RAPID ASSESSMENT OF RIVER WATER QUALITY USING MACROINVERTEBRATES: A FAMILY LEVEL BIOTIC INDEX FOR THE PATAGONIC ANDEAN ZONE

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RESUMO- Avaliação rápida da qualidade da água em ríos utilizando macroinvertebrados: um índice biótico ao nível família para a região andino-patagônica: A atividade das sociedades modernas tem reflexos negativos sobre os ecossistemas aquáticos, conduzindo a acentuadas e rápidas variações da qualidade das águas superficiais. Os organismos bentônicos, por apresentarem ciclos de vida longos e reduzida mobilidade, têm sido utilizados como indicadores da qualidade da água. Os rios da Patagonia têm sido influenciados pela atividade antrópica. No entanto, a avaliação biológica da qualidade da água torna-se difícil, não só pelo elevado grau de endemismo, que condiciona a aplicação de outros índices, como também pela pouca informação taxonômica sobre alguns grupos. No presente estudo propõe-se a aplicação de um índice biótico, no nível de família, o B.M.P.S. (Biotic Monitoring Patagonian Stream) para avaliação da qualidade biológica em rios. O B.M.P.S. é uma adaptação do BMWP (Biological Monitoring Working Party) e foi desenvolvido a partir de amostragens efetuadas entre 1991 e 1996 em 43 rios da Patagônia, cobrindo mais de 200 locais com características biogeográficas diferentes. O BMPS baseia-se na diferente sensibilidade à poluição de 95 famílias e foi testado no sistema hídrico Esquel-Percy (Chubut- Argentina). Os resultados da aplicação do B.M.P.S. foram comparados como o IAP (Andean Patagonian Index), verificando-se alguma correlação entre os dois valores, apesar das diferentes pontuações obtidas 7 a 109,4 para B.M.P.S. e 2,5 a 9,75 para IAP, fato que permite inferir da boa aplicação do B.M.P.S. como indicador biológico. Uma análise hierárquica permitiu também verificar uma grande proximidade entre os dois índices aplicados e a riqueza específica.

Palavras-chave: ríos, macroinvertebrados, índice biótico, Patagonia

ABSTRACT -Rapid assessment of river water quality using macroinvertebrates: a family level biotic index for the Patagonic Andean zone. The progressive damage produced to the aquatic ecosystems by modern societies makes it necessary to rapidly detect water quality-changes. Macrobenthic organisms have been the most commonly used indicators of running water quality as they present appropriate size, sedentary habits and long-life cycles. The watercourses of Patagonia have also suffered the impact of anthropic activities. The high degree of endemism in several zoobenthic species prevents the use of foreign indices. Moreover, the status of the knowledge of some taxonomical groups is deficient. There are several groups of macroinvertebrates in Patagonian rivers for which no keys are available at the generic or specific levels. In this study we propose a family-level biotic index, the BMPS (Biotic Monitoring Patagonian Streams) to estimate water quality in rivers. We also compare the performance of the BMPS with a previous tested index: the IAP (Andean Patagonic Index) in an organic polluted system. The BMPS is an adaptation of the BMWP (Biological Monitoring Working Party). In its construction, different surveys carried out in 43 Patagonian rivers, from 1991 to 1996, were taken into account. More than 200 macroinvertebrate samples collected were used to obtain biogeographical and ecological information of the species. The BMPS resulted in a table of 95 families with different pollution sensivity grades: 1 to 10. The BMPS was tested in the Esquel-Percy river system (Chubut, Argentina). The mean annual values of the BMPS were comprised between 7 and 109.4, while the IAP mean values were between 2.5 and 9.75. A cluster among of BMPS, IAP, specific richness and Shannon-Weaver Diversity Index values was obtained. The BMPS, specific richness and the IAP were closely related. The BMPS was highly correlated with the IAP (r=0.96 n=106, regression multiplicative model) what indicates that the BMPS is a good estimator of the organic pollution levels.

