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Temporal and spatial variability of fish assemblages in a river basin with an environmental degradation gradient

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Abstract: We analyzed long-term data related to temporal and spatial variation in fish assemblages from five sites along the Suquía River Basin (Córdoba, Argentina). We aimed at determining whether water quality variations generate changes in fish assemblage structure and composition along the river. Despite deterioration of water quality recorded along the basin, fish assemblages were characterized as qualitatively persistent and quantitatively stable, indicating that the specific composition were relatively constant over time. However, on a temporal scale, fish assemblages from the most polluted areas responded to the water quality degradation with a greater variation of species abundance than those from pristine sites. On a spatial scale, changes in fish assemblage structure were related with watershed disturbance gradient and indicated a strong association between fish species distribution and water quality variation. The alterations found in our study suggest a potential imbalance of fish assemblage structure in the long term.

Introduction

Streams are complex ecosystems that depend on a large variety of dynamic processes involving biological communities and physical and chemical domains. Impacts caused by human activities tend to alter the ecosystem functioning, leading to deviations from the potential natural status (Siligato and Böhmer 2002). It is necessary to understand natural temporal variability before developing testable hypotheses about parameters that affect assemblage structure. Understanding the consequences of stress and disturbance may help to predict the effects of altered water quality on a river system (Meffe and Berra 1988).

As commonly defined in ecology, stability can include resistance and resilience. Resistance is the ability of a system to remain unchanged in the face of external influences and resilience concept involves the rapidity with which a system returns to a previous equilibrium after a perturbation (Wu and Loucks 1995, Dunham et al. 2003). Species assemblages can also show stability. Persistence is also related to assemblage stability and is defined as a continued presence or absence of species over time. Assemblage stability and persistence of assemblages across time are both spatially and temporally scale dependent (Matthews 1998), but such information is lacking for most stream types.

The abundance and richness characteristics of fish assemblages and the abundances of individual species may fluctuate differently across spatial and temporal scales (Smith et al. 1999, Greenfield and Bart 2004). Connel and Sousa (1983) indicated that the temporal analysis of assemblage structure is more meaningful if 1) the system experiences disturbances of a magnitude that could potentially disrupt structure; and 2) the time period of analysis covers more than one generation. Moreover, abundance of individual species may rise and fall in response to both abiotic and biotic (density dependent) factors, but some species persist, barring unusual (often anthropogenic) changes in the environment (Matthews 1998).

The knowledge of fish fauna in the Province of Córdoba (Central Argentina) has increased noticeably in the last few years through investigations being conducted with special emphasis on the fish species richness of its main rivers (Menni et al. 1984, Haro and Bistoni 1996, Hued and Bistoni 2001, 2005, 2007, Bistoni and Hued 2002). However, studies on the status of the structure and function of fish assemblages in both near-pristine and polluted environments are scarce.

Córdoba city has a population of approximately 1.2 million inhabitants, of which only 500,000 people have access to the public sewage system. The main sewage goes into the groundwater after home treatment. The city has almost doubled its population in the last 20 years and has many new industries that discharge toxic effluents into the river (Pesce and Wunderlin 2000). This creates a strong water quality gradient on the river and consequently alters longitudinal fish assemblage structure (Bistoni et al. 1999, Hued and Bistoni 2005). Water quality conditions and fish assemblage characteristics of the Suquía have also become an important issue because this river flows into Mar Chiquita Lake, one of the largest saline lakes in the world. This water body, together with the swamps of the Dulce River on its northern shore and the mouths of the Suquía and Xanaes rivers, has been designated as an area for conservation and wise use of wetlands resources (Ramsar Convention Bureau 2002). This site, ranging from freshwater to very saline environments, is considered as one of the most important wetlands in Argentina in terms of biodiversity richness.

Understanding Neotropical ichthyofauna is a prerequisite to evaluating and predicting the consequences of human impacts on this freshwater ecosystem. Our main objective was to analyze long-term data in order to describe temporal and spatial variation in fish assemblages from five sites on the Suquía River, and to test the hypothesis that greater temporal variation and differences of fish assemblages on a spatial scale will occur in polluted than near-pristine areas.

Materials and methods

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 upper basin proceeds from the mountain area of the Sierras Grandes. The Suquía River watershed includes the San Francisco Brook, Cosquín River, San Antonio River, Los Chorrillos Brook and Las Mojarras Brook, all flowing into San Roque Dam (Fig. 1). The Suquía River begins at this dam and flows mainly from west to east for about 40 km across Córdoba city and then continues to Mar Chiquita Lake (150 km downstream).

