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Fish Assemblages in Pampean Streams (Buenos Aires, Argentina): Relationship to Abiotic and Anthropic Variables

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Abstract: The present study reported the effect of natural and anthropic environmental variables on the fish assemblages in the pampean streams, in the coastal strip along the Río de la Plata, Buenos Aires province, Argentina. Five streams were sampled at 12 sites surrounded by land devoted to different uses. A correspondence analysis sorted the streams into two groups: a less impacted group formed by sites surrounded by livestock- raising pastures and a more impacted one passing through urban sites and including a stream adjacent to a modest rural urbanization with a dairy in the stream's basin. The nutrient concentrations were significantly higher in the more impacted group; with species richness, diversity, abundance, and biomass being significantly lower. A canonical-correspondence analysis linked the more impacted sites to high concentrations of soluble reactive phosphorus and impoverished fish assemblages, composed of species tolerant to environmental pollution. On the other hand, sites with higher oxygen concentrations and pH were related to richer assemblages pointing to good environmental conditions at the sites surrounded by livestock-raising pastures. The downstream sites on the less impacted streams contained fish assemblages in which the juvenile stages of species corresponding to the Río de la Plata were dominant.

Key words: environmental variables, freshwater fish, land use, nutrient concentrations.

INTRODUCTION

Water quality in streams is strongly dependent on the surrounding terrestrial environment (Wallace et al. 1999, Pinto et al. 2006). Changes in land use are the most expected source of alterations in stream biodiversity (Sala et al. 2000). The principal modifications include increased agriculture, horticulture, urban and industrial development. More than 68% of the world's population will live in urban areas by the year 2050 (UN DESA 2018). The effects of urbanization involve increased concentrations of nutrients, metals, and pesticides plus erratic hydrology, channelization, and bank destabilization (Paul & Meyer 2001, Allan 2004). Streams draining urban basins have often exhibited low richness and diversity of the fish species (Klein 1979, Helms et al. 2009), low biomass, and the absence of pollution-sensitive species (Lenat & Crawford 1994, Oronato et al. 2000). The number of invasive species was observed to increase (Boet et al. 1999), whereas the biotic integrity was found to decrease in urban basins (Steedman 1988, Wang et al. 1997, Yoder et al. 1999).

Several references involving the effect of land use on fish assemblages refer to Holartic fauna, whereas the Neotropical region—it has the most diversified freshwater-fish fauna in the world (Lévêque et al. 2008)—remains largely unreported (Cunico et al. 2006). The

pampas region around the city of Buenos Aires, Argentina, contains a high population density and degree of urbanization (Herrero et al. 2009). The streams of that region often receive runoff from industrial and household sources, with a consequent deterioration in water quality (Padulles et al. 2017). The composition of the fish assemblages in a few pampean streams has been reported by Di Marzio et al. (2003), Remes Lenicov et al. (2005), Fernández et al. (2008), Colautti et al. (2009) and Granitto et al. (2016). A comprehensive assessment on a larger scale of the relationship between community structure and environmental variables, however, remains unreported. Under natural conditions, the structure and the composition of fish assemblages respond more to variations on a local scale—*i. e.*, the distance from sources, the basin area, and the stream order and width—than on a regional scale (ecoregion; Tejerina-Garro et al. 2005). Those authors underscored the necessity to identify natural and human effects on assemblage compositions in order to develop more comprehensive conservation-management policies.

Fish are useful organisms for assessing environmental degradation because many species are sensitive to different types of disturbances and can reflect the adverse effects on the habitat modifications. Fish thus, represent an appropriate tool for diagnosing anthropic impact on their environment (Karr 1981).

Within this context, the aim of this study was to assess fish assemblages in pampean streams and to determine their structure in relation to natural *versus* anthropically impacted environmental variables. Our hypothesis was that urbanization would produce assemblages of lower abundance and diversity along with a predominance of a few tolerant species.