Key-words: Rivers, macroinvertebrates, biotic index, Patagonia

INTRODUCTION

Monitoring the changes of water quality in streams and rivers can be performed through studies of the organisms living in water. Surface water-quality assessment based on biological indicators of pollution has been well developed in the Northern Hemisphere (Metcalfe, 1989). Resident biota in a water body are natural monitors of environmental quality and can reveal the effects of episodic as well as cumulative pollution and habitat alteration (Barbour *et al.*, 1996). Macrobenthic organisms have been the most commonly used as indicators of running water quality (Hellawell, 1978; Rosenberg & Resh, 1993). Macroinvertebrates present several advantages compared to other groups of organisms: they are ubiquitous and diverse (Mesanza *et al*, 1988), exhibit different feeding habits, are sedentary and have life cycles ranging from a few weeks to a few years, and are of convenient size for field examination, storage and transport (Chessman, 1995).

Rapid procedures for assessing the biotic communities of rivers and streams have become widely used in recent years as they allow a large number of sites to be examined at a relatively low cost (Rosenberg & Resh, 1993). Several countries have developed family-level biotic indices: the Biological Monitoring Working Party (BMWP) used in Great Britain (Armitage *et al.*, 1983), the New Zealand Macroinvertebrate Community Index (MCI) (Stark; 1985); the Australia Stream Invertebrate Grade Number -Average Level (SIGNAL) (Chessman, 1995); the Wisconsin Biotic Index (BI) (Hilsenhoff, 1987); the Spanish Biological Monitoring Water Quality (BMWQ) (Camargo, 1993), and the South African Score System (SASS) (Chutter, 1994). In the U.S.A., rapid bioassessment protocols have been designed to provide basic aquatic life data for water quality management purposes. Benthic macroinvertebrate protocols have been the most popular ones among water resource agencies, and include benthic metrics at species, genus or family level identifications. The family level provides a higher degree of precision among samples and taxonomists, requires less expertise to perform, and accelerates assessment results (Jacobi et al., 1998; Barbour et al., 1999). Records on evaluation of water quality using macroinvertebrates as indicators in Argentina are scarce (Gualdoni & Corigliano 1991; Gualdoni *et al*, 1994 a, b; Miserendino & Pizzolón, 1992; Domínguez & Fernández, 1998). Pollution problems are increasingly notorious in many Patagonian rivers and creeks. As a result of isolation there are many strong genera and supra-genera level endemisms in the fauna of the Patagonian mountain chain (Ringuelet, 1961). Consequently, the direct use of foreign indices as well as from other regions of Argentina is inappropriate. A genera level index, the IAP (Andean Patagonic Index) was previously proposed (Miserendino & Pizzolón, 1992) and evaluated (Pizzolón *et al.*, 1992). The convenience to use more than one index with comparative purposes has been suggested (Welch & Lindell, 1992; Resh *et al.*, 1993; Barbour *et al.*, 1999). In this work we propose a new biotic index based on family level, the BMPS (Biotic Monitoring Patagonian Streams). We also compare the performance of the BMPS with the IAP in an organic polluted system.

STUDY AREA

Morphological description of the Patagonian Area:

Two main geographical areas characterize Patagonia: Patagonian Andes cordillera and Patagonian plateau. Patagonian Andes cordillera presents chains and several eastern counterforts. They range along 2000 kilometers from Neuquén to Tierra del Fuego. Maximum elevations in the area scarcely exceed 3600 m. a.s.l. The climate is classified as temperate-cool, and rainfall decreases dramatically eastwards from the mountains to the steppe. Some sites in the Chilean border show 3000 mm y^{-1} precipitation, and the steppe is characterized by high drought (100-150 mm y^{-1}).

This strong climatic gradient has originated two main phytogeographical provinces: the Sub-Antarctic Forest and the Patagonian Steppe. Perennial (*Austrocedrus chilensis, Nothofagus dombeyi* and *Maitenus boaria*), and deciduous species (*N. pumilio, N. anctarctica*) constitute the Sub-Antarctic forests. The deciduous tree locally named "lenga" (*N. pumilio*) covers especially low-order streams (Hueck, 1978). Low watercourses are mainly flanked by *Salix fragilis* and *S. nigra.* Patagonian plateau shows an herbaceous-shrub-like steppe of several xerophytic forms: *Mulimun spinosum*, *Stipa* spp., *Senecio* spp., *Colletia spinossisima*, *Adesmia* sp., *Fabiana imbricata* and *Poa* sp. (Tell *et al.*, 1997).

