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Primary Research Paper

Development and validation of a Biotic Index for evaluation of environmental quality in the central region of Argentina

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Abstract

The Suquía River (Córdoba, Argentina) has become an important issue because it flows into Mar Chiquita Lake, one of the largest saline lakes in the world. This water body, together with the expansive swamps of the Dulce River on the northern shore and the mouth of Suquía and Xanaes River, is considered one of the most important wetlands in Argentina in terms of biodiversity in a range of freshwater to very saline environments. Nevertheless, the presence of densely populated urban settlements and the increasing environmental impact due to anthropogenic activities characterize the central and lower sections of Suquía River Basin. Fishes are particularly affected and change their distribution and abundance as a consequence of the environmental deterioration. We collected information on fish fauna to develop and validate a Biotic Index to assess degradation of the Suquía River Basin. We classified fish species according to their sensitiveness or tolerance to environmental degradation, based on their distribution and abundance variations along a water quality gradient in order to design a Biotic Index for Suquía River Basin. The set of metrics used in the Biotic Index calculation was conformed by: the abundance of *Astyanax eigenmanniorum*, *Rineloricaria catamarcensis*, *Gambusia affinis* and *Cnesterodon decemmacultus*, the proportion of sensitive species richness, and the proportion of tolerant species richness. They clearly distinguished between the impaired and referenced sites. We demonstrated that it is possible to use fish as indicators of water quality in Córdoba Province (central part of Argentina) in order to carry out rapid and relatively inexpensive monitoring and conservation programs. The application of this Biotic Index showed that fish assemblages reflect the watershed conditions and are sensitive to changes in water quality across the environmental gradient.

Introduction

Human activities have altered the physical, chemical and biological processes of water resources, affecting the resident biota. Numerous studies have shown that both fish species richness and diversity decrease in polluted systems (Hildrew & Towsend, 1984; Crunkilton & Duchrow, 1991; Maret et al., 1997). Fish are sensitive indicators of the relative health of aquatic ecosystems and their surrounding watershed and manifest the ecological significance of the perturbation (Fausch et al., 1990). This premise forms the basis for monitoring fish to assess environmental degradation and ecosystem health in rivers and lakes.

Although many experimental studies have explored the response of fishes to environmental factors, fish behavior in relation to complex interactions among diverse variables in nature is difficult to describe. In Argentina there are few works that attempted to relate changes in fish assemblage composition with variations of physicochemical water characteristics in the field (Menni et al., 1984, 1996). Consequently, the aquatic system bioassessment has been difficult due to the lack of fish assemblage data as well as life-history information on most fish species. Furthermore, there is a scarcity of information about fish assemblage changes in relation to water quality degradation.

The quality conditions of Suquía River Basin (Córdoba, Argentina) has become an important issue because it flows into Mar Chiquita Lake (one of the largest saline lakes in the world). This lake together with the expansive swamps of the Dulce River on the northern shore and the mouth of Suquía and Xanaes River have been designated as a Ramsar site (Ramsar Convention Bureau, 2002), as it is considered one of the most important wetlands in Argentina in terms of biodiversity in a range of freshwater to very saline environments. Nevertheless, the presence of densely populated urban settlements and the increasing environmental impact due to the anthropogenic activities characterize the central and lower sections of Suquía River Basin (Gaiero et al., 1997). Macroinvertebrates and fishes are particularly affected and change their distributions and abundance as a consequence of the environmental deterioration (Mangeaud, 1998; Bistoni et al., 1999).

Pesce & Wunderlin (2000) reported a 3-year monitoring of Suquía River water in Córdoba city and nearby locations. They assessed the impact of urban activities through the application of Water Quality Indices (WQI) at spatial and seasonal scales, all based on physicochemical parameters. This evaluation demonstrated that urban activities produce a serious and negative influence on water quality, which is particularly severe in locations downstream from the city sewage discharge. However, this approach gives a partial view of the water quality degradation. The main limitation of WQI used is that it does not give us information about the status of the biota. Biological communities reflect a combination of current and past watershed conditions because organisms are sensitive to changes across a wide array of environmental factors (Karr et al., 1986). Particularly, fish are useful to assess environmental degradation. Their major advantages are that they integrate the direct and indirect effects of stress on the entire aquatic ecosystem, manifest the ecological significance of the perturbation (Fausch et al., 1990), and integrate adverse effects of varied stress on other components, such as habitat, macroinvertebrates, since they depend on those components for reproduction, survival, and growth (Karr, 1981). Furthermore, Fausch et al. (1990) pointed out that fish communities can be used to evaluate societal costs of degradation more directly than other taxa because their economic or aesthetic values are widely recognized.

We collected information on fish fauna to develop and validate a Biotic Index to assess degradation of the Suquía River Basin, located in the central region of Argentina. In order to achieve our main goal, we classified fish species and fish community attributes according to their sensitiveness or tolerance to environmental degradation, based on the distribution and abundance variations of fish species along a water quality gradient. Once the index was developed, we evaluated how well it corresponded with estimates of environmental conditions based on water quality analyses. Our study also provides a solid database that can be used to document and suggest causes for changes in the abundance and distribution of individual species along a system with degraded environmental conditions.

Study area

The Suquía River basin is located in a semi-arid region of Córdoba Province (Argentina), with a mean annual rainfall in the range of 700–900 mm (Vázquez et al., 1979). The watershed covers approximately 7700 km^2, of which almost 900 km^2 correspond to the Córdoba city drainage area. The higher basin proceeds from the mountain area named Sierras Grandes (Big Hills). The Suquía River watershed includes the Cosquín River (estimated annual mean flow: 4.5 $m^3 s^{-1}$), San Antonio River (estimated annual mean flow: 3 $m^3 s^{-1}$), Los Chorrillos Brook (estimated annual mean flow: 1.2 $m^3 s^{-1}$) and Las Mojarras Brook (estimated annual mean flow: 0.5 $m^3 s^{-1}$), all flowing into San Roque Dam (Dasso, 1998). The San Francisco and Yuspe Rivers form the Cosquin River. The Icho Cruz and Malambo Rivers converge to form the San Antonio River (Fig. 1). The Suquía River begins at the San Roque Dam and flows mainly from west to east for about 40 km across Córdoba city and then continues up to Mar Chiquita Lake (150 km downstream).