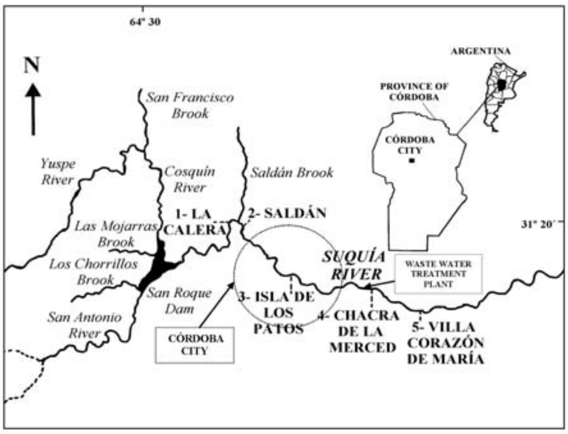

Figure 1. Study area showing the location of sampling sites. References: 1–La Calera and 2–Saldán (upstream of Córdoba City), 3–Isla de los Patos (in the center of the city), 4–Chacra de la Merced, and 5–Villa Corazón de María (located downstream of the city and of the Bajo Grande Sewage Treatment Plant). Sites 3, 4, and 5 are influenced by urbanization and anthropogenic activities.

San Roque Dam is an artificial lake and a popular recreation site (for fishing, swimming and sailing). Human presence and urbanization lead to an increased nutrient load, especially on the borders of the San Antonio River mouth in the city of Villa Carlos Paz (Wunderlin et al. 2001). The dam is also the main drinking water source of Córdoba city. The most important cities on the San Francisco Brook and the Cosquín River are La Falda and Cosquín. Neither city has a sewage treatment plant and directly discharge the domestic effluents, without previous treatment, into the stream. In Córdoba city, located 35 km downstream from the dam, only 42% of the population have access to the city sewage; the rest of the sewage goes into groundwater after home treatment (Pesce and Wunderlin 2000). Many industries have increased the risk of toxic effluents flowing into the river and near the eastern edge of the city, the river receives the city sewage discharge from the Waste Water Treatment Plant of Bajo Grande.

Nowadays, the main causes of water quality degradation in the Suquía River basin are: waste waters from the Treatment Plant of Bajo Grande, clandestine discharges of industrial effluents, sewage discharges from residential villages, and sand extraction and washing at the eastern edge of Córdoba. These latter alter the natural stream habitats through the sediment removal, increasing the suspended dissolved material in the aquatic environment.

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

Sampling sites were selected according to previous studies which have reported the water quality variations along Suquía River Basin (Mangeaud 1998, Bistoni et al. 1999, Pesce and Wunderlin 2000, Hued and Bistoni 2005). These gradients were linked to the location with respect to the largest cities in the watershed. Consequently, we identified areas upstream of cities as sites representative of near pristine conditions, and those near the cities, or downstream of them, as polluted sites.

To compare temporal and spatial variations of fish assemblage structure, five sites along the Suquía River were selected according to the presence of Córdoba city and the location of the waste water treatment plant (Fig. 1).

Fish survey and physico-chemical characterization

Study sites were sampled twice during the rainy season (October-March) and twice during the dry season (April-September) per year, from 1998 to 2002. Each sampling site was representative of the overall habitats included within the stream reach under investigation, capturing several examples of all the major macrohabitat types within the reach (pools, runs, riffles, bend backwaters, side channels, etc.). We established a permanent sampling reach on each site and sampled fishes by electrofishing an approximately 150 m $\times$ 3 m area in a downstream direction toward the seine (Niemelä et al. 2000, Adams et al. 2004, Sály et al. 2009). Species identification was made following López et al. (2003). Individuals were counted and then released into the stream. Only the data of adult individuals were used for the analyses. For each sampling site, we estimated the total abundance and the abundance of each species as the number of fish captured per unit area (m^2) of water surface sampled (Paller 1995, Langford and Hawkins 1997).

Following Pesce and Wunderlin (2000), we registered 19 physico-chemical parameters in Suquía River Basin, in order to characterize the water quality conditions: pH, Temperature (^oC), Conductivity ($mS \cdot cm^{-1}$), Alkalinity ($mg \cdot L^{-1}$), Dissolved Oxygen ($mg \cdot L^{-1}$), Carbon Dioxide ($mg \cdot L^{-1}$), Total Solids ($mg \cdot L^{-1}$), Ammonia ($mg \cdot L^{-1}$), Nitrites ($mg \cdot L^{-1}$), Nitrates ($mg \cdot L^{-1}$), 5-day Biological Oxygen Demand (BOD) ($mg \cdot L^{-1}$), Total Phosphorus ($mg \cdot L^{-1}$), Hardness ($mg \cdot L^{-1}$), Calcium ($mg \cdot L^{-1}$), Magnesium ($mg \cdot L^{-1}$), Sulfates ($mg \cdot L^{-1}$), Chlorides ($mg \cdot L^{-1}$), Total Iron ($mg \cdot L^{-1}$), Total Coliforms and Fecal Coliforms (MPN·100 ml: most probable number per 100 ml). Analytical methods were standard (APHA et al. 1998).