MATERIALS AND METHODS

Study sites

Five streams were sampled between January 2009 and March 2011 at 12 separate sites surrounded by different types of land use. The streams studied are located at the Río de la Plata coastal fringe, around the cities of La Plata and Magdalena, Buenos Aires province, Argentina (Fig. 1).

The Rodríguez Stream drains an urbanized basin in the area around the city of La Plata. The Pescado Stream was sampled at sites surrounded by fields devoted to extensive livestock raising. The Zapata Stream drains a heterogeneous basin of multiple land uses, but mainly livestock. A small rural urbanization, General Mansilla, containing 2,000 inhabitants and a dairy, however, are also located in the upstream area of the basin (Fig. 1). The Buñirigo Stream drains an extensive livestock basin. At the southernmost sampling site, close to the mouth of the stream, two industrial establishments are located, a food-production plant and a tannery. The Juan Blanco Stream drains an extensive homogeneous livestock-containing basin. Livestock-raising throughout the whole area involves cattle at low densities grazing on pastures.

The climate is mild and humid with mean monthly temperatures ranging from 9.9 °C in July to 22.4 °C in January. The mean annual precipitation is 1,060 mm featuring small seasonal variations (Hurtado et al. 2006). All the streams under study drain the eastern part of the pampas plain, it has a small regional slope. The streams have low water flow, silt bottoms, and a high suspended-matter content (Rodrigues Capítulo et al. 2010). As there are not well defined wet and dry seasons, the streams lack seasonal high and low water periods. Rather, a basal-flow occurs all year round coupled to ephemeral peak floodings following heavy rains.

The samplings were performed during the basal-flow conditions thus, avoiding peak floods.

The borders of these streams are not forested, but rather contain abundant riparian vegetation. In the lower stretches, the streams run through the Río-de-la-Plata coastal plain (Cavallotto 2002), a lowland area covered with wetlands and separated from the Río de la Plata by a small forested ridge. The largest streams—Pescado, Buñirigo, and Rodríguez—traverse the ridge and remain in permanent contact with the Río de la Plata. The lower stretch of the Rodríguez was channelized to prevent floodings in the urban areas. The Juan Blanco and Zapata streams extend into the coastal wetland, and as such, do not remain in contact with the Río de la Plata; moreover, their water can spill over the ridge when heavy rains occur (Table I).