Mountain rivers have a pluvial regime, with two maximum discharge periods, one of them is due to heavy winter precipitation and the other to watermelt from ice and snow on the Andes Mountains. The rivers of the Steppe are fed mainly by the pluvial precipitation from the West (Coronato & del Valle, 1988)

Zoogeographical features:

There are two main zoogeographical sub-regions in Patagonia: the Araucanian and the Andean-Patagonic. As a result of isolation, the Araucanian sub-region has a strong dominance of Austral or Notogeic fauna, there are also Nearctic and Brasilic elements (Ringuelet, 1961).

Several families of insects are endemic of the Andes mountain chain. This is notorious in Plecoptera (Illies, 1965). Ephemeroptera in Patagonia is dominated by oligo-stenothermic species, and are related to Australia and New Zealand fauna (Domínguez *et al.*, 1994). Trichoptera shows exclusive local elements and few of them are shared by the Brazilian sub-region (Angrisano, 1995). Coleoptera and Heteroptera present genera and species exclusive of the South mountain chain (Bachmann, 1995).

Some cosmopolitan or widely distributed families of insects are absent from Patagonian rivers: *Taeniopterygidae, Leuctridae, Capniidae, Nemouridae, Perlodidae, Chloroperlidae* (Plecoptera), *Heptageniidae, Potamanthidae, Ephemerellidae* (Ephemeroptera), *Goeridae,* (Trichoptera), *Dryopidae, Helophoridae, Hydrochidae* (Coleoptera). Among Crustacea, *Gammaridae* is not represented and *Hyalellidae* is the most common family in Patagonian streams. Among Gastropoda, *Neritiidae* and *Viviparidae* are absent and the endemic family *Chilinidae* is widespread in the area.

The Esquel-Percy System

The Esquel-Percy system is born in the east side of the Andes cordillera and drains through the Futaleufú River to the Pacific Ocean (42° 30' S). The upper catchment is mostly natural *Nothofagus* forest, and the lower part is mainly flanked by *Salix* spp. Agriculture is poorly developed in the basin, extensive cattle-raising being the main land use. The system is disturbed in its middle reach by the sewage effluents coming from Esquel (25,000 inhabitants) which has no sewage treatment plant. The rivers are characterized by rocky substrata and mainly turbulent flows. Stream orders range from 2 to 6 and altitude varies from 400 to 1300 m and the width of the streams vary from 2 to 100 m. A complete description of the sampling sites has been presented in previous studies (Miserendino, 1995; 1998).

METHODS:

Construction and use of the BMPS

The BMPS (Biotic Monitoring Patagonian Streams) is an adaptation of the BMWP (Biological Monitoring Working Party) (Armitage et al., 1983). Its construction was carried out considering different surveys of 43 Patagonian rivers, from 1991 to 1996. More than 200 samples collected were used to obtain biogeographical and ecological information of macroinvertebrate species.

Families absent in Patagonian streams were cancelled from the B.M.W.P and replaced by families present or with possibilities to be found in the lotic systems of the region. Some Heteroptera and Odonata were included since they are found in marginal areas or in river floodplains. Different score was reassigned to each family, according to their sensitivity as revealed in published studies (Lopretto & Tell, 1995; Muzón, 1995, Miserendino, 1994, 1995, 1998; Angrisano 1995, Domínguez *et al.*, 1994, Wais, 1987, 1990; Pizzolón *et al.*, 1992) (Tab. I).

Since several macroinvertebrates families from Patagonia are shared by New Zealand and Australia, different family level biotic indices from these countries (Chessman, 1995; Chessman *et al.*, 1997) were specially considered. The families of the BMWP: *Blephariceridae, Athericidae, Sericostomatidae, Glossossomatidae, Limnephilidae*, and others, were placed in the BMPS with the same sensitivity grade. More than 50 % of the BMWP families were replaced in the BMPS, which included a final number of 95 families.

