cyclotella meneghiniana</i> Kützing						
<i>Cymbella affinis</i> Kützing						
<i>Cymbella</i> aff. <i>hustedti</i> Krasske						
<i>Diademsis contenta</i> (Grunow ex Van Heurck) D.G. Mann						
<i>Gomphonema</i> cf. <i>clevei</i> Fricke						
<i>Melosira varians</i> Agardh						
<i>Navicula cryptotenella</i> Lange-Bertalot	B	High	4			
<i>Navicula gregaria</i> Donkin						
<i>Navicula symmetrica</i> Patrick						
<i>Nitzschia linearis</i> (Agardh) W. Smith						
<i>Nitzschia palea</i> (Kützing) W. Smith						
<i>Eolimna minima</i> (Grunow) Lange-Bertalot						
<i>Fragilaria capucina</i> Desmazières var. <i>rumpens</i> (Kützing) Lange-Bertalot						
<i>Gomphonema angustatum</i> (Kützing) Rabenhorst						
<i>Gomphonema parvulum</i> Kützing						
<i>Navicula rostellata</i> Kützing						
<i>Achnanthes exigua</i> Grunow var. <i>exigua</i>	E	Very High	5			
<i>Achnantheidium minutissimum</i> (Kützing) Czarnecki						
<i>Mayamea atomus</i> (Kützing) Lange-Bertalot						
<i>Sellaphora seminulum</i> (Grunow) D. G. Mann						

freshwaters, little attention has been paid to the use of this group as bioindicator. Only a few related studies have been carried out, especially in the South of Brazil (i.e. Lobo *et al.* 1996, Lobo & Bender 1998, Oliveira *et al.* 2001). A detailed review of the use of epilithic diatoms as bioindicator organisms in lotic systems of Southern Brazil between 1988 and 1998 was published by Lobo & Callegaro (2000).

The first attempt to classify diatom species according to their tolerance to organic pollution was made in Southern-Brazilian rivers in 1996 (Lobo *et al.* 1996). Continuing this research, Lobo *et al.*

(2002) published the first Brazilian saprobic system. In this work, in order to describe the pattern of occurrence of diatom species to water pollution, a total of 183 samples of epilithic diatoms and water samples for determination of BOD<sub>5</sub> were collected in 31 stations from 18 lotic systems (including rivers and streams), belonging to the Guaíba Hydrographical Basin. This region comprises about 50 % of the municipal districts of Rio Grande do Sul State, including the capital and the metropolitan region, with an approximate area of 86.000 km<sup>2</sup>. Its main course, named Jacuí River, has a length of about 720 km with a depth ranging



Table VII. Summary of the main chemical characteristics of the sample units that form the TWINSPAN groups of Lobo *et al.* (2004). VL= Very low tolerance to eutrophication; L= Low tolerance to eutrophication; M= Medium tolerance to eutrophication; H= High tolerance to eutrophication; VH= Very high tolerance to eutrophication.

		TWINSPAN Group				
		C	D	A	B	E
		VL	L	M	H	VH
Cond ( $\mu\text{S cm}^{-1}$ )	Mean	0.083	0.122	0.130	0.118	0.078
	Standard deviation	0.041	0.025	0.48	0.130	0.032
NID ( $\text{mg L}^{-1}$ )	Mean	2.54	2.23	3.53	1.88	1.66
	Standard deviation	1.35	0.08	5.12	1.82	1.32
BOD ( $\text{mg L}^{-1}$ )	Mean	34.6	24.3	11.9	4.7	6.1
	Standard deviation	18.1	17.0	4.8	4.0	5.8
$\text{PO}_4^{3-}\text{-P}$ ( $\text{mg L}^{-1}$ )	Mean	0.059	0.070	0.058	0.172	0.251
	Standard deviation	0.063	0.023	0.024	0.123	0.273
*	Percentage < 0.025 ( $\text{mg L}^{-1}$ ) $\text{PO}_4^{3-}\text{-P}$	18%	0%	14%	0%	0%
**	Percentage < 0.037 ( $\text{mg L}^{-1}$ ) $\text{PO}_4^{3-}\text{-P}$	36%	10%	21%	0%	0%
***	Percentage < 0.050 ( $\text{mg L}^{-1}$ ) $\text{PO}_4^{3-}\text{-P}$	82%	20%	29%	10%	13%
****	Percentage > 0.100 ( $\text{mg L}^{-1}$ ) $\text{PO}_4^{3-}\text{-P}$	9%	10%	0%	60%	56%
*****	Percentage > 0.200 ( $\text{mg L}^{-1}$ ) $\text{PO}_4^{3-}\text{-P}$	0%	0%	0%	40%	44%
*****	Percentage > 0.400 ( $\text{mg L}^{-1}$ ) $\text{PO}_4^{3-}\text{-P}$	0%	0%	0%	0%	25%