Environmental variables

Before each fish sampling, environmental parameters were measured *in situ*. Water temperature and dissolved oxygen concentration were measured with a YSI 51B oxymeter (YSI Incorporated, Yellow Springs, OH, USA), the pH with a Hanna checker (Hanna Instruments, Woonsocket, RI, USA), the conductivity with a Hanna HI 8733 conductivity meter, and the stream depth with a graduated rod. Water samples were taken for nutrient analysis and then immediately passed through Whatman GF/C filters having a 1.2-μm pore size (Whatman Incorporated, Clifton, NJ, USA) and transported to the laboratory on ice. The concentration of soluble reactive phosphorus (SRP), ammonium, and nitrate were measured following APHA (1998). The concentration of non-ionized ammonia was estimated from the ionized-ammonia concentration, pH, and temperature after Emerson et al. (1975).
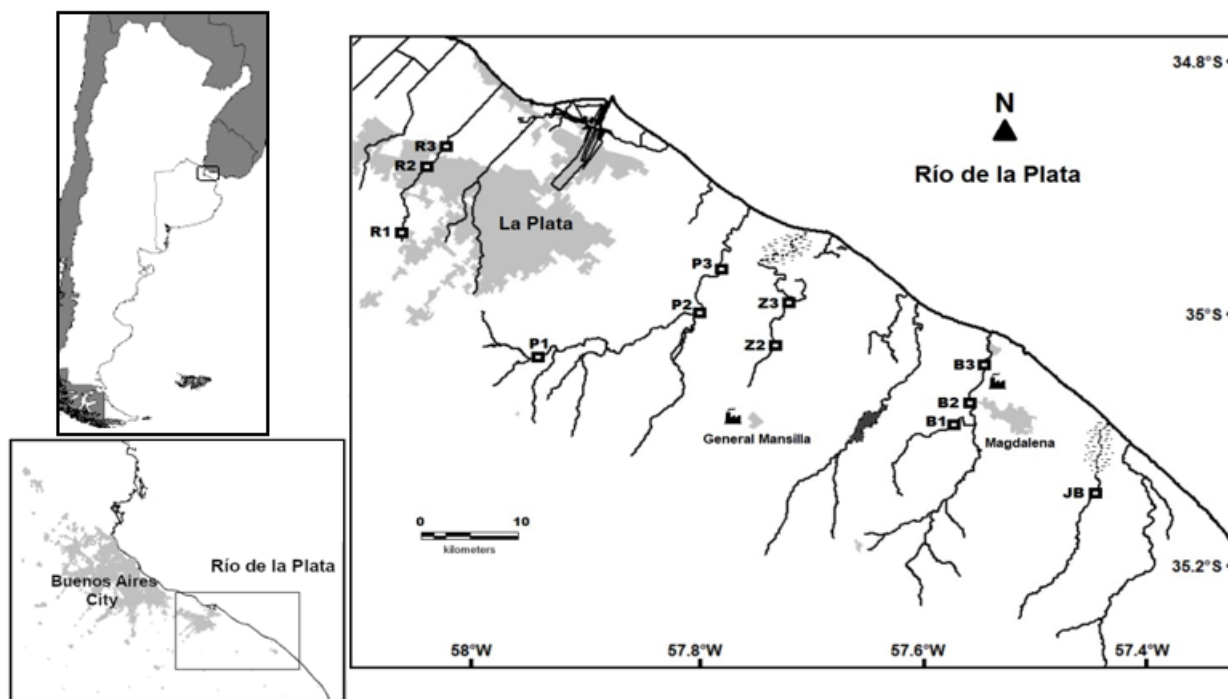

Figure 1. Study sites in pampean streams, Buenos Aires province, Argentina. R1-R3: Rodríguez, P1-P3: Pescado, Z2 and Z3: Zapata, B1-B3: Buñirigo, JB: Juan Blanco.

Table I. Features of the study sites on pampean streams, Buenos Aires province, Argentina. Distance to the mouth (km) measured in length of the downstream river course.

Site	Code	Nº of samples	Main land use	Depth (cm)	Distance to the mouth (km)
Rodríguez upper stretch	R1	3	intensive urban use	24.7 ± 0.6	16.9
Rodríguez middle stretch	R2	2	intensive urban use	32.5 ± 3.5	9.8
Rodríguez lower stretch	R3	2	intensive urban use	51.5 ± 4.9	7.2
Pescado upper stretch	P1	5	livestock	84.2 ± 33.7	31
Pescado middle stretch	P2	4	livestock	65.8 ± 16	13.7
Pescado lower stretch	P3	4	livestock	95 ± 8.2	8.2
Zapata middle stretch	Z2	2	livestock, dairy, low-impact urban use	58 ± 4.2	19
Zapata downstream stretch	Z3	3	livestock	75 ± 5	14
Buñirigo upstream stretch	B1	3	livestock	54.7 ± 16.7	12.9
Buñirigo middle stretch	B2	4	livestock	116 ± 27.7	7.6
Buñirigo downstream stretch	B3	3	livestock, food industry tannery	40.3 ± 7.6	4.5
Juan Blanco lower stretch	JB	4	livestock	104 ± 34.4	7.6

Fish sampling and data analysis

The same fishing gear and sampling effort were used along all the surveys. Before each sampling, a section of the stream was completely closed off with a net 1 m high and with a 5-mm mesh. In each sampling, a seine net—of 15-m width, 1-m height, |cod end| 1.5 m, and mesh of 50-10 mm—was dragged along a 50-m stretch towards the fixed net. The study sites were sampled until no major changes in species richness or abundance was registered, with two successive seine hauls being enough to assess the assemblage composition. Care during collection and handling of fish for this study complied with the Buenos Aires Province (Argentina) Wildlife and Fisheries Authority guidelines and policies (Law 11,477).