To evaluate changes in water quality due to the combined effects of many parameters we calculated the Water Quality Index (WQI) proposed for Suquía River Basin (Pesce and Wunderlin 2000). This indicator aims at characterizing the conditions of sampling sites based on the physico-chemical variables. The construction of the WQI requires first a normalization step, where each parameter is transformed into a 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. Briefly, 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 index is calculated as:

$$WQI = \Sigma\ (C_i \cdot P_i) / \Sigma\ P_i$$

where C_i is the value assigned to each parameter after normalization. P_i values 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). The constructed WQI gives a number that can be associated with a quality percentage. WQI values less than 50% are considered not compatible with aquatic life.

Temporal analyses

Temporal variation of total abundance of each assemblage was examined with a One Way Analysis of Variance to determine differences between hydrological seasons (rainy and dry season) and between years of collection. Following the criterion proposed by Almirón et al. (2000), species were classified as "permanent" if they were present in ≥70% of the samples, "semi-permanent" in 30 - 70%, and "occasional" if they were present in <30% of the samples. In order to verify that permanent species are descriptive assemblage elements of each site, a Correlation Analysis between total fish abundance and total permanent fish abundance was performed.

Persistence of fish assemblage (continued presence or absence of species over time) was estimated through the Affinity Index proposed by Amezcua-Linares and Yańes-Arancibia (1980). This indicator refers to species composition and establishes similarities between consecutive samples for each site:

$$AF = 100\ (N_C/N_A + N_C/N_B)\ /\ 2$$

where N_A is the number of species of sample A, N_B is the number of species of sample B, in the same area, and N_C is the number of common species between A and B. To establish if fish assemblages were persistent over time, a One Way Analysis of Variance of the Affinity Index between years of collection was performed.

Assemblage stability was examined using Kendall's Coefficient of Concordance (W). This is a nonparametric procedure that tests the null hypothesis by which the abundance rankings change randomly through time. Rejection of randomness supports the alternative hypothesis that rankings have some degree of constancy over time (common species remain common and rare species remain rare) (Meffe and Berra 1988). The mean abundance of each species, for each year of collection, was calculated to examine assemblage stability, and Kendall's W was subsequently applied across multiple ranges of consecutive years.

The Coefficient of Variation (CV) of total abundance and abundance of each species was used to describe variability in fish assemblages on temporal scale. CV values were calculated by dividing the standard deviation of population estimates by mean abundance (Grossman et al. 1990). CV values were classified following the criteria proposed by Freeman et al. (1988): $CV \leq 0.25$: highly stable; $0.25 < CV \leq 0.50$: moderately stable; $0.50 < CV \leq 0.75$: moderately fluctuating and > 0.75: highly fluctuating. These authors described variation in populations, with an overall view of assemblage stability based on examining CV values for all assemblage members.

Spatial analyses

The Affinity Index was applied to measure the constancy of fish species between sampling sites (spatial analyses). To evaluate the efficiency of each site in predicting assemblage changes in relation to water quality, we used a Discriminant Analysis (DA). Sampling sites were used as grouping variable, while the physico-chemical parameters were considered as independent variables. The spatial variation of fish assemblages along the river was analyzed through another DA where sampling sites form the grouping variable and the abundance of each fish species were considered as independent variables.

Table 1. Fish species abundance (N = No individuals·m^{-2}), total abundance and frequency of occurrence (FO) of each species at each sample site. References: 1–La Calera, 2–Saldán, 3–Isla de los Patos, 4–Chacra de la Merced and5–Villa Corazón de María; P = permanent species, SP = semipermanent species and O = occasional species.