San Roque Dam is an artificial lake where fishing, swimming, and sailing are some activities

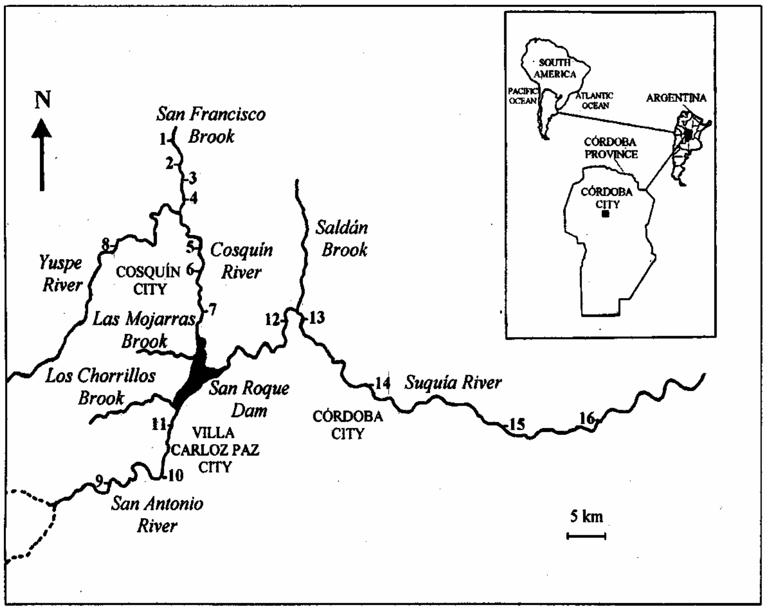

Figure 1. Studied area showing the location of sampling sites. References: 1, Villa Giardino; 2, Huerta Grande; 3, Valle Hermoso; 4, Molinari; 5, Pre-Cosquín; 6, Villa Bustos; 7, Villa Caeiro; 8, Puente Subiría; 9, Cuesta Blanca; 10, San Antonio de Arredondo; 11, Villa Carlos Paz; 12, La Calera; 13, Saldán; 14, Isla de los Patos; 15, Chacra de la Merced; 16, Villa Corazón de María.

practiced in its waters, which promotes an increase in the urbanization of the surroundings of the lake, especially on the coast of the San Antonio River mouth in Villa Carlos Paz city (Wunderlin et al., 2001). It is also the main drinking water source of Córdoba city. The most important city on San Francisco Brook and Cosquín River are La Falda city and the Cosquín city, respectively. Both cities do not have a sewage treatment plant and discharge the domestic effluents without previous treatment directly into the stream. Córdoba city, located 35 km downstream from the dam, has a population of approximately 1.2 million inhabitants of which nearly 500 000 are connected to the city sewage; the rest of the sewage goes into groundwater after home treatment (Pesce & Wunderlin, 2000). In the last 20 years the city has almost doubled its population and many industries have increased the risk of toxic effluents to the river. Near the eastern edge of Córdoba city, the Suquía River receives the city sewage discharge from the Waste Water Treatment Plant of Bajo Grande.

Nowadays, the main problems that the Suquía River Basin is coping are:

1. The negative influences of cattle grazing.
2. Cleaning forest land activities.
3. Sporadic accidental fires or inadequate use of fire.
4. Some agricultural activities at the head and middle sections of the basin.
5. The high population density along the watershed and tourism activities at the most important cities.
6. The presence of the Waste Water Treatment Plant of Bajo Grande located at the end of Córdoba city, which makes an inadequate effluent treatment or discharges wastewaters without previous treatment, directly into the river, when the capacity of the plant is over passed.
7. Clandestine discharges of industrial effluents as well as sewage discharges from residential villages.
8. Sand extraction and sand washing at the eastern edge of Córdoba city, which alter the natural stream habitats through the sediment removal and increase the suspended dissolved material in the aquatic environment.

The headwaters of Suquía River Basin are characterized by rocky substrates, high slope, fast flowing waters with scarce macrophyte cover. The middle sections of the basin present gravel substrate alternated with sandy substrate. Downstream Córdoba city the river presents a high proportion of fine substrates, waters are less faster and the river becomes wider.

The samplings sites were selected according to previous studies which have reported the water quality variations along the Suquía River Basin (Mangeaud, 1998; Bistoni et al., 1999; Pesce & Wunderlin, 2000) and due to the location respect to the most important cities in the watershed. Consequently, we identified areas upstream of cities as sites representative of pristine or near-pristine conditions, and areas at or downstream of cities as hypothetically polluted areas. Sixteen sampling sites were selected (Fig. 1):

- San Francisco River: 1 – Villa Giardino and 2 – Huerta Grande (before La Falda city), 3 – Valle Hermoso and 4 – Molinari (both after the mentioned city).
- Cosquín River: 5 – Cosquín and 6 – Villa Bustos (before and after the Cosquín city, respectively), 7 – Villa Caeiro.
- Yuspe River: 8 – Zuviría Bridge.
- San Antonio River: 9 – Cuesta Blanca and 10 – San Antonio de Arredondo (before Villa Carlos Paz city) and 11 – Villa Carlos Paz (at the mentioned city).
- Suquía River: 12 – La Calera and 13 – Saldán (before Córdoba city), 14 – Isla de los Patos (at the mentioned city), 15 – Chacra de la Merced and 16 – Villa Corazón de María (after Córdoba city).

Materials and methods

Water quality assessment

Following Pesce and Wunderlin (2000), we registered 21 physicochemical parameters on Suquía River Basin in order to characterize the water quality conditions of each site: pH, temperature (°C), conductivity (mS cm^{-1}), alkalinity (mg L^{-1}), dissolved oxygen (mg L^{-1}), carbon dioxide (mg L^{-1}), total solids (mg L^{-1}), ammonia (mg L^{-1}), nitrites (mg L^{-1}), nitrates (mg L^{-1}), chemical oxygen demand (mg L^{-1}l), 5-day biological oxygen demand (mg L^{-1}), total phosphorus (mg L^{-1}), hardness (mg L^{-1}), calcium (mg L^{-1}), magnesium (mg L^{-1}), sulfates (mg L^{-1}), chlorides (mg L^{-1}), total iron (mg L^{-1}), total coliforms and faecal coliforms (MPN · 100 ml: most probable number per 100 ml). Analytical methods were standard (APHA, 1995).

To evaluate the changes in water quality due to combined effects of many parameters we calculated a WQI proposed for Suquía River Basin (Pesce & Wunderlin, 2000) in order to characterize the conditions of sampling sites based on the physicochemical variables. The construction of WQI requires first a normalization step, where each parameter is transformed into 0–100% scale, with 100% representing the highest quality. The next step is to apply weighting factors that reflect the importance of each parameter as an indicator of the water quality. The constructed WQI gives a number that can be associated with a quality percentage, easy to understand for everyone, and based on scientific criteria for water quality.

The calculation was as follows:

$$\mathrm{WQI} = \Sigma(C_i \cdot P_i)|\Sigma P_i$$

C_i is the value assigned to each parameter after normalization. P_i-value range from 1 to 4, with 4 representing a parameter that has the most importance for aquatic life preservation (e.g. dissolved oxygen), while a value of 1 means that such parameters has a smaller impact (e.g. chloride).

Fish data collection

Studied sites were sampled twice during the rainy season (October–March) and twice during the dry season (April–September) per year, from 1998 to 2002. Fish were captured with backpack electrofisher equipment. Collections covered 150 m of stream length. The sampling sites were representative of the overall habitat of the stream reach and they were long enough to encompass several examples of all the major macrohabitat types within the reach (pools, runs, riffles, bend backwaters, side channels, etc.). Individuals were identified to the species level, counted, checked for external deformities, erosion, lesions and tumors (Sanders et al., 1999) and then released alive into the stream.

The abundance of each species were estimated as the number of fish captured per unit area of water surface sampled (m^2) (Paller, 1995; Langford & Hawkins, 1997).

Developing the Biotic Index for the Suquía Basin

The Biotic Index for the Suquía Basin consists in an aggregation of metrics that are based on the fish assemblages, taxonomic and trophic composition, and the abundance and conditions of fishes. We classified the biological parameters according to their sensitiveness or tolerance to the water quality degradation through changes in their distribution, abundance variations, and position in the water column. The metrics considered were the following.