Easily identified species were determined and weighed in the field with an Ohaus 0.5-g–precision balance. All other specimens captured were initially preserved in 10%, formaldehyde later replaced by 70% aqueous ethanol for routine laboratory determination. The fish were identified following Azpelicueta & Braga (1991), Braga (1993), Braga (1994), Aquino (1997), Reis & Pereira (2000), Casciotta et al. (2005), Miquelarena & Menni (2004), and Almirón et al. (2015). Updates in the taxonomy were reviewed following Mirande & Koerber (2015), Koerber et al. (2017), and Rosso et al. (2018). Voucher specimens were stored at the ichthyological collection of the Félix de Azara Natural History Foundation (CFA-IC), Buenos Aires, Argentina. Fish species typically recorded in pampean streams (Di Marzio et al. 2003, Remes Lenicov et al. 2005, Fernández et al. 2008, Colautti et al. 2009, Granitto et al. 2016) hereafter will be referred as "pampean" species, to differentiate them from the species most commonly reported in the Río de la Plata (Ringuelet et al. 1967, CARU-CARP 2012, 2016), those being hereafter referred as "riverine" species.

Statistical analysis

The biological data matrix was composed of relative abundance. The species whose total relative abundance was lower than 0.25% were eliminated from the analysis to reduce the influence of rare species. Thirty one species were eliminated for the multivariate analysis. The biological data matrix was then composed of the relative abundance of 24 species and 39 samples. A Detrended Correspondence Analysis (DCA) was performed. Since the length of the gradient for the first axis was 4.2 units of standard deviation, unimodal response models were used (Ter Braak & Smilauer 1998, Leps & Smilauer 2003). A Correspondence Analysis (CA) was performed to assess the distribution of the sampled sites in an exploratory fashion. Nutrient concentration, richness, the Shannon index (Magurran 1988), abundance, and biomass were compared by means of the Student *t-test*. Whenever data did not fit a normal distribution (*i. e.*, abundance and biomass), the nonparametric equivalent (*i. e.*, the Mann-Whitney test) was performed. The level of significance used was $p < 0.05$.

In order to evaluate if differences existed in the number of riverine species between stream reaches, a nonparametric one-way analysis of variance (*i. e.*, Kruskal-Wallis) and a pairwise multiple comparisons were performed.

Relationships between the environmental variables and the composition of the fish assemblages were studied with a partial Canonical Correspondence Analysis (CCA). Because environmental variables had different units of measurement, the data were normalized. The environmental matrix consisted of 5 variables (O_2, pH, conductivity, $N-NH_4^+$, and SRP). The water depth and temperature were treated as covariables. The inflation factor (Ter Braak & Smilauer 1998) was used in order to assess multicollinearity among the selected environmental variables; with values higher than 20 indicating collinearity.

RESULTS

The Correspondence Analysis pointed to the existence of two patterns defined by the relation to the Río de la Plata in the first and land use in the second axis (Fig. 2). The sites close to and in permanent contact with the Río de la Plata—*i. e.*, P3 and B3— were surrounded by livestock fields.

The sites were therefore sorted into two groups: the reaches surrounded by urban land use on the Rodriguez Stream (R1-R3), along with the Zapata Stream, bordered by a small rural urbanization and a dairy in the basin (Z2 & Z3), were grouped together, and will hereafter be termed the more impacted (MI); whereas the rest of the sites, located on streams surrounded by pasturing livestock (P1-P3, B1-B3, and JB), constituted the second group, which will hereafter be called the less impacted (LI).

The water conductivity did not evidence significant differences between the MI and the LI groups (Table II). The dissolved oxygen concentration was generally high at most sites although sites in the MI group occasionally registered low concentrations: 0.3 and 0.5 mg/l at R1 and Z3, respectively.

Soluble reactive phosphorus, nitrate, and ammonium concentrations were significantly higher in the MI than in the LI group (Mann-Whitney test; $p < 0.05$; Fig. 3). The maximum concentrations were recorded at 5 mg/l of SRP and 15 mg/l of $N-NH_4^{+1}$ at site R1. The non-ionized ammonia concentrations calculated were high, attaining maxima of 0.8 and 0.9 mg/l on two occasions at Site Z2.