\* Percentage of sampling units with total phosphate concentration less than 0.025 ( $\text{mg L}^{-1}$ )  $\text{PO}_4^{3-}\text{-P}$   
\*\* Percentage of sampling units with total phosphate concentration less than 0.037 ( $\text{mg L}^{-1}$ )  $\text{PO}_4^{3-}\text{-P}$   
\*\*\* Percentage of sampling units with total phosphate concentration less than 0.050 ( $\text{mg L}^{-1}$ )  $\text{PO}_4^{3-}\text{-P}$   
\*\*\*\* Percentage of sampling units with total phosphate concentration higher than 0.100 ( $\text{mg L}^{-1}$ )  $\text{PO}_4^{3-}\text{-P}$   
\*\*\*\*\* Percentage of sampling units with total phosphate concentration higher than 0.200 ( $\text{mg L}^{-1}$ )  $\text{PO}_4^{3-}\text{-P}$   
\*\*\*\*\* Percentage of sampling units with total phosphate concentration higher than 0.400 ( $\text{mg L}^{-1}$ )  $\text{PO}_4^{3-}\text{-P}$

from 12 to 14 m and an average annual discharge ca.  $714 \text{ m}^3 \text{ s}^{-1}$  (Lobo *et al.* 1996). The relative abundance of each species was plotted against the log-transformed  $\text{BOD}_5$  values of the water from which it was collected. The height of the mode for the distribution pattern of each species was determined by considering the weighted average between relative abundance and  $\text{BOD}_5$ . The different levels of pollution used to characterize the distribution pattern of each diatom species were determined following Hamm's (1969) chemical classification of water quality. The results indicated the occurrence of three differential diatom groups: Group A (highly pollution-tolerant species), Group B (pollution-tolerant species) and Group C (less pollution-tolerant species). The groups are listed in Table V.

Lobo *et al.* (2004) proposed the use of the *Biological Water Quality Index* (BWQI), integrating the effects of organic enrichment, from the classification proposed by Lobo *et al.* (2002), and eutrophication, from the indicative values determined using multivariate analyses techniques. Physical, chemical and biological data were obtained from the project "Water quality evaluation of Sampaio, Grande and Bonito Streams, Mato Leitão, RS, Brazil" carried out between 1993 and 1998. Sampling consisted of seasonal field trips to 12 sites. Water temperature ( $^{\circ}\text{C}$ ), pH, conductivity (Cond), turbidity (Turb), dissolved oxygen (DO), biochemical oxygen demand ( $\text{BOD}_5$ ), dissolved inorganic nitrogen (DIN), phosphate ( $\text{PO}_4$ ), and total solids (TS) were used as parameters for organic pollution and eutrophication assessment.

For an integrated analysis, firstly, species and samples were grouped using TWINSPAN – Two-way Indicator Species Analysis (Hill 1979). CCA – Canonical Correspondence Analysis (Ter Braak 1986) was then applied in order to evaluate the relationship between the abiotic variables and diatom species composition patterns, within the groups defined by TWINSPAN, using the covariance matrices. For each diatom species from the five TWINSPAN groups distributed along the eutrophication gradient detected, operational indicative values from one to five were given, based on their tolerances to eutrophication. These corresponded, respectively, to very low, low, medium, high, and very high tolerance levels. Table VI summarises this information, highlighting the indicative values for each species. Using these values, the *Biological Water Quality Index* (BWQI) can be calculated, according to the equation given by Wegl (1983), modified by the authors:

$$\text{BWQI} = \frac{\sum (s \cdot h \cdot vi)}{\sum (h \cdot vi)}$$

where  $s$  is the species saprobic value, according to the classification of Lobo *et al.* (2002);  $h$  is the percentage of occurrence (abundance) of each species in the sample and  $vi$  is the species indicative value. Values of BWQI vary from 1 to 4 in aquatic environments: 0-0.9 (pollution absent), 1.0-1.4 (low pollution), 1.5-2.0 (moderate pollution), 2.1-2.7 (heavy pollution) and 2.8-4.0 (very heavy pollution).

The characterisation of the trophic spectrum of this research was done on the basis of the percent-

ages of sampling units – for each TWINSPAN group – which were found to contain total phosphate values of less than 0.025, 0.032 and 0.050 (mg L<sup>-1</sup>) PO<sub>4</sub><sup>3-</sup>-P, and values higher than 0.100, 0.200 and 0.400 (mg L<sup>-1</sup>) PO<sub>4</sub><sup>3-</sup>-P (Table VI). These values corresponded, respectively, to: the limit established by the Brazilian National Environment Council for waters free of eutrophication; the phosphate concentration considered normal for freshwaters in Rio Grande do Sul State (Haase *et al.* 1997); the phosphate concentration necessary to cause eutrophication problems in streams that flow into lentic water bodies (Train 1979); the phosphate concentration considered excessive and extremely excessive according to Lobo *et al.* (2004).

The results of Lobo *et al.* (2004) generally confirmed conclusions by other studies in streams and rivers of Europe. *Sellaphora seminulum* and *Mayamea atomus*, grouped among the species with high tolerance to eutrophication, were described by Van Dam *et al.* (1994) as species characteristic of respectively eutrophic and hypereutrophic waters. The same authors described *Achnanthes exigua* var. *exigua* and *Achnantidium minutissimum* as species with broad tolerance ranges, occurring successfully from oligotrophic to eutrophic environments.

Kelly and Whitton (1995) assigned the indicative value five to *Gomphonema parvulum* and small (< 12 µm) species of the genera *Navicula* and *Sellaphora*, which were qualified as typical species of environments with phosphate values (≥ 0.3 mg L<sup>-1</sup>). In the present study the same trend was found, with these species also showing high and very high tolerances to eutrophication. Kelly *et al.* (1996) reported *Cocconeis placentula* as dominant species in less eutrophic environments of the River Kennet, England; a similar situation was found in the present study, where it showed low tolerance to eutrophication.

The differences observed in the tolerances of some species such as *Ulnaria ulna* and *Luticola goeppertiana*, widely cited as eutrophic species, however classified as “less tolerant to eutrophication” taxa in Brazilian rivers, can be ascribed to specific adaptations to the regional ecotones, confirming that trophic indices developed in other countries are not always adequate to be used successfully in South American freshwater environments.

### **Perspectives of the work with microalgae in Brazil**

In this country, there is a general lack of specialised human resources, mostly regarding taxonomical work. The majority of technicians and researchers in Brazil study industrial and domestic effluents for public water supply, where the need

for immediate action makes accurate taxonomical work very difficult to carry out.

These aspects reinforce the importance of the creation of research groups dedicated to taxonomy, and the development of a National Centre for Taxonomy, serving as a data reporting for microflora, allowing knowledge transfer between Brazilian researchers and institutions.

### **Final remarks**

It is clear that there are regional differences determining the use of distinct methodologies, such as the use of the epipellic community in Argentina for the assessment of the quality of surface freshwaters on the Pampean Plain.

Monitoring studies have to be approached with a holistic perspective, incorporating saprobic and trophic indices, as well as diatom and macro-invertebrate communities and, more recently, biological and ecological status of water bodies. A more specific analysis revealed the need to unify methodological criteria and technical information in order to establish unified investigation protocols.