Proportion of total species richness, total abundance, and fish species abundance

The 'proportion of total species richness' was calculated based on the total number of species detected in each river (100%). Both 'proportion of species richness' and 'total abundance' are expected to be reduced as the degradation increases (Karr et al., 1986; Fausch et al., 1990). The 'abundance of each fish species' was also considered as candidate metric.

Proportion of sensitive species and proportion of tolerant species

Based on the metrics suggested by Karr (1981) we considered the 'number of intolerant species' and 'number of tolerant species', both expressed as proportion of the total fish species richness of each sample. Intolerant species are those that are sensitive to environmental stress and tend to be in very low number or absent in those sites with severe environmental degradation. On the contrary, tolerant species are able to tolerate a wide range of water quality conditions and they are often common in highly polluted zones (Karr et al., 1986).

Proportion of individuals as surface, water column and benthic species

Fish species were classified according to their position in the water column in: 'proportion of individuals as surface, water column and benthic species'. 'Proportion of individuals as surface species' comprised *Gambusia affinis*, *Cnesterodon decemmaculatus*, and *Jenynsia multidentata*. These species have morphologic adaptations for water surface respiration (Tagliani et al., 1992), which allows us to consider this metric as an indicator of water degradation. The 'proportion of individuals as water column species' was proposed by Oberdorff & Hughes (1992) in a modification of the Index of Biotic Integrity (IBI) to characterize rivers of the Seine Basin, in France. It comprises active swimmers that typically feed on drifting and surface invertebrates or other fish. In our case this metric was conformed by: *Oligosarcus jenynsi*, *Astyanax eigenmanniorum*, *Bryconamericus iheringi*, and *Cheirodon interruptus*. The 'proportion of individuals as benthic species' was conformed by *Rineloricaria catamarcensis* and *Hypostomus cordovae*. Both water column species and benthic species could be strongly affected by water quality and habitat structure alterations (Oberdorff & Hughes, 1992).

Trophic groups

The trophic structure of fish assemblages has been widely used as indicator of aquatic degradation (Karr, 1981; Angermeier & Schlosser, 1987; Karr et al., 1987; Lyons, 1992; Oberdorff & Hughes, 1992; Mundahl & Simon, 1998; Kamdem Toham & Teugels, 1999; An et al., 2002). Karr et al. (1986) pointed out that alterations in water quality commonly result in changes in fish assemblages due to fluctuating food resources. We assigned fish species to a trophic group following the available literature (Destefanis & Freyre, 1972; Gutiérrez et al., 1983, 1986; Escalante, 1983, 1984; Haro & Gutiérrez, 1985) and use our own data on stomach contents from subsamples of those species that were commonly frequent along the river. Species were assigned to one of the following trophic categories: herbivore – diet usually more than 75% plant material; invertivore – species that typically eat terrestrial and aquatic insects, little crustaceans, oligochaetes and mollusks (Oberdorff & Hughes, 1992); omnivore – diet usually more than 25% plant material and more than 25% animal material; carnivore – eat mainly other fishes and invertebrates in a less proportion; limnivores and detritivore – applied to species that consume animal and/or plant material from mud and detritus from the river bed, respectively.

Proportion of unhealthy fishes

Several authors have pointed out a high incidence of unhealthy individuals as the water degradation increases (Karr, 1981; Karr et al., 1987; Fausch et al., 1990; Sanders et al., 1999). Thus we considered the 'proportion of individuals with diseases, tumors, erosions or skeletal anomalies' as a candidate metric for index calculation.

Statistical analysis

The data distribution were analyzed through the Shapiro–Wilks Index (Sokal & Rohlf, 1979). To identify differences in WQI along the stream courses we performed a one-way analysis of variance. Multiple comparison test was made using the Di Rienzo, Guzmán and Casanoves (DGC) test in order to determine which means differed significantly (Infostat, 2003). The same analysis was applied in order to determine the changes of each metric across different water quality categories. Those metrics with non-normal distribution were analyzed through the non-parametric Kruskal–Wallis test (Infostat, 2003). Candidate metrics that were significantly different between water quality characteristics were considered for the index calculation. When a metric did not differ between reference and impaired sites it was eliminated from further consideration. Once the Biotic Index was developed it was correlated to water quality characteristics through Spearman rank correlation coefficient (Hollander & Wolfe, 1973) and we performed an analysis of variance in order to determine how well it corresponded with estimates of environmental conditions.

Results

Water quality assessment

According to the one-way analysis of variance, significant differences of WQI between sampling sites ($F = 40.97$; $p < 0.0001$) were observed. The multiple comparison test determined four groups that we called water quality categories (WQC: 1–4) and they comprised sites with similar water quality (Table 1). Table 2 shows the mean values of the physicochemical parameters at each WQC.

The WQC 1 is conformed by sites of high water quality (Cuesta Blanca, San Antonio de Arredondo, Villa Carlos Paz, Zuviría Bridge, and Saldán). WQC 2 was classified as having good water quality and it comprised sampling sites with WQI mean values significantly different but slightly lower than WQC 1 (Villa Giardino, Huerta Grande, Villa Bustos, Molinari, Pre-Cosquín, Villa Caeiro and La Calera). Only two sites (Valle Hermoso and Isla de los Patos) conformed WQC 3. These river sections were characterized by low water quality and were classified as moderately degraded sites. WQC 4 also comprised two river sections, Chacra de la Merced and Villa Corazón de María. Both sampling sites were the most affected areas and presented the highest polluted conditions on Suquía River.

Water quality decreased downstream in the San Francisco system, showing the lowest mean value after La Falda city, in Valle Hermoso (Table 1). This sampling site is negatively influenced by the impact of the city and, like other localities situated on San Francisco and Cosquín Rivers, it does not have a wastewater treatment plant, so all the domestic sewages are discharged into the river. The self-purification processes downstream Valle Hermoso and the enter of Yuspe River into Cosquín system promote an increase of WQI from Molinari until the end of the river into San Roque Dam.

The sampling site on the Yuspe River did not show symptoms of alterations. There are no urban settlements on their margins and the physicochemical analyses always indicated high water quality.

Although there are some previous reports of water quality degradation when the San Antonio River crosses Villa Carlos Paz city and flows into San Roque Dam as well as some evidence of deterioration of the water quality of this dam (Scarafia et al., 1995; Pizzolón et al., 1997; Amé et al., 2003), the sampling sites studied on San Antonio River were characterized by high WQI values, indicating pristine or near-pristine conditions.