A total of 18,061 fish were collected, corresponding to 55 species belonging to 22 families and nine orders (Table SI - Supplementary Material). The order Characiformes was characterized by the largest species richness at 28 (50.9%), followed by the Siluriformes, at 16 (29.1%); the Cichliformes at 3

(5.4%); the Cyprinodontiformes and Perciformes at 2 (3.6%); and the Clupeiformes, Cypriniformes, Atheriniformes, and Synbranchiformes with a single species each. The Characidae family contained the largest number of species (18). In terms of abundance, a similar pattern was observed. The Characiformes and Siluriformes were widely dominant, accounting for 54.2 and 39.9% of the total catch, respectively.

The species richness, the diversity (*t-test*), abundance and the biomass (Mann-Whitney test) were significantly higher in the LI than in the MI group (Fig. 4). The fish assemblage in the urban Rodríguez Stream contained only 7 species. Of the total catch, 95% was represented by only two species: *Cnesterodon decemmaculatus* (90%) and *Corydoras paleatus* (4.8%).

The number of riverine species in the Pescado and Buñirigo stream, in permanent contact with the Río de la Plata, was significantly higher in the downstream than in the upstream

reaches (Kruskal-Wallis test, Dunn's method for multiple comparison).

The CCA analysis indicated that the relationship between sites and species with environmental variables was significant, the significance of the first and all the canonical axes being *p* = 0.002. The percent variance contributed by the covariables (depth and temperature) was comparatively modest (5.3%). The maximum value of the inflation factor of environmental variables was 3.2, indicating the absence of multicollinearity among the set of selected variables.

The first and second axes of the CCA accounted for 76.6% of the relationship between species and the environmental variables. The conductivity (0.83), dissolved oxygen (0.31), and pH (0.21) were positively correlated with the first axis, while the SRP (−0.43) and ammonium (−0.26) were negatively correlated. The SRP and ammonium were the environmental variables that
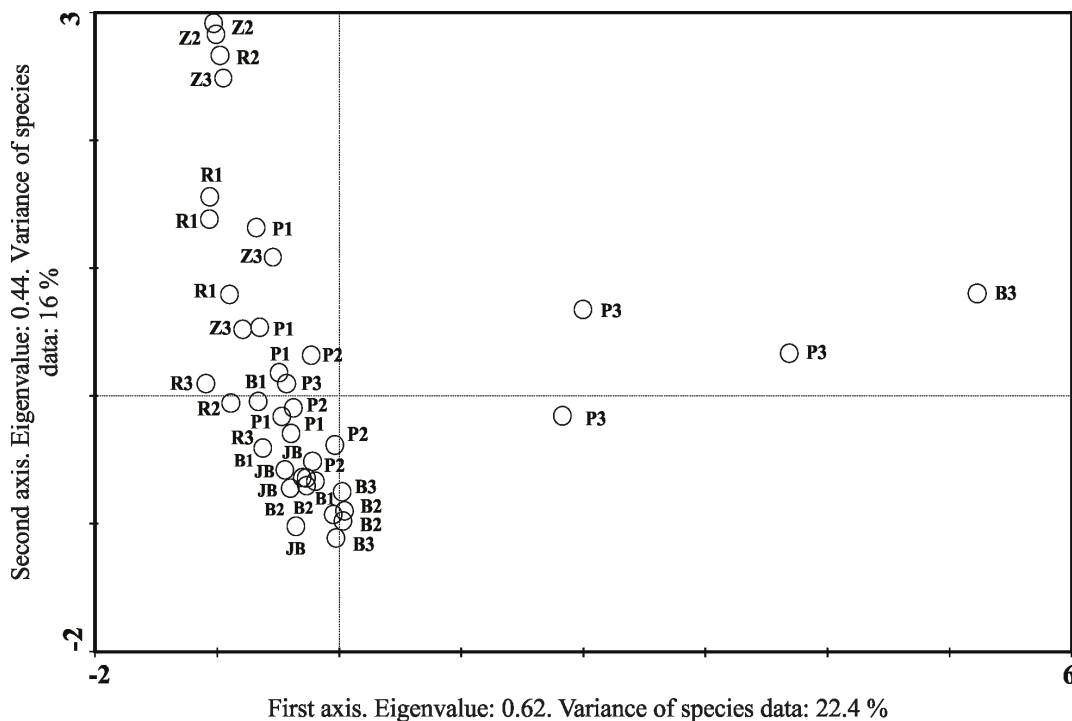