Tab. I - Punctuations assigned to the families of macroinvertebrates for obtaining the BMPS (Biotic Monitoring Patagonian Streams).

FAMILY	PUNCTUATION
Eustheniidae Diamphipnoidae Perlidae Notonemouridae Gripopterygidae Austroperlidae Ameletopsidae Leptophlebiidae Siphlonuridae Leptoceridae Sericostomatidae Philorheithridae Helicophidae Anomalopsychidae Tasimiidae Kokiriidae Athericidae Blephariceridae	10
Coloboruscidae Glossossomatidae Philopotamidae Calamoceratidae Odontoceridae Helicopsychidae	8
Limnephilidae Hidrobiosidae Polycentropodidae Gomphidae	7
Baetidae Hydroptilidae Gelastocoridae Lestidae Austropetaliidae Aeshnidae Petaluridae Gomphomacromiidae Neopetaliidae Libellulidae Coenagrioniidae Hyalellidae Chilinidae	6
Ecnomidae Hydraenidae Eubriidae Scirtidae Elmidae Corydalidae Hydropsychidae Tipulidae Simuliidae Parastacidae Aeglidae Dugesiidae Ancylidae Phreodrilidae Osmylidae	5
Caenidae Haliplidae Chrysomelidae Curculionidae Tabanidae Stratiomyidae Empididae Ceratopogonidae Psychodidae Tanyderidae Thaumaleidae Sialidae Hyriidae Hydracarina	4
Notonectidae Corixidae Mesoveliidae Hydrometridae Belostomatidae Dytiscidae Girinidae Hydrophilidae Mycetopodidae Sphaeriidae Hydrobiidae Lymnaeidae Physidae Planorbidae Glossiphoniidae Semiscolecidae Macrobdellidae	3
Chironomidae Culicidae Muscidae Ephydridae Syrphidae	2
Lumbriculidae Tubificidae Naididae	1

The BMPS of each sample is obtained by classifying the organisms up to family level and adding the corresponding score assigned on the right side of Table I. Sampling units are based on eight integrated samples collected using a Surber net. The BMPS index can vary from 0 to more than 150 points. The status of sampling sites is assigned according to BMPS values in Tab. II.

Tab.II - Water quality scale corresponding to BMPS values.

CLASS	SYMBOL	VALUE	SIGNIFICANCE
I	□	Δ 150 >101	Very clean waters Unpolluted waters
II	□	61-100	Probably incipient pollution or other kinds of perturbation
III	■	36-60	Probably polluted waters
IV	■	16-35	Polluted waters
V	■	< 15	Strongly polluted waters

Biological test of the BMPS

The performance of the BMPS was assessed against the IAP by regression model, the IAP being previously tested with chemical and bacteriological variables (Pizzolón *et al.*, 1992). Both the IAP and BMPS were also compared by means of cluster analysis with specific richness and Shannon-Weaver diversity index (Miserendino, 1994, 1995). The Statistica package for Windows (4.3 Stat Soft, Inc., 1995) was used for statistical analyses.

RESULTS

The BMPS index

The families included in the BMPS and their corresponding sensitivity grades are presented in Table I. Water quality level assignments are given in Table II. Their application on the Esquel Percy system is showed in Fig. 1.