	SITES									
	1		2		3		4		5	
SPECIES	N	FO	N	FO	N	FO	N	FO	N	FO
CHARACIDAE										
Oligosarcus jenynsi	0.0113	O								
Astyanax eigenmanniorum	0.2841	P	0.0317	SP			0.0085	O	0.0044	O
Astyanax cordovae			0.0049	O						
Bryconamericus iheringi	0.2596	P	0.3421	P	0.1630	P	0.0866	P	0.0653	P
Cheirodon interruptus	0.0384	SP			0.0025	O	0.0085	O	0.0044	O
ERYTHRINIDAE										
Hoplias malabaricus	0.0045	O			0.0049	O				
HEMIODIDAE										
Parodon cf. *tortuosus*			0.6061	P	0.0938	P	0.0219	SP		
PIMELODIDAE										
Pimelodella laticeps	0.0180	O	0.0229	SP						
Pimelodus albicans					0.0025	O				
Rhamdia quelen	0.0271	SP	0.0088	O						
TRICHOMYCTERIDAE										
Trichomycterus corduvense			0.1637	P	0.3580	P	0.0125	O	0.0044	O
CALLICHTHYDAE										
Corydoras paleatus	0.1804	P	0.0267	P	0.0790	P	0.0362	P	0.1099	P
LORICARIIDAE										
Rineloricaria catamarcensis	0.1534	P	0.2105	P	0.0420	P	0.0405	SP	0.0044	O
Hypostomus cordovae	0.0857	P	0.8706	P	0.2765	P	0.1563	P	0.0455	P
ANABLEPIDAE										
Jenynsia multidentata	2.1170	P	0.1309	P	0.6617	P	0.8545	P	2.5081	P
POECILIIDAE										
Gambusia affinis	0.2032	P	0.0149	O	0.0222	SP	0.9945	P	0.1343	P
Cnesterodon decenmaculatus	0.2822	P	0.0288	SP	0.0494	SP	0.8479	SP	0.3503	P
SYNBRANCHIDAE										
Synbranchus marmoratus	0.0023	O			0.0099	O	0.0172	SP		
CICHLIDAE										
Australoheros facetum	0.0181	O					0.0022	O		
TOTAL ABUNDANCE	3.6850		2.4624		1.7655		3.0872		3.2309	

Statistical analysis

The data distribution of each variable was analyzed through the Shapiro-Wilks Index (Sokal and Rohlf 1979). For the statistical analyses we used the Infostat Software Package (2003).

Results

Physico-chemical characteristics varied along the Suquía River. The Water Quality Index (WQI) varied significantly between sample sites (Fig. 2), showing that some study sections were seriously disturbed. The areas located downstream where the river has crossed Córdoba City (Chacra de la Merced and Villa Corazón de María) had the lowest WQI, indicating that the system had experienced environmental degradation. The sampling site located in the center of the city (Isla de los Patos) was characterized as moderately polluted. Conversely, high values of WQI corresponded to La Calera and Saldán, indicating almost pristine water conditions.

A total of 5231 individuals belonging to 19 fish species from 11 families were collected (Table 1), which represents 40 - 43% of the fish fauna recorded for Córdoba Province (Haro and Bistoni 1996).

Temporal analyses

According to the results of the Analysis of Variance, total fish abundance at each site did not change between hydrological seasons (Table 2); therefore, the data were considered as a whole in the subsequent analyses.

According to the frequency of occurrence of fish species at each sampling site (Table 1) *Bryconamericus iheringi*, *Corydoras paleatus*, *Hypostomus cordovae* and *Jenynsia mul-*

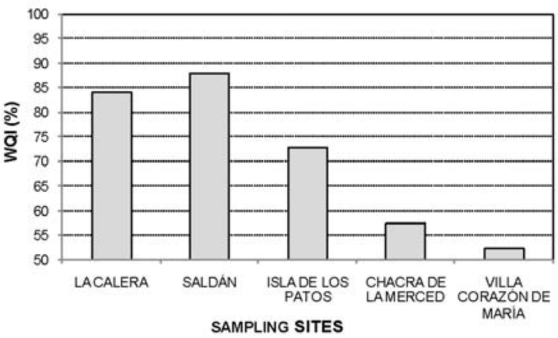

Figure 2. Pattern of variation of Water Quality Index (WQI). The WQI varied significantly between sample sites. The lowest values correspond to the the most degraded sites (Chacra de la Merced y Villa Corazón de María). References: 1. La Calera, 2. Saldán, 3. Isla de los Patos, 4. Chacra de la Merced, 5. Villa Corazón de María.

Table 2. One Way Analysis of Variance of total abundance at each sampling site on the Suquía River between hydrological seasons ($p<0.05$). Total fish abundance at each sampling site did not change between hydrological seasons.

SITES	F	p
La Calera (n= 8)	3.75	0.432
Saldán (n=7)	4.79	0.101
Isla de los Patos (n= 10)	0.67	0.436
Chacra de la Merced (n=8)	0.71	0.080
Villa Corazón de María (n= 8)	0.64	0.456

Table 3. Average values and standard deviations (SD) of Affinity Index across samples at each site, with the results from the One Way Analysis of Variance of Affinity Index at each sampled site between years of collection (*$p<0.05$). The index presented significant differences between years of collection in Chacra de la Merced only.