Figure 2. Correspondence analysis. Scatter plot of samples sites in pampean streams, Buenos Aires province, Argentina. R1-R3: Rodríguez, P1-P3: Pescado, Z2 and Z3: Zapata, B1-B3: Buñirigo, JB: Juan Blanco.
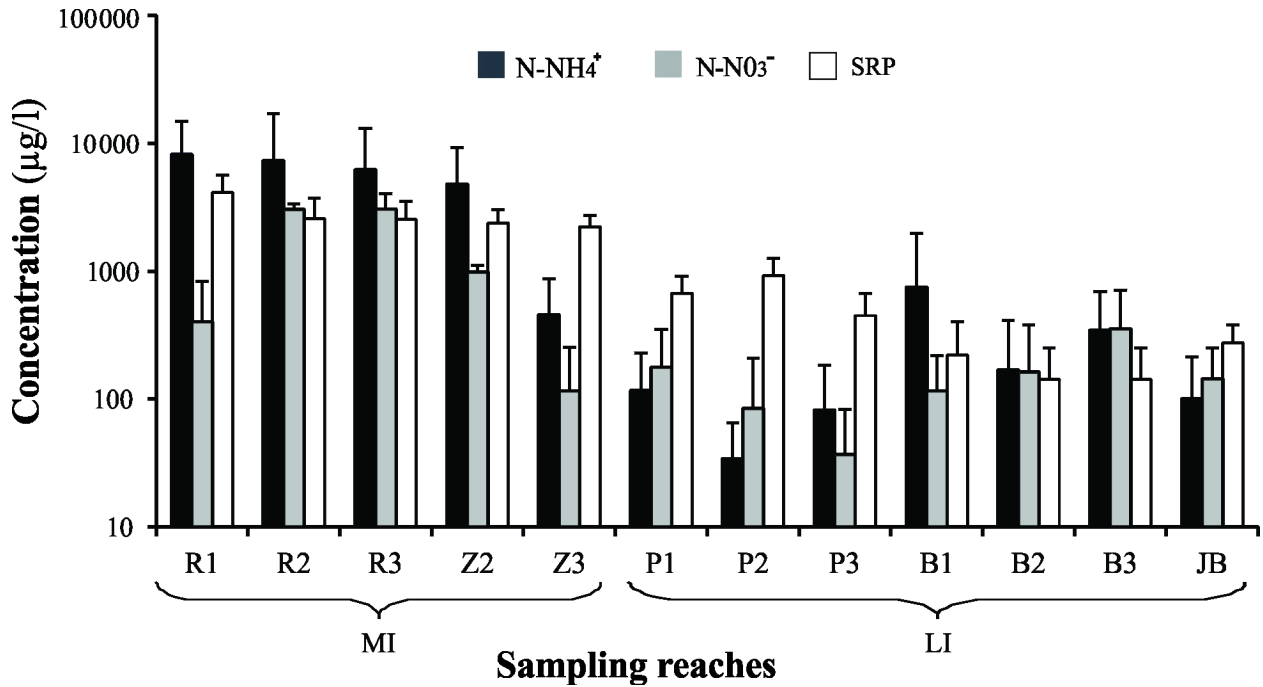
Figure 3. Mean concentration of nutrients in pampean streams sampled, Buenos Aires province, Argentina. MI: more impacted group; LI: less impacted group.