The river sections studied on Suquía River varied markedly, with a decrease of water quality conditions in downstream sites. Before Córdoba city (in La Calera and Saldán) the mean WQI values were high, indicating pristine or

Table 1. Mean values and standard deviation (SD) of Water Quality Index (WQI)

Sampling Sites	WQI		WQI Categories
	Mean values (%)	SD	
Puente Zuviría	89.58	2.31	1
Cuesta Blanca	89.46	0.64	1
San Antonio de Arredondo	87.71	2.83	1
Villa Carlos Paz	87.46	1.97	1
Saldán	87.80	5.74	1
Villa Giardino	79.97	4.93	2
Huerta Grande	77.63	5.55	2
Molinari	81.04	3.13	2
Pre-Cosquín	83.66	4.52	2
Villa Bustos	81.27	5.53	2
Villa Caeiro	83.96	3.34	2
La Calera	83.99	3.39	2
Valle Hermoso	67.27	2.59	3
Isla de los Patos	72.75	5.33	3
Chacra de la Merced	57.38	5.27	4
Villa Corazón de María	52.21	5.87	4

WQI categories are from the analyses of variance and multiple comparison test. Different numbers indicate significant differences between WQI ($p < 0.05$).

quasi-pristine conditions (Table 1), whereas both Chacra de la Merced and Villa Corazón de María presented the lowest mean WQI values (48.29 and 41.52%, respectively), showing heavily degraded conditions. These sites, located downstream from Córdoba city received the major industrial effluents and municipal waste discharge from the Waste Water Treatment Plant of Bajo Grande.

Fish species and metric selection

A total of 9375 individual fish were collected along the Suquía River Basin and were classified into 21 fish species in 12 families (Table 3).

The data collected for each metric have to be compared with data representative of 'excellent' fish assemblages in pristine sites on a stream of similar size in the same geographic region. The Kruskal–Wallis analyses and one-way analyses of variance were applied in order to know the variability of the biological parameters at each WQC, determined by the WQI. Most of the metrics presented significant differences between WQCs along Suquía River Basin. However, they showed different patterns of variation (Table 4).

The 'proportion of species richness' presented significant differences and showed the highest values at pristine sites (Table 4). These results are in agreement with several authors who point out that species richness increases with the improvement of water quality conditions (Fausch et al., 1990; Oberdorff & Hughes, 1992; Lyons et al., 1995; Paller et al., 1996; Zampella & Bunnel, 1998; Kleynhans, 1999).

The abundance of *O. jenynsi*, *A. eigenmanniorum*, *Ch. interruptus*, *Pimelodella laticeps*, *R. catamarcensis*, and *H. cordovae* was highest in pristine areas (WQC 1) whereas *C. paleatus*, *G. affinis*, and *C. decemmaculatus* presented the highest mean values in the most degraded zones (Table 4).

Both *Trichomycterus corduvense* and *Synbranchus marmoratus* presented the highest mean values at sites with moderate water quality. The former was abundant at WQC 3 and the latter at WQC 2 and 3. *Parodon tortuosus* showed significant differences between WQCs and presented similar abundance values in WQC 1 and 4 (Table 4).

The abundance of *B. iheringi* and *J. multidentata* did not present significant differences along

Table 2. Mean, standard deviation (SD), minimum (Min.) and maximum (Max.) values of physicochemical parameters at each WQI category

Physicochemical parameters	WQI Categories															
	1 (n = 24)				2 (n = 32)				3 (n = 15)				4 (n = 16)			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Temperature (°C)	18.333	4.964	9.000	26.000	18.844	5.441	8.000	27.000	18.833	5.404	8.000	26.000	18.313	5.816	11.0000	28.500
pH	8.015	0.399	6.970	8.800	8.428	0.548	7.000	9.580	8.320	0.426	7.530	8.950	7.569	0.269	7.110	7.960
Conductivity	0.142	0.091	0.020	0.383	0.338	0.155	0.130	0.580	0.507	0.178	0.280	0.863	0.737	0.246	0.410	1.150
Dissolved oxygen	9.821	1.487	8.000	12.400	10.075	1.862	8.000	14.800	10.273	2.186	7.500	16.000	5.163	1.956	2.500	8.800
5-DBO	0.784	0.403	0.250	1.600	1.265	0.737	0.450	3.600	2.464	1.573	0.750	5.500	3.102	1.721	1.444	8.550
COD	19.610	10680	8.096	53.72	17.270	12.439	0.000	53.720	20.636	10.884	8.000	37.550	53.112	29.988	19.760	119.250
Carbon dioxide	1.706	1.189	0.200	5.000	2.267	4.097	0.000	20.000	1.974	2.167	0.260	8.000	9.025	6.261	3.000	20.500
Ammonia	0.194	0.167	0.000	0.640	0.376	0.207	0.101	0.953	0.507	0.408	0.026	1.567	4.041	4.844	0.332	17.420
Nitrites	0.006	0.012	0.000	0.059	0.042	0.093	0.002	0.440	0.364	0.993	0.003	3.910	0.308	0.217	0.107	0.768
Nitrates	1.233	3.208	0.130	15.925	1.677	1.930	0.145	9.570	5.530	6.742	0.982	23.830	5.203	7.374	0.268	26.770
Total phosphorous	0.057	0.077	0.000	0.309	0.085	0.080	0.000	0.296	0.121	0.163	0.000	0.538	1.005	0.595	0.346	2.889
Total hardness	58.388	34.674	14.058	163.770	126.493	52.311	57.420	215.660	190.426	70.219	114.590	363.220	225.577	53.601	145.940	340.510
Calcium	16.323	8.769	3.450	40.810	35.569	15.261	13.890	62.020	63.025	50.909	23.730	216.200	62.686	14.719	42.890	96.180
Magnesium	4.501	3.122	1.320	15.051	9.552	4.995	1.560	19.060	16.666	7.269	8.940	35.750	16.633	4.392	9.460	24.450
Alkalinity	74.542	28.642	24.000	140.000	155.531	65.718	75.000	282.000	170.267	60.386	90.000	285.000	161.000	19.201	128.000	195.000
Chlorides	5.593	2.671	2.483	11.320	11.849	5.242	4.110	22.298	28.329	12.596	12.030	54.620	60.516	27.001	25.4000	127.000
Sulfates	11.920	8.793	2.514	29.635	26.996	11.169	9.810	54.940	61.097	42.579	22.070	165.490	135.386	47.152	64.800	217.750
Total iron	0.034	0.028	0.000	0.083	0.050	0.053	0.000	0.216	0.046	0.071	0.000	0.280	0.118	0.120	0.000	0.479
Total solids	101.25	46.299	38.000	232.000	226.775	115.559	46.000	420.000	351.200	121.964	186.000	594.000	528.188	201.516	306.000	1145.000
Total coliforms	2.714	6.349	0.050	31.000	3.242	5.942	0.055	31.000	17.524	12.841	2.800	38.000	566.708	710.250	15.000	2400.000
Faecal coliforms	0.543	0.651	0.000	2.180	1.635	4.242	0.022	24.000	11.201	9.979	0.440	30.000	207.531	195.994	15.000	760.000

Values in mg L^{-1}; bacteria correspond to E + 3 exponential values (i.e. 2.3 = 2300) and are expressed as MNP·100 ml^{-1} (most probable number per 100 ml).

Table 3. Distribution and abundance (number of individuals·m^{-2}) of fish species collected at each sampling site along the Suquía River Basin.