SITES	Affinity Index	SD	F	p
La Calera (n= 8)	85.14	12.78	2.53	0.233
Saldán (n=7)	81.82	8.45	0.12	0.894
Isla de los Patos (n= 10)	83.61	14.48	1.87	0.280
Chacra de la Merced (n=8)	71.66	33.33	16.26	0.023*
Villa Corazón de María (n= 8)	80.24	9.14	0.30	0.608

tidentata were the only permanent residents in all sampling sites. The presence of *Astyanax eigenmanniorum*, *Cheirodon interruptus* and *Rineloricaria catamarcensis*, was occasionally registered at the most polluted sites, indicating the sensitiveness of these species. *Trichomycterus corduvense* was also an occasional species; however this fish presented the highest abundance at the moderately polluted site (Isla de los Patos).

The relationship between total fish abundance and total permanent fish abundance was significant ($r = 0.973$; $p<0.0001$) and justifies the use of these species as descriptive elements of the stream fish assemblages studied (Meffe and Berra 1988). The average and standard deviation of the Affinity Index for each sampling site are shown in Table 3. This index presented significant differences between years of collection in Chacra de la Merced only (Table 3), because no fish were collected in October 1999 due to the high water quality degradation that characterized this area (WQI = 53.03%). Despite this, all sites presented high mean Affinity Index values, demonstrating high persistence of their specific composition over time (mean values of Affinity Index above 70%).

The results (Table 4) showed all the relationships obtained through the Kendall's W to be significant over the period studied, supporting the conclusion of some stability of abundance rankings.

The lack of significant differences of total abundance over time was due to the high fluctuation of total population size (Table 5). These findings suggest the high natural variability that characterizes lotic fish assemblages, which are supported by the high CV values of total abundance for each site. The highest CV values corresponded to the most polluted areas, with an increase higher than 100% with respect to the near-pristine sites. An increase of temporal variation was observed in areas with the highest pollution (Table 5).

Table 4. Kendall (W) Coefficient values that relate the mean fish species abundance between different years of collection at each site (*$p<0.05$). All the relationships obtained were significant over the studied period.

Sites	W	p
LA CALERA (n=8)		
1998 vs 1999	0.667	0.0003*
1998 vs 2000	0.489	0.0082*
1999 vs 2000	0.640	0.0005*
SALDÁN (n= 7)		
1999 vs 2001	0.687	0.0002*
1999 vs 2002	0.585	0.0016*
2001 vs 2002	0.778	0.0000*
ISLA DE LOS PATOS (n= 10)		
1998 vs 1999	0.717	0.0001*
1998 vs 2000	0.525	0.0046*
1998 vs 2001	0.761	0.0000*
1998 vs 2002	0.644	0.0005*
1999 vs 2000	0.458	0.0134*
1999 vs 2001	0,6566	0.0004*
1999 vs 2002	0.558	0.0026*
2000 vs 2001	0.525	0.0046*
2000 vs 2002	0.384	0.0378*
2001 vs 2002	0.832	0.0000*
CHACRA DE LA MERCED (n= 8)		
1999 vs 2000		
1999 vs 2001	No fish species collected	
1999 vs 2002		
2000 vs 2001	0.542	0.0034*
2000 vs 2002	0.536	0.0038*
2001 vs 2002	0.635	0.0006*
CORAZÓN DE MARÍA (n=8)		
2001 vs 2002	0,775	0.0000*

Table 5. One Way Analysis of Variance of total fish abundance between years of collection and the Coefficient of Variation (CV) at each sample site on Suquía River ($p<0.05$). There were no significant differences of total abundance over time due to the high fluctuation of total population size.

SITES	F	p	CV
La Calera (n= 8)	0.58	0.659	0.412
Saldán (n=7)	4.20	0.104	0.490
Isla de los Patos (n= 10)	4.46	0.066	0.530
Chacra de la Merced (n=8)	1.54	0.335	1.060
Villa Corazón de María (n= 8)	3.99	0.093	1.110

According to the classification proposed by Freeman et al. (1988), the abundance of each fish species varied from moderately to highly fluctuating (Table 6). *Jenynsia multidentata*, *Rineloricaria catamarcensis* and *Corydoras*

Table 6. Variation of each fish species abundance through the estimation of the Coefficient of Variation (CV). According to Freeman et al. (1988) CV values were classified as follows: $\leq$ 0.25: highly stable; 0.25 < CV $\leq$ 0.50: moderately stable; 0.50 < CV $\leq$ 0.75: moderately fluctuating and > 0.75: highly fluctuating References: 1–La Calera, 2–Saldán, 3–Isla de los Patos, 4–Chacra de la Merced and 5–Villa Corazón de María.