Moreover, the development of biomonitoring Environmental Sciences in South America using microalgae and particularly diatoms is still incipient and restricted, basically, to Argentina and Brazil. Efforts should be put into increasing the number of researchers and countries involved in such studies, through programs of human resource development, especially in diatom taxonomy, as well as the permanent review of the tolerances of diatom species to organic pollution and eutrophication. Such efforts will allow the biological systems for environmental assessment to be kept up-to-date, aiming to develop a tested model adapted to the characteristics of the water systems of each country, able to fulfill the needs of routine water quality evaluation in freshwater ecosystems.

### **REFERENCES**

- Azevedo P, Kawai H, Vaz J O 1967. Study of limnology and pollution of River Pedras for fish production assessment (in Portuguese). Ver DAE São Paulo, 27: 216-227.
- Bauer D E, Conde M E, Gómez N 2002a. Phytoplankton of a small lowland stream related to water quality and hydraulic discontinuities. *Arch Hydrobiol* 153 (3): 421-442.
- Bauer D E J, Donadelli J, Gómez N, Licursi M, Ocón C Paggi A C, Rodrigues Capítulo A, Tangorra M 2002b. Ecological status of pampean plain streams and rivers. *Verh Internat Verein Limnol* 28: 259-262.
- Bicudo C E M, Bicudo R M T 1967. Floating community of algae in an artificial pond in the Parque do Estado de São Paulo. *J Phycol* 3: 233-234.