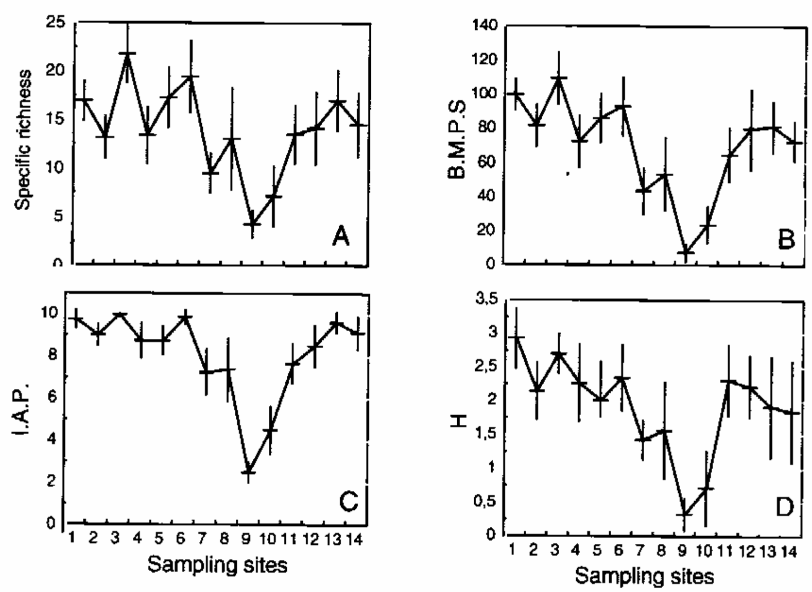

Fig. 1. a,b,c,d,: Mean annual values and standard deviation of specific richness.

BMPS test and comparisons:

The BMPS was compared and tested in 112 samples obtained in 14 stations of the Esquel-Percy system. Specific richness, Shannon-Weaver diversity index, IAP and BMPS are presented in Fig. 2. The annual mean specific richness and Shannon-Weaver diversity index varied between 4.7-21.75 and 0.32-2.93, respectively. The IAP and BMPS mean values varied between 2.5-9.75 and 7-109.4, respectively. All these variables show a system with great longitudinal heterogeneity. Both, IAP and BMPS indices gave a good picture of pollution patterns and recovery processes along the watercourse (Fig.1 and Fig. 2). However, it seems that BMPS has a greater discriminative power than IAP, due to their variation coefficients (46 % and 28%, respectively). Furthermore, BMPS has a higher extended scale than IAP (0 to more than 150 for BMPS and 0 to 10 for IAP). These different trends could be observed in Fig. 1 where, while IAP assigned only one kind of water quality, BMPS allowed to distinguish two kinds. This happened in sites with low perturbation (upper and lower stations, Fig. 1). In sites with strong or notorious pollution, BMPS gave a worse picture than IAP.

The BMPS was highly correlated with IAP ($r=0.96$; $p<0.0000001$; $N= 106$; multiplicative model) (Fig.3). Cluster analysis based on Pearson correlation matrix, showed that BMPS runs closely to specific richness and IAP. It was less correlated with Shannon-Weaver diversity index, which is based on quantitative data (Fig.4).

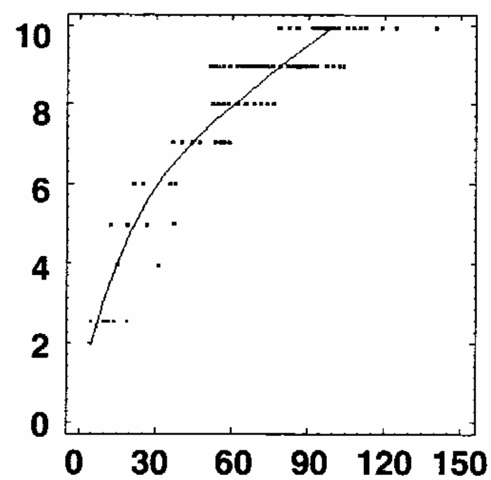

Fig. 2. Regression (multiplicative model) between IAP and BMPS ($r=0.96$ $n=106$).

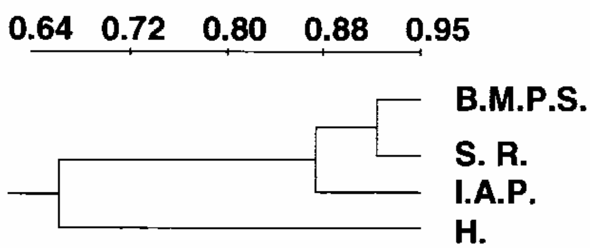

Fig. 3. Grouping analysis between the values of the specific richness, IAP, BMPS and Shannon-Weaver diversity index.