	SITES				
SPECIES	1	2	3	4	5
Oligosarcus jenynsi	2.83				
Astyanax eigenmanniorum	0.93	1.25		2.83	---
Astyanax cordovae		---			
Bryconamericus iheringi	1.15	0.72	1.27	1.20	1.18
Cheirodon interruptus	1.35		---	2.83	---
Hoplias malabaricus	---		---		
Parodon sp.		1.16	1.15	2.83	
Pimelodella laticeps	---	2.65			
Pimelodus albicans			---		
Rhamdia quelen	1.85	2.65			
Trichomycterus corduvense		0.92	0.80	2.82	---
Corydoras paleatus	0.62	1.71	1.51	1.07	1.50
Rineloricaria catamarcensis	0.72	0.97	1.61	1.51	---
Hypostomus cordovae	1.07	0.98	0.84	1.49	1.51
Jenynsia multidentata	0.70	1.20	1.36	1.40	1.40
Gambusia affinis	1.64	2.65	2.11	1.32	0.85
Cnesterodon decenmaculatus	1.21	1.71	1.75	1.25	1.67
Synbranchus marmoratus	---		3.16	1.85	
Australoheros facetum	2.83			---	

Table 7. Spatial variation of fish assemblage composition through the Affinity Index between sampling sites on Suquía River. The results obtained revealed a high fish species similarity.

SITES	La Calera	Saldán	Isla de los Patos	Chacra de la Merced	Villa Corazón de María
La Calera	---	71.0	82.0	71.0	75.0
Saldán	---	---	72.0	77.0	79.5
Isla de los Patos	---	---	---	88.0	72.0
Chacra de la Merced	---	---	---	---	88.5
Villa Corazón de María	---	---	---	---	---

paleatus were the only moderately fluctuating species in La Calera and *Bryconamericus iheringi* in Saldán. The remaining species were highly fluctuating over the studied period. Grossman et al. (1990) pointed out that CV is a good estimator of population/assemblage stability and Matthews (1998) indicates that CVs appear to be useful tool for detecting differences among species in their variation in samples over time.

Spatial analyses

The Affinity Index estimation between sites revealed a high fish species similarity (Table 7). These results suggest that fish assemblages along Suquía River are characterized by the constancy of their components.

Table 8. Discriminant Analysis based on physico-chemical variables. **a:** Classification matrix (stepwise mode). **b:** Common covariance standardized discriminant functions. Asterisk indicates the most important variables yielded by the analysis.

a

Group (sampling sites)	Group assigned by DA					Total	Right assignation (%)
	1	2	3	4	5		
1	8	0	0	0	0	8	100.00
2	1	6	0	0	0	7	85.71
3	0	0	10	0	0	10	100.00
4	0	0	0	8	0	8	100.00
5	0	0	0	0	8	8	100.00
Total	9	6	10	8	8	41	97.56

b

Physico-chemical variables	Canonical Axis 1	Canonical Axis 2
pH	-1.04	0.42
Temperature	0.92	-0.12
Conductivity	2.55*	2.20
Alkalinity	-0.23	-0.6
Dissolved Oxygen	2.51*	-0.09
Carbon Dioxide	-0.04	1.96*
Total Solids	-1.54	0.02
Ammonia	-0.21	1.63*
Nitrites	-0.82	-0.38
Nitrates	-0.11	0.64
BOD	-1.03	-0.75
Total Phosphorus	3.62*	1.06
Hardness	-2.15	-0.24
Calcium	1.20	-0.28
Magnesium	0.95	-0.07
Sulfates	1.39	1.55
Chlorides	-4.1 *	-4.63*
Total Coliforms	-1.31	-1.96*
Fecal Coliforms	0.54	1.57*

Table 9. Discriminant Analysis based on fish species abundance. a) Classification matrix (stepwise mode). b) Common covariance standardized discriminant functions. Asterisk indicates the most important variables yielded by the analysis.

a

Group (sampling sites)	Group assigned by DA 1	2	3	4	5	Total	Right assignation (%)
1	7	0	0	0	1	8	87.50
2	0	7	0	0	0	7	100.00
3	0	0	10	0	0	10	100.00
4	0	0	0	8	0	8	100.00
5	0	0	0	2	6	8	75.00
Total	7	7	10	10	7	41	92.68

b

Fish Species	Canonical Axis 1	Canonical Axis 2
O. jenynsi	-0.68	-0.13
A. eigenmanniorum	1.05*	-0.62
B. iheiringi	0.64	0.76*
Ch. interruptus	-0.05	-1.00*
Parodon sp	0.73	0.21
P. laticeps	-0.89*	0.27
R. quelen	0.43	0.14
T. corduvense	-0.95*	0.06
C. paleatus	0.81	-0.50
R. catamarcensis	0.86	0.43
H. cordovae	0.61	0.70
J. multidentata	0.42	-0.41
G. affinis	-0.88*	-0.20
C. decenmaculatus	0.42	-0.08
S. marmoratus	0.38	0.56
A. facetum	0.22	0.25