Family and Species	Abundance of fish species along Suquía River basin															
	San Francisco Brook				Cosquín River			Yuspe River	San Antonio River			Suquía River				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Salmonidae																
Oncorhynchus mykiss (I)									0.0110							
Characidae																
Oligosarcus jenynsi (I)		0.0016			0.0245		0.0900	0:0064	0.0091	0.1007	0.0521	0.0113				
Astyanax eigenmanniorum (I)	0.0818	0.0521			0.0367	0.0082	0.0025	0.0096		0.2222	0.0932	0.2841	0.0317		0.0085	0.0044
Astyanax cordovae (I)													0.0049			
Bryconamericus iheringi (I)	0.8364	0.4234	0.9910	0.1050	0.0531	0.0103		0.1568	0.1180	0.0208	0.0122	0.2596	0.3421	0.1630	0.0866	0.0653
Cheirodon interruptus		0.0348		0.0200	0.0122	0.0493	0.4875	0.0016			0.0369	0.0394		0.0025	0.0085	0.0044
Erythrinidae																
Hoplias malabaricus (C)												0.0045		0.0049		
Hemiodidae																
Parodon tortuosus (H)													0.6061	0.0938	0.0219	
Pimelodidae																
Pimelodella laticeps (C)	0.3273	0.0142		0.0200	0.0980	0.0308	0.4450	0.0176		0.0035	0.0082	0.0180	0.0229			
Pimelodus albicans (C)														0.0025		
Rhamdia sapo (C)			0.0272	0.0050		0.0082	0.0025				0.0061	0.0271	0.0088			
Trichomycteridae																
Trichomycterus corduvense (I)	0.0091	0.0016	0.0272										0.1637	0.3580	0.0125	0.0044
Callichthydae																
Corydoras paleatus (D)												0.1804	0.0267	0.0790	0.0362	0.1099
Loricariidae																
Rineloricaria catamarcensis (L)	0.0545	0.0284	0.1239	0.0317	0.1224	0.0205	0.0525	0.0400	0.0259	0.0868	0.1805	0.1534	0.2105	0.0420	0.0405	0.0044
Hypostomus cordovae (L)	0.3727	0.0664	0.1299	0.1067	0.0776	0.0862	0.0225	0.1872	0.0921	0.1632	0.2771	0.0857	0.8706	0.2765	0.1563	0.0455
Anablepidae																
Jenynsia multidentata (I)	0.1273	0.1232	0.1027	0.0050	0.0449	0.2916	0.0075	0.2128	0.0558	0.4896	1.0257	2.1170	0.1309	0.6617	0.8545	2.5081

Continued on page 288

Table 3. (Continued)

Family and Species	Abundance of fish species along Suquía River basin															
	San Francisco Brook				Cosquín River			Yuspe River	San Antonio River			Suquía River				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Poeciliidae																
Gambusia affinis (I)												0.2032	0.0149	0.0222	0.9945	0.1343
Cnesterodon decenmaculatus (I)	0.7327	0.0411	0.4622	0.0050	0.0041	0.0123		0.0064	0.0013			0.2822	0.0288	0.0494	0.8479	0.3503
Phalloceros caudimaculatus (I)	0.0182															
Synbranchidae																
Synbranchus marmoratus (I)	0.0091	0.0095	0.0091		0.0082	0.0493	0.0025					0.0023		0.0099	0.0172	
Cichlidae																
Cichlasoma facetum (O)		0.0095						0.0016				0.0181		0.0022		

The letters between parentheses indicate the trophic group category (D: detritivore, H: herbivore, I: invertivore, L: limnovore, O: omnivore, P: piscivore). References: San Francisco Brook: 1, Villa Giardino; 2, Huerta Grande; 3, Valle Hermoso; 4, Molinari; Cosquín River: 5, Pre-Cosquín; 6, Villa Bustos; 7. Villa Caeiro; Yuspe River: 8, Puente Subiría; San Antonio River: 9,Cuesta Blanca, 10. San Antonio de Arredondo, 11, Villa Carlos Paz; Suquía River: 12, La Calera; 13, Saldán; 14, Isla de los Patos; 15, Chacra de la Merced; 16. Villa Corazón de María.

the environmental gradient, however *B. iheringi* showed its highest abundance at pristine or near pristine sites (WQC 1 and 2) (Table 4). Bistoni et al. (1999) have classified *B. iheringi* as a sensitive species. They indicated that its abundance decreased significantly with the increase of water quality degradation in Suquía River. On the other hand, *J. multidentata* presented high abundance values at both pristine and impaired sites (Table 4).

A fish species could be considered as intolerant if its abundance or distribution has been drastically reduced or if it is retricted to high water quality sites. According to the performed analyses, *O. jenynsi*, *A. eigenmanniorum*, *B. iheringi*, *Ch. interruptus*, *P. laticeps*, *R. catamarcensis*, and *H. cordovae* were considered as intolerant species; *P. tortuosus*, *T. corduvense* and *S. marmoratus* corresponded to moderate tolerant species and *C. paleatus*, *G. affinis*, *C. decemmaculatus*, and *J. multidentata* were considered as tolerant species. *Phalloceros caudimaculatus*, which also belongs to Poeciilidae family, was not considered in the analyses because it registered only two female individuals along the study.

The metric 'number of individuals in a sample' evaluates population (Karr et al., 1986) and it is expressed as abundance per unit area sampled. Impaired sites are generally expected to support fewer individuals that reference sites. However, the total abundance did not differ between WQCs (Table 4). This metric showed a great variation at polluted sites, reaching extremely high values in several samples or presenting few or no fish at all. These results agree with Seegert (2000), who pointed out the same disadvantage when this parameter is used as indicator of water quality conditions. The high variability that total abundance presented suggests that it is not a reliable metric to be used in a multimetric biological index.

In one collection carried out in one of the most impaired sites (Chacra de la Merced), the highest total abundance represented by 400 individuals was observed. In this occasion the dominance corresponded to the three surface species; *G. affinis*, *C. decemmaculatus*, and *J. multidentata*. These fishes, which belong to the order of Cyprinodontiformes (Costa, 1998), always dominated those sites altered by wastewater discharges and tolerated chronic conditions of hypoxia. Tagliani et al. (1992) have indicated that the vertical distribution of the Family Poeciliidae is restricted to the first centimeters of the water column, and show morphologic adaptations to the aquatic surface respiration, such as small size and mouth turned upwards. The same features are present in *J. multidentata*, which belongs to the Family Anablepidae. These characteristics allow these species to tolerate the low oxygen concentrations registered in the most polluted sites. On the other hand, these species are characterized by their viviparity and high reproductive effort. Since they do not produce eggs (which need high oxygen concentrations for their development) and can tolerate hypoxic conditions, they do not find restrictions to reproduction and survivorship in altered environments. Rupp (1996) indicated that the viviparity condition of *Gambusia* sp. which is a non-native species of Suquía River Basin, may give to this fish an advantage over native oviparous species, because their fry are larger, feed at birth, grow more quickly and become predators faster. These characteristics are also present in the native fish *C. decemmaculatus* and *J. multidentata* and become an important advantage over other native species. Therefore, the three fish species are able to resist the aquatic pollution registered in Suquía River Basin and they have to be considered as tolerant species.