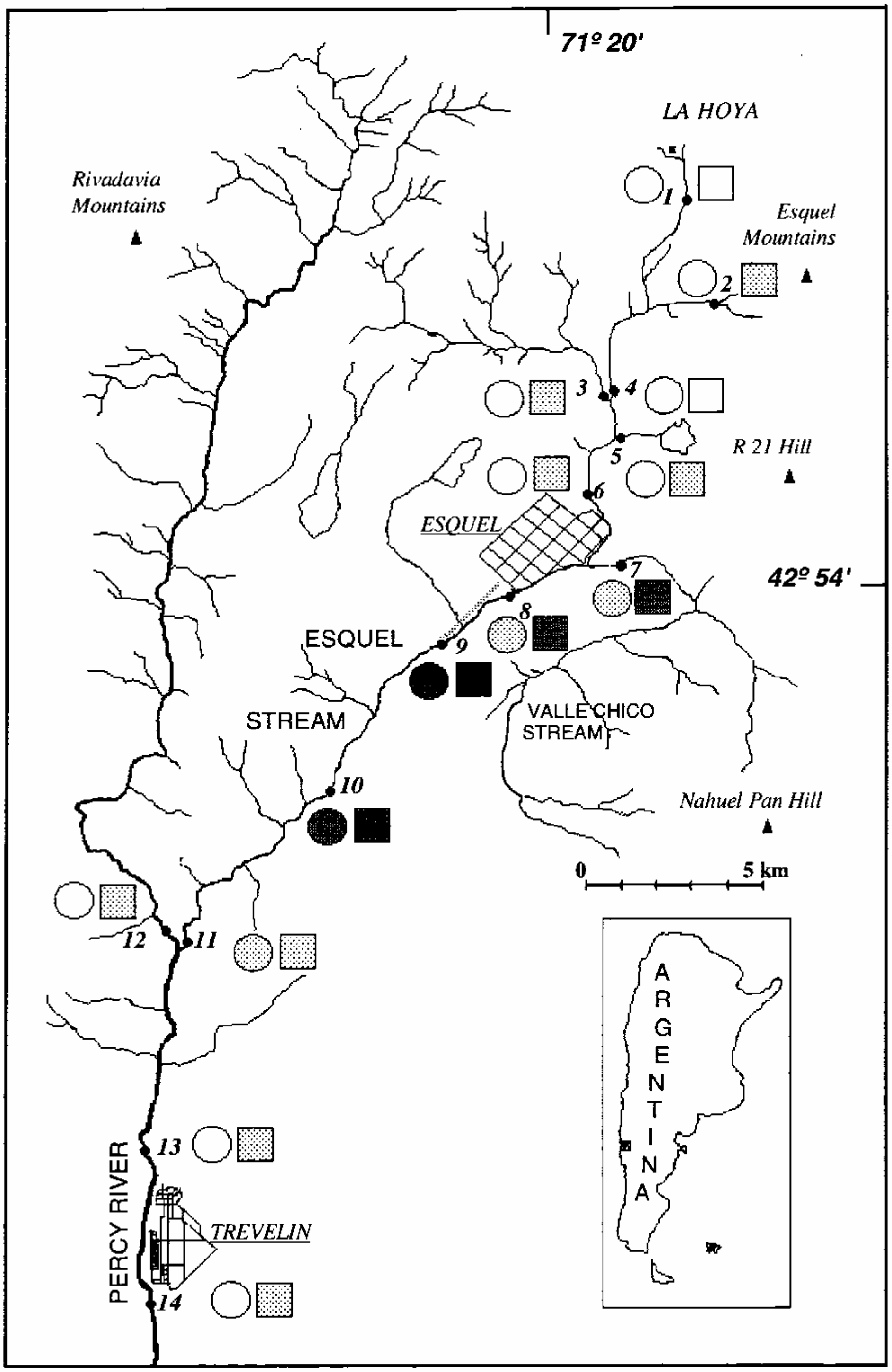

Fig. 4. Biological water quality mapping for Esquel-Percy system. Circles represent classes of quality of the IAP and squares of the BMPS.