Discriminant Analysis (DA) enables evaluation of the differences between areas and also the identification of parameters that make the main contribution to such differences. The DA based on physico-chemical parameters yielded 97.56% right assignment (Table 8). The most important variables in discriminating the sampling sites were: Conductivity, Dissolved Oxygen, Total Phosphorous, Chlorides, Carbone Dioxide, Ammonia, Total and Fecal Coliforms. The DA based on fish species abundance afforded 96.68% right classification. The most important variables in discriminating the sampling sites were the abundance of *Astyanax eigenmanniorum, Pimelodella laticeps, Trichomycterus corduvense, Gambusia affinis, Bryconamericus iheringi* and *Cheirodon interruptus* (Table 9).

The application of DA demonstrated that both physico-chemical and fish assemblages variation presented similar spatial variation patterns. These analyses showed significant differences between sampling sites and enabled a quite good differentiation of high and moderately polluted sites from those with high water quality. The fish abundance variation between sampling sites is the results from the environmental quality gradient along the Suquía River.

Discussion

Management of natural variability relies on two concepts: first, past conditions and processes provide context and guidance for managing ecological system today; second, disturbance-driven spatial and temporal variability is a vital attribute of nearly all ecological systems (Landres et al. 1999). Human activities may alter the physical, chemical or biological processes associated with water resources (Chovanec et al. 2003). Karr (1991), who identified the primary classes of environmental factors that result in ecosystem degradation, pointed out how the impairment of water quality conditions (e.g. dissolved oxygen, nutrients, toxic substances, etc.) modify resident biological communities. The modifications of fish assemblages due to water quality variations could be analyzed through temporal and spatial scale (Fausch et al. 1990, Siligato and Böhmer 2002, Adams et al. 2004, Greenfield and Bart 2004).

Fish assemblages with stable and persistent composition are considered to be regulated by deterministic or equilibrium processes whereas assemblages that lack these properties are regulated by stochastic or non-equilibrium processes (Grossman et al. 1982, Schlosser 1982, Moyle and Vondracek 1985). Stability and persistence of natural fish assemblage structure across temporal scales has received much empirical and theoretical attention in recent years (Grossman et al. 1990, Drake 1991, Oberdorff and Porcher 1992, Hugueny and Paugy 1995, Dunham et al. 2003). Nevertheless none of them has attempted to compare temporal variation of fish assemblages between zones of different water quality conditions. The present study evaluated the impact of water quality degradation on the variability of the structure of fish assemblages on temporal and spatial scales.

The Suquía River Basin is characterized by an environmental degradation gradient, with almost pristine water conditions in the upper portions. Lower water quality conditions characterize the sections of the river flowing through and below the city.

Most of the fish species were permanent residents. However, *A. eigenmanniorum*, *Ch. interruptus* and *R. catamarcensis* were occasional species at sites with severe alteration, which agrees with Hued and Bistoni (2005) who considered them as sensitive species. *T. corduvense*, another occasional and moderately tolerant species (Hued and Bistoni 2005), presented the highest abundance at the moderately polluted site.

Kendall's Coefficient of Concordance (W) has been used in several studies to determine the temporal variation of fish assemblages (Grossman et al. 1982, Moyle and Vondracek 1985, Ross et al. 1985, Meffe and Berra 1988). This coefficient responds to changes in species abundance and tests for the correlation in the abundance rankings of species over time. Measurements of stability using this non-parametric method showed that Suquía River fish fauna at each site was stable and consistent over time. An assemblage that is stable or near equilibrium has more constant rankings of its species compared with a fluctuating one (Medeiros and Maltchick 2001). The stability of the species rankings of fish assemblages indicates that some species continually dominated the assemblage, whereas others were always rare. Meffe and Berra (1988) reached a similar conclusion regarding persistence and stability, and pointed out that these results were indicative of a system in some degree of equilibrium.