The analyses of variance showed that the species grouped according to their position in the water column presented significant differences between WQCs (Table 4). The 'proportion of individuals as surface species' showed the highest mean abundance at the most severe polluted waters (WQC 4), but they present similar mean values between the remaining categories (Table 4). The lowest mean of the 'proportion of individuals as water column species' corresponded to the most degraded zones (WQC 4). A similar pattern was observed in the variation of the 'proportion of individuals as benthic species' (Table 4). However, the multiple comparison test indicated that the 'proportion of individuals as surface species and water column species' were not able to distinguish between high and moderate water quality. The 'proportion of individuals as benthic species,' which presented the highest mean abundance at WQC 1, did not discriminate between WQC 2 and the most severe polluted waters (WQC 3 and 4). Based on these results it was decided not to

Table 4. Mean and standard deviation (SD) of candidate metrics at each WQI category

Candidate metrics	WQI Categories								
	1		2		3		4		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*p*-value
Abundance of									
O. jenynsi	0.0070	0.0164	0.0040	0.0106	–	–	–	–	*
A. eigenmanniorum	0.0149	0.0302	0.0145	0.0229	–	–	0.0008	0.0019	*
B. iheringi	0.0271	0.380	0.0526	0.0988	0.0769	0.1185	0.0095	0.0092	
Ch. interruptus	0.0016	0.0055	0.0201	0.0628	0.0002	0.0006	0.0008	0.0017	*
Parodon sp.	0.0253	0.0646	—	—	0.0063	0.0088	0.0014	0.0045	*
P. laticeps	0.0022	0.0043	0.0298	0.0592	—	—	—	—	*
T. corduvense	0.0068	0.0147	0.0003	0.0016	0.0251	0.0281	0.0011	0.0027	*
C. paleatus	0.0011	0.0025	0.0058	0.0120	0.0053	0.0085	0.0091	0.0143	*
R. catamarcensis	0.0227	0.0203	0.0145	0.0146	0.0111	0.0264	0.0028	0.0055	*
H. cordovae	0.0663	0.0746	0.0256	0.0471	0.0271	0.0294	0.0126	0.0232	*
J. multidentata	0.0798	0.0831	0.0849	0.1399	0.0510	0.0740	0.2102	0.3325	
G. affinis	0.0006	0.0022	0.0063	0.0219	0.0015	0.0028	0.0706	0.1245	*
C. decemmaculatus	0.0015	0.0035	0.0338	0.0858	0.0341	0.0805	0.0749	0.1064	*
S. mamoratus	–	–	0.0014	0.0030	0.0013	0.0021	0.0011	0.0022	*
Total abundance	0.2579	0.1521	0.2961	0.2873	0.2416	0.1654	0.3951	0.4150	
Species richness (%)	54.1037	13.4781	52.8975	12.0288	43.4920	6.0193	36.4000	14.2116	*
Number of individuals as surface species (%)	32.5867	28.4966	33.8897	29.4340	31.0545	25.4669	69.6163	33.9886	*
Number of individuals as water column species (%)	21.5067	20.9391	29.7210	22.4082	24.7038	28.5816	5.7496	8.9171	*
Number of individuals as benthic species (%)	45.6336	14.5757	48.1837	18.5278	56.3571	11.1906	37.1034	14.3358	*
Number of sensitive species (%)	68.1612	15.5690	67.2777	16.6496	41.9127	12.2208	35.4544	17.7659	*
Number of tolerant species (%)	26.7956	14.8015	27.5503	11.8651	56.5873	13.0191	61.5648	23.4681	*

The results obtained from the Kruskal–Wallis test and one way analysis of Variance between biological variables and water quality categories are shown in the last column (*$p < 0.05$). Abundance values are expressed as the number of individuals·m^{-2}.

Table 5. Scoring criteria for metrics used to calculate the Biotic Index for Suquía River Basin

Metric	Criteria for each scoring category			
	Very poor 1	Poor 2	Fair 3	Good 4
Abundance of *A. eigenmanniorum*	0.00–< 0.01		0.01–0.012	> 0.012
Abundance of *R. catamarcensis*	0.00–< 0.01	0.01–< 0.02	0.02–< 0.11	> 0.11
Abundance of *G. affinis*	> 0.49			0.00–< 0.49
Abundance of *C. decenmaculatus*	> 0.38	0.01–< 0.38		0.00–< 0.01
% Number of sensitive species	0.00–< 42.86	42.86–< 60.00	60.00–< 75.00	75.00–100.00
% Number of tolerant species	53.85–100.00	36.36–< 53.85	20.00–< 36.36	0.00–< 20.00

Abundance values are expressed as the number of individuals·m^{-2}.

consider the mentioned metrics in the Biotic Index calculation.

The knowledge of the tolerance of fish species is limited for Suquía River Basin, but it can be suggested by the patterns they manifest along an environmental gradient. According to the results obtained through the Kruskal–Wallis analyses the 'proportion of sensitive species richness' and 'proportion of tolerant species richness' presented significant differences between WQCs. They were able to discriminate between sites characterized by high water quality and those with degraded conditions (Table 4).

The variation patterns of trophic groups that have been observed along environmental quality gradient in rivers of the North Hemisphere (Karr et al., 1986; Fausch et al. 1990) do not agree with our findings in Suquía River Basin. The groups were not efficient indicators of water quality characteristics, due to the low trophic diversity. Fish classified as 'omnivores' by the literature demonstrated to be 'invertivores' according to our analyses (Table 2). These fishes typically eat crustaceans, oligochaetes and mollusks, as well as insects (Karr et al., 1986; Oberdorff & Hughes, 1992). *Rineloricaria catamarcensis* and *H. cordovae* are recognized as 'limnivore species' while *C. paleatus* has been classified as a 'detritivore species.' The 'herbivore group' was represented only by one species, *P. tortuosus*. The 'carnivore group' comprised four species: *H. malabaricus, P. laticeps, P. albicans* and *R. quelen* and it was poorly represented as *H. malabaricus, P. albicans*, and *R. quelen* were occasionally registered. Based on these results, we do not recommend the use of trophic groups as bioindicators of Suquía River

Table 6. Spearman rank correlation coefficient (r) between each metric and the Biotic Index for Suquía River Basin ($^*p < 0.05$)

Metrics	r	p-Value
Abundance of *A. eigenmanniorum*	0.314	0.0031*
Abundance of *R. catamarcensis*	0.496	0.0000*
Abundance of *G. affinis*	−0.407	0.0000*
Abundance of *C. decenmaculatus*	−0.352	0.0008*
% Number of sensitive species	0.807	0.0000*
% Number of Tolerant species	−0.752	0.0000*

Basin quality. These trophic metrics could cause a loss of information when a wide range of fish species that inhabits different habitat types and have different morphological characteristics are grouped in the same feeding metric.

Polluted sites are expected to have high proportions of unhealthy individuals (Sanders et al., 1999). We registered a similar incidence of anomalies in both pristine and polluted river sections, thus we decided to omit this metric.

The 'proportion of hybrids' has been a widely used metric in the IBI estimation. Karr et al. (1986) indicated that this metric is useful to assess the extent to which degradation has altered reproductive isolation among species. However, we did not consider it because the presence of hybrids in the fish fauna of Cordoba Province is unknown.

Calculation of the Biotic Index

According to the earlier performed analyses, we selected a first set of metrics based on the statistical analyses and the displayed variation patterns. It comprises the following variables:

- Indicators of high water quality: abundance of *O. jenynsi*, *A. eigenmanniorum*, *R. catamarcensis* and *H. cordovae*, proportion of species richness and the proportion of sensitive species richness.
- Indicators of low water quality: abundance of *G. affinis* and *C. decemmacultus* and the proportion of tolerant species richness.