DISCUSSION

The new biotic index proposed for the Andean-Patagonic region is a procedure for rapid water-quality assessment. It only requires a family level identification. The taxonomic knowledge of regional macrobenthic community is fragmentary and unequal and no keys are available at the generic or specific level in some insect groups (Lopretto & Tell; 1995). Even when the keys are available, in many cases (Chironomidae, Oligochaeta, and Trichoptera) reliable identification of species level requires the involvement of taxonomic experts. On the other hand, the high degree of endemisms in several families of macroinvertebrates is an obstacle to use biotic indices from other regions of Argentina, such as the IBC (Gualdoni & Corigliano, 1991) or BMWP index adaptation (Domínguez *et al.*, 1998). The IBC, a genus/species level index, was proposed for rivers and streams in the Córdoba province, where stoneflies are poorly represented. The BMWP index was adapted by Domínguez *et al.* (1998) to the Tucumán province, in which Austroperlidae, Notonemouridae and Gripopterygidae are absent. It means that each geographical region presents particular conditions in both faunal assemblages and environmental features. The BMPS, compared to the BMWP adaptation (Domínguez *et al.*, 1998), presents some families with different punctuation. Several species of Baetidae seem to be strongly affected by organic pollution in Patagonia (Miserendino, 1998); for this reason, we assigned them a higher punctuation. The BMPS was compared with IAP and both were checked in a system with high ranges of organic pollution. Both indices were also used with good results in other disturbed rivers of Patagonia (Pizzolón *et al*, 1997 a; b). In general, family-level, and genus/species-level biotic indices are highly correlated, but family level indices tend to indicate a slightly worse quality than the genus/species indices (Hilsenhoff, 1988; Muñoz & Prat, 1994); BMPS and IAP also exhibited this pattern. The slightly low values of the BMPS could be due to natural perturbations such as hydrological instabilities, turbidity, hydro-geochemical conditions as well as low levels of organic pollution. Selection of a representative stream reach is recommended in biomonitoring protocols using benthic invertebrates. Recently studies showed that a single well-chosen reach, adequately sampled, can be representative of an entire stream segment, and sampling additional reaches within a segment may not be cost effective (Rabeni *et al.*, 1999). In the Esquel-Percy system, 14 sampling sites were chosen; similar information could probably be obtained with a minor number of sites at each reach: upper, middle and low.

An ideal biotic index shows a strong response to a human impact and little variation in response to natural gradients (Chessman *et al.*, 1997). Multivariate techniques could be appropriate, in the future, to check this kind of influence on the IAP and the B.M.P.S. Ordination methods have been successfully used to test the effectiveness on rapid procedures in several countries (Growns et al., 1995; Chessman *et al.*, 1997).

Biotic indices themselves do not indicate the causes of a disturbance, only their existence, and they should be used together with physical, chemical and bacteriological variables (De Pauw & Vanhooren, 1983; Rosenberg & Resh, 1993). An integrated assessment requires a component of most water quality evaluations (Hannaford *et al.*, 1997). At present, several ecological aspects of Patagonian running waters are still unknown. It should be necessary to compile habitat conditions data, such as: riffle-pool proportion, available cover, sediment deposition, channel alteration, bank stability and vegetative protection. Aquatic fauna often has specific habitat requirements that are independent of water quality (Barbour *et al.*, 1996).

Biotic indices are an important tool in territorial planning and management of surface waters (Mesanza *et al.*, 1988; Metcalfe, 1989). In North America, rapid bioassessment usually permits quick turn-around of results for management decisions (Barbour *et al.*, 1999). In Argentina, bioassessment have not been considered in water quality regulation and sometimes, is also ignored by environmental managers. The results presented as a water quality mapping is a good alternative to transfer clear and concise information to environmental management authorities and to the public (Domínguez & Fernández, 1998).

Rapid techniques are appropriate for preliminary surveys or when a large number of sites are required to be analyzed (Muñoz & Prat, 1992). Moreover, family-level studies of river macroinvertebrates have been also used successfully in describing biogeographical patterns across large areas (Chessman, 1995) and for appraising the conservation value of river reaches (Wright *et al.*, 1998). Moreover, some studies support the use of biotic indices as indicators of both degradation and recovery of stream ecosystem processes (Wallace *et al.*, 1996). Due to its relative simplicity and low cost, we suggest the use of BMPS to detect incipient pollution. It can also be used to detect other kinds of disturbances coming from the increasing economic activities based on natural resources exploitation of Patagonia (river regulations, forest fires, desertification, mining).

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