Nevertheless, Kendall's W yielded no results for one sample taken in Chacra de la Merced in October 1999 due to the lack of fish species at that moment. Besides this, the Analysis of Variance of the Affinity Index estimated for this site yielded significant differences. On that sampling date, the chemical analysis demonstrated extremely severe water quality conditions and created harsher conditions for fish assemblages. Fish did not tolerate the high environmental degradation. Some parameters like Dissolved Oxygen ($3.40\ mg \cdot L^{-1}$), Ammonia ($17.42\ mg \cdot L^{-1}$) and Nitrate ($26.77\ mg \cdot L^{-1}$), exceeded the maximum allowable concentrations for fisheries and aquaic life (Chapman 1992, Pesce and Wunderlin 2000, Guzmán et al. 2004, Cazenave et al. 2005, Hued et al. 2006). Thus, the environment was classified as inappropriate for aquatic life, which was supported by the absence of fish species. The low water quality condition of this sample was an important disturbance that functioned as a reset mechanism. After this event the assemblage recovered and showed a stable structure over time. It is important to point out that chemical analysis in the successive samples in this area always indicated water quality deterioration, but did not reach such extreme values as in October 1999. Our results indicated a strong association between fish species distribution and water quality. Changes in the structure of fish assemblages on a spatial scale were associated with the watershed disturbance gradient. However, it was possible to characterize fish assemblages of the Suquía River as qualitatively persistent and quantitatively stable at each sampling site, indicating that the specific composition and the assemblage structure were relatively constant over time, despite of the water quality gradient. The differences found in our work can be largely attributed to the decline in water quality conditions (Hued and Bistoni 2005). Decline in abundance is a response to physical-chemical characteristics of the sewage that lead to higher rates of mortality and toxic effects which alter behavioral responses (Adams et al. 1993). Also fecundity and size of fish can be affected (EPA 1993).

Although the relative abundances remain without significant changes over time, the total abundance of each assemblage fluctuated greatly, suggesting that populations from pristine sites are characterized by their natural variation. This phenomenon is common in mountain streams where fish assemblages are adapted to fluctuating hydrological regimes (Grossman et al. 1990). Individual fish species fluctuated in abundances but, at most locations, it is possible to find essentially the same assemblage year after year with respect to the presence of species (Matthews 1998). Despite the environmental quality degradation, fish assemblages in polluted areas were stable and persistent, but they responded to water quality degradation with a greater variation of species abundance.

Ross et al. (1985) proposed that the degree of stability, as well as persistence, may result from several causes: first, elasticity achieved by high intrinsic rates of increase allowing rapid and constant repopulation; second, a high mobility that permits a local refuge-seeking behavior and the return of the species after the perturbation; finally, fish species may have some degree of resistance through increased physiological tolerance to environmental changes. Organisms are usually classified on the basis of variability range in the absence of human disturbance, and variations outside these bounds may be more disruptive (Dunham et al. 2003). Our study revealed that fish assemblages in polluted areas have some degree of physiological tolerance, because they resisted the adverse water quality conditions of the Suquía River. Fish species like *J. multidentata, G. affinis* and *C. decenmaculatus*, have been considered as tolerant because of their population increase in the most altered waters (Bistoni et al. 1999, Hued and Bistoni 2005).

Schlosser (1987) described these fish assemblages as "colonizing assemblages" characterized by small-bodied, short-lived species that are able to recolonize stream reaches and by high temporal variability in composition and abundance. These assemblages are characteristic of headwater streams, but their presence is common in simple degraded habitats of larger streams, where assemblages show reduced species richness and increased dominance. We suggest that the recovery of fish assemblage after the severe environmental disturbance in October 1999 (reset mechanism) could be attributed to a re-colonization from adjacent sites due to the high fish-fauna similarities along the Suquía River.

Even though our results indicate fish assemblage stability, there is still a high degree of variance and uncertainty in the study area. It is unknown for how long the fish assemblages have been under the negative influences of the city sewage discharge and it is unpredictable in which way they could change in the future if these conditions persist. The variance increase observed in the present study could also be considered as an indicator of whether the system is getting close to a critical threshold. Scheffer et al. (2009) pointed out that variance increase in the pattern of fluctuations is a possible consequence of a critical slowing down that precedes sudden drastic switches that could drive the system to an alternative state.

Despite the stability and persistence exhibited by fish along the Suquía River, the most polluted sites showed higher variability than the pristine areas. McCann (2000) pointed out that community-diversity-stability is dependent on the differential response of species, or functional groups, to variable conditions. Yachi and Loreau (1999) proposed that the greater the variance in species' responses contained in a community, the lower is the species richness required to insure the ecosystem. In our study, fish species that live under the most degraded water quality conditions could be responding to these conditions to tolerate the altered environment.

Conclusions

The present study evaluated the impact of degraded water quality conditions on fish assemblage structure on temporal and spatial scales. We compared the variability of natural fish assemblages to those present in polluted areas. Despite water quality deterioration along the basin, fish assemblages could be characterized as qualitatively persistent and quantitatively stable, indicating that the specific composition was relatively constant over time along the basin. However, fish assemblages from the most polluted areas responded to the negative impact with a greater variation of species abundance than fish assemblages from pristine sites.

Fish species distribution and water quality are strongly associated. On a spatial scale, changes in the structure of fish assemblages were associated with a watershed disturbance gradient. This research provides indications of what might occur in natural systems affected by water quality alteration over long periods of time.

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