The predicted values for the scoring criteria were established by comparison with minimally disturbed sites in streams of similar ecological characteristics and zoogeographic region. The assigned scores indicate whether the index values approximate, deviate somewhat or strongly from those values expected at reference sites.

Metrics were categorized by dividing into percentiles (P25, P50 and P75). Thus, four categories were obtained for each of them (excellent, good, fair, and poor quality). A score of 4 was assigned to values that represent the best reference conditions; a score of 3 and 2 to values that represent some reduce and good quality conditions, respectively, and a score of 1 to those values that indicated the greatest deviation from those expected in reference sites.

Table 7. Mean Biotic Index values and standard deviation (SD) for each sampling site along Suquía River Basin

Sites	Biotic Index		Biotic Index group
	Mean values (%)	SD	
San Antonio de Arredondo	97.22	4.81	1
Pre-Cosquín	86.67	4.56	1
Villa Carlos Paz	83.93	11.39	1
Villa Caeiro	79.17	0.10	1
Puente Zuviría	73.61	10.49	2
Molinari	73.61	2.41	2
Cuesta Blanca	69.79	3.99	2
Huerta Grande	69.17	7.57	2
La Calera	65.10	12.78	2
Villa Bustos	65.00	7.57	2
Saldán	64.29	7.16	2
Villa Giardino	63.89	6.36	2
Valle Hermoso	56.67	12.71	3
Isla de los Patos	46.25	9.10	3
Villa Corazón de María	35.94	12.59	4
Chacra de la Merced	32.81	16.28	4

Different numbers indicate significant differences between Biotic Index values ($p < 0.05$).

To produce a total sample score, the scores of each metric were summed and the values obtained were transformed into percentage, taking as 100% the maximum value that the sum could reach. Each metric was tested through its absence or presence in the index calculation until the best set of metrics that significantly differentiates the water quality registered along Suquía River Basin was obtained. Analysis of variance was used in order to determine whether the new Biotic Index was able to distinguish different water quality conditions.

Six of the nine metrics selected for the Biotic Index estimation accounted for the most important water quality differences and were considered as the best indicators of species–environment relationships (Table 5). This set of metrics was conformed by: the abundance of *A. eigenmanniorum*, *R. catamarcensis*, *G. affinis* and *C. decemmacultus*, the proportion of sensitive species richness and the proportion of tolerant species richness. They clearly distinguished between the impaired and referenced sites.

Based on the selected metrics, the maximum score that the Biotic Index could reach is 24 (100%) while the minimum value is 0, which indicates the worst quality condition where no fish could live. The overall strength of the relationships between individual metric and total Biotic Index scores for all samples was assessed through non-parametric Spearman's rank correlation coefficient. According to the correlation coefficient, the six metrics were correlated significantly with the Biotic Index value (Table 6). The proportion of sensitive species richness and the proportion of tolerant species richness showed the strongest correlation with the new index.

The mean values and the standard deviations of the Biotic Index of each site are shown in Table 7. The variation pattern of the new index along the studied basin is shown in Fig. 2. The new index completely based on biological information, identified an environmental gradient and it was significantly different among sampling areas ($F = 17.19$; $p < 0.001$). Impaired sites did have significantly lower scores than reference sites. The multiple comparison test yielded four groups, which were conformed by river sections with similar fish assemblages characteristics and, consequently, with similar environmental conditions (Table 7).

Group 1 comprised high quality sites: San Antonio de Arredondo, Pre-Cosquín, Villa Carlos Paz and Villa Caeiro. Group 2 was conformed by Zuviría Bridge, Molinari, Cuesta Blanca, Huerta Grande, La Calera, Villa Bustos, Saldán and Villa Giardino. Group 3 comprised only two sites: Valle Hermoso and Isla de los Patos. According to the Biotic Index values, these sampling sites were

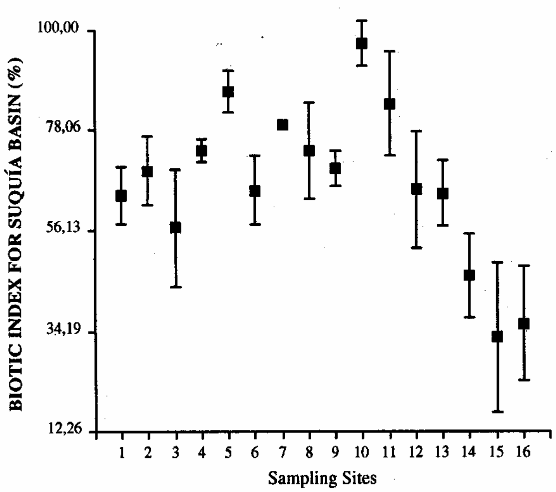

Figure 2. Pattern of variation of the Biotic Index along Suquía River Basin. References: 1, Villa Giardino; 2, Huerta Grande; 3, Valle Hermoso; 4, Molinari; 5, Pre-Cosquín; 6, Villa Bustos; 7, Villa Caeiro; 8, Puente Zubiría; 9, Cuesta Blanca; 10, San Antonio de Arredondo; 11, Villa Carlos Paz; 12, La Calera; 13, Saldán; 14, Isla de los Patos; 15, Chacra de la Merced; 16, Villa Corazón de María. ⊥ Standard deviation, ■ Mean.

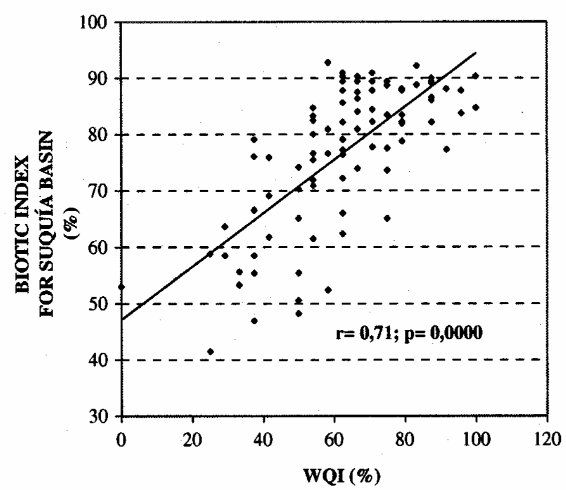

Figure 3. Spearman rank correlation coefficient (*r*) between the Biotic Index for Suquía River Basin and the Water Quality Index (WQI).

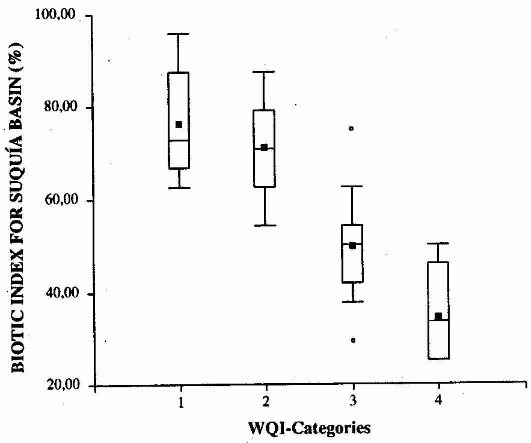

Figure 4. Box and whisker plot showing the variation pattern of the Biotic Index for Suquía River Basin through the Water Quality Categories (WQCs). References: ⊥ Standard deviation, Standard error, ■ mean.

classified as moderate altered areas. Finally, Chacra de la Merced and Villa Corazón de María conformed group 4. Fish assemblages of these sites demonstrated the severe alteration of the aquatic environment, which was reflected by the lowest Biotic Index values (32.81 and 35.94%, respectively).