- Branco S M 1964. On the use of flagellate microorganisms as pollution indicators (in Portuguese). Dsc Thesis, Univ São Paulo, São Paulo, 118p.
- Del Giorgio P A, Vinocour A L, Lombardo R J, Tell H G 1991. Progressive changes in the structure and dynamics of the phytoplankton community along a pollution gradient in lowland river: a multivariate approach. *Hydrobiol* 224: 129-154.
- Gómez N 1998. Use of epipellic diatoms for evaluation of water quality in the Matanza-Riachuelo (Argentina), a Pampean plain river. *Wat Res* 32 (7): 2029-2034.
- Gómez N 1999. Epipellic diatoms from the Matanza-Riachuelo river (Argentina), a highly polluted basin from the Pampean plain: biotic indices and multivariate analysis. *Aquat Ecosyst Health Manag* 2: 301-309.
- Gómez N, Licursi M 2001. The Pampean Diatom Index (DPI) for assessment of rivers and streams in Argentina. *Aquat Ecol* 35: 173-181.
- Haase J, Cobalchini M S, Leite E H, Pineda M D, Silva M L C 1997. Questionamento da aplicabilidade da resolução CONAMA 20/86. FEPAM, Porto Alegre, Relatório Final. Fundação Estadual de Proteção Ambiental Henrique Luís Roessler, RS.
- Hamm A 1969. Die Ermittlung der Gewässergüteklassen bei Fließgewässern nach dem Gewässergütesystem und Gewässergütemogramm. *Müncher Beitr Abw Fisch Flussbiol* 15: 46-48.
- Hill M O 1979. TWINSPLAN – A FORTRAN Program for Arranging Multivariate Data in an Ordered Two-way Table by Classification of the Individuals and Attributes. Cornell University, Ithaca, New York, 60p.
- Huszar V L M, Silva L H S 1999. Phytoplankton community structure in Brazil: five decades of studies (in Portuguese). *Limnotemas* 2. Brazil Soc Limnol (electronic publ).
- Kleerekoper H 1944. Introduction to the study of Limnology (in Portuguese). Rio de Janeiro, Ministry of Agriculture, National Dep Animal Production (Publication #4 – Didatic ser).
- Licursi M, Gómez N 2002. Benthic diatoms and some environmental conditions in three lowland streams. *Ann Limnol* 38 (2): 109-118.
- Loez C R, Topalián M L 1999. Use of algae for monitoring rivers in Argentina with a special emphasis for the Reconquista river (region of Buenos Aires). In Use of algae for monitoring rivers III. J Prygiel, B A Whitton & J Bukowska eds: 72-83.
- Lobo E A, Callegaro V L 2000. Water quality evaluation in continental freshwaters based on epilithic diatoms: methodological approach (in Portuguese): 277-300. In Evaluation and control of urban drainage, Tucci C E M & Marques D M eds., Porto Alegre: Ed. Universidade/UFRGS. 558 p.
- Lobo E A, Callegaro V L M, Oliveira M A, Salomoni S E, Schuler S, Asai K, 1996. Pollution tolerant diatoms from lotic systems in the Jacui Basin, Rio Grande do Sul, Brasil, Iher Ser Bot, Porto Alegre 47: 45-72.
- Lobo E A, Callegaro V L, Bender P 2002. Use of epilithic diatoms as water quality indicators in rivers and streams of the Guaíba hydrographic region, RS, Brasil (in Portuguese). Santa Cruz do Sul: EDUNISC. 127 p.
- Lobo E A, Callegaro V L, Hermany G, Bes D, Wetzel C E, Oliveira M A 2004. Use of epilithic diatoms as bioindicators, with special emphasis to the eutrophication problem of lotic systems in southern Brazil. *Act Biol Brasil* 16(1) (in press).
- Michels-Estrada A 2003. Ökologie und Verbreitung von Kieselalgen in Fließgewässern Costa Ricas als Grundlage für eine biologische Gewässergütebeurteilung in den Tropen. Dissert Bot, J Cramer, Berlin, Bd 377. 244p.
- Oliveira L P H, Krau L 1970. General Hydrobiology specifically applied to schistosomiasis vectors: hipertrophy, a modern problem of water (in Portuguese). *Mems Inst Oswaldo Cruz* 68: 89-118.
- Oliveira M A, Torgan L, Lobo E A, Schwarzbold A 2001. Association of periphytic diatom species on artificial substrate in lotic environments in the Arroio Sampaio basin, RS, Brazil: relationships with abiotic variables. *Ver Bras Biol* 61(4): 523-540.
- Palmer C M 1960. Algae and water supply in Sao Paulo area (in Portuguese). *Rev DAE São Paulo* 37: 11-15.
- Palmer C M 1969. A composite rating of algae tolerating organic pollution. *J Phycol* 5: 78-82.
- Pellin J J A, Zini M C 1971. Guaíba River and its physical, chemical and biological characteristics (in Portuguese). Porto Alegre, Congresso Brasileiro de Química – DMAE.
- Pillar V P, Orlóci L 1996. On randomization testing in vegetation science: multifactor comparisons of revealed groups. *J Vegetation Sc* 7: 585-592.
- Rocha A A, Branco W C 1970. Study of sanitary conditions of the lagoons in Ibirapuera Park, São Paulo (in Portuguese). CETESB/ Prefeitura Municipal de São Paulo.
- Rocha A A 1992. Algae as biological indicators of water pollution. In Algae and Environment: A General Approach. Cordeiro-Marino M, Azevedo MTP, Sant'Anna CL, Tomita NY, Plastino EM eds, Brazilian Phycol Soc, CETESB: São Paulo: 34-52.
- Rodrigues Capítulo A, Tangorra M, Ocón C 2001. Use of benthic macroinvertebrates to asses the biological status of pampean streams in Argentina. *Aquat Ecol* 35: 109-119.
- Sioli H 1965. Limnology and its importance for research in the Amazon (in Portuguese). *Amazoniana* 1: 11-35.
- Souza R M 1970. Contribution to the study of diatoms in public supply waters of Florianópolis, Pilfes Dam (in Portuguese). *Insula* 4: 1-31.
- Ter Braak C J F 1986. Canonical Correspondence Analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67: 1167-1179.
- Train R E 1979. Quality criteria for water. U.S. Environmental Protection Agency. Castle House Publications: Washington.
- Tolcach E R, Gómez N 2002. The effect of translocation of microbenthic communities in a polluted lowland stream. *Verh Internat Verein Limnol* 28: 254-258.
- Wegl R 1983. Index of saprobity of freshwater (in German). *Wass Abw* 26: 1-175.
- Wright S 1935. Limnology and aquaculture (in Portuguese). Fish Culture Technical Commission of the Northeast Brazil (Publ #12).

Reçu le 10 septembre 2003; received September 10, 2003

Accepté le 8 avril 2004; accepted April 8, 2004