The proposed Biotic Index version for Suquía River Basin was sensitive to changes in water quality characteristics. The new index displayed a strong relationship to the WQI values ($r = 0.71$; $p < 0.000$) (Fig. 3). However, sampling sites of groups 1 and 2 are not the same than those proposed by WQI. Some areas that were classified as WQC 1 by WQI (Table 1), belonged to group 2 of the Biotic Index classification (Table 7). This situation only occurred with the highest quality sites. The remaining sites (WQC 3 and 4; Biotic Index groups 3 and 4) were classified in the same manner for both indexes.

According to the analysis of variance, mean Biotic Index scores were significantly different among WQCs 2–4, but were not distinctive between WQC 1 and 2 ($F = 47.00$; $p < 0.0001$; Fig. 4). We took as an advantage the ability of the proposed Biotic Index to discriminate the moderate and severe polluted sites than those with pristine and quasi-pristine conditions. Thus, we recommend a further refinement and modification of this index that will make possible to separate sites with excellent water quality from those with good water quality.

Discussion

Water quality can be determined using different approaches, including the variation of chemical, physical, and biological parameters along a river basin. Despite the usefulness of chemical and physical parameters, they do not predict the changes in aquatic living systems and give partial information of the overall quality.

Karr et al. (1986) pointed out that the strength of the IBI is its ability to integrate information from individual, population, community, zoogeographic, and ecosystem levels into a single ecologically based index of the quality of a water resource. The assessment of river health through the application of the IBI, proposed by Karr (1981), has been successfully used in different regions of the world like France (Oberdorff & Hughes, 1992; Oberdorff & Porcher, 1994; Oberdorff et al., 2002), Mexico (Lyons et al., 1995; Soto-Galera et al., 1998), Africa (Kandem Toham & Teugels, 1999, Kleynhans, 1999); Australia (Harris, 1995), Guinea (Hugueny et al., 1996), and Venezuela (Gutiérrez, 1994).

Seegert (2000) indicated that each investigator must determine what metrics work in his/her geographic area and develop appropriate scoring cutoffs for each metric. Since the limitations of each aquatic system must be taken into account, we had to select metrics that clearly distinguished between high water quality and low water quality sites and to determine appropriate scoring criteria. Bistoni et al. (1999) highlighted a strong relationship between water quality characteristics and changes in fish assemblage structure in the Suquía River Basin. Based on this first approach and the results obtain from our work, the set of variables identified by the statistical analyses represents different biological responses of fish assemblages to water quality degradation along the system.

In Argentina, few attempts have been made to quantify the impact of human activities on the biological status of aquatic resources. Menni et al. (1984, 1996) were the first authors who described the relationship between water chemistry and the occurrence and distribution of fishes in several regions of Argentina. Despite providing new insights in the studies of the fish fauna, these papers did not establish changes of fish assemblages in relation to water degradation. Bistoni et al.

(1999) determined the fish community attributes that consistently changed with water quality degradation in Suquía River and analyzed the influence of physicochemical variables on fish species. This work was the first research that attempted to provide useful information for management and protection of water resources.

Effective conservation is further hindered by the lack of a comprehensive scientific knowledge to support it (Kandem Toham & Teugels, 1999). The scarcity of previous studies about biotic integrity of rivers in Córdoba Province makes difficult to find reference sites and to infer the fish assemblage characteristics in the past. Thus, a sound ecological management framework of our water bodies is needed. Based on the significant need to establish water quality monitoring programs, we decided to perform a preliminary Biotic Index for Suquía River Basin based on the IBI proposed by Karr (1981).

Through the application of the Biotic Index we assessed the impact of urban activities represented by sewage discharge, run-off, and non-point pollution. The proposed index consists in a multimetric approach, gives a holistic view on the fish assemblage integrity and accurately reflects a spatial pattern in water quality of Suquía River Basin. This multimetric technique based on biological data, resulted to be an excellent tool for evaluating and comparing environmental health among sites. The biological variables used in the index calculation are easy estimates to obtain and allow a clear differentiation between stations with different water quality conditions as it was shown by the Biotic Index values.

Our findings indicated that human activities have greatly altered the environmental characteristics of Suquía River Basin. The upper sections of the basin were characterized by high Biotic Index values, which indicated pristine water conditions. Conversely, the areas located at or downstream of urban zones were characterized by degraded water quality conditions, as it was shown by the lowest Biotic Index values. Few species found favorable conditions for their establishment in degraded zones, which is in agreement with Bistoni et al. (1999). Fish assemblages changed with increasing water degradation, displaying a simpler structure in the most polluted sites. Our study demonstrated that the system had experienced a severe environmental degradation after Córdoba city. This urban center exerts the most negative impact on water quality of Suquía River. The different pollution sources and the sewage discharges from the wastewater treatment plant are the main cause of the altered conditions. Chacra de la Merced is the first site that suffers the strongest influence of urban run-off and domestic sewage discharges. On the other hand, Villa Corazón de María, located 16 km downstream Chacra de la Merced maintained severe water pollution since it receives the discharge of the Interfactory Channel that collects the effluents of the industries located at this zone. The degradation registered exceeds the river dilution and self-purification capacity (Honorable Municipal Commission, 1998).

The results obtained through the Biotic Index application reflect the water quality conditions characterized by WQI and they are in agreement with those obtain from previous studies carried out by Pesce & Wunderlin (2000) and Wunderlin et al. (2001) who based their work on physicochemical characteristics only. Fausch et al. (1990) pointed out that perturbations caused by human activities often interact in complex ways and influence the aquatic ecosystems, thus they can rarely be assessed by using only physicochemical variables as indirect measures of the aquatic biota health. The use of Biotic Index is a feasible tool, which allows assessing changes in the water quality by interaction of multiple biological parameters scored with consideration of basin singularity. The basic conceptual framework of the Biotic Index we proposed is valid for the central part of Córdoba Province. Both, the metrics and the scoring criteria, need to be refined and modified to be used in other areas of our country. Furthermore, many more data about fish species life history, trophic and reproductive ecology and sensitiveness or tolerance to environmental degradation are needed. This information will allow a better understanding about fish assemblage variation in relation to environmental quality changes. Although the Biotic Index we proposed has some limitations, it can also be used as monitoring and evaluation tool to identify stream sections where restoration activities could be needed.

Conclusions

In the present paper we proposed a preliminary Biotic Index for Suquía River Basin. We demonstrated that it is possible to use fish as indicators of water quality in Córdoba Province in order to carry out rapid and relatively inexpensive monitoring programs. Although it needs further refinement, its application showed that fish assemblages reflected the watershed conditions and demonstrated to be sensitive to changes in water quality across the environmental gradient. This valuable tool is an easy applicable method to describe the compositional, structural and functional changes that occur in fish assemblages as the biotic integrity of aquatic ecosystems becomes impaired, but it is also sets quantitative criteria that enable the investigators to determine the water quality state and the citizens to know and understand the environmental conditions of Suquía River Basin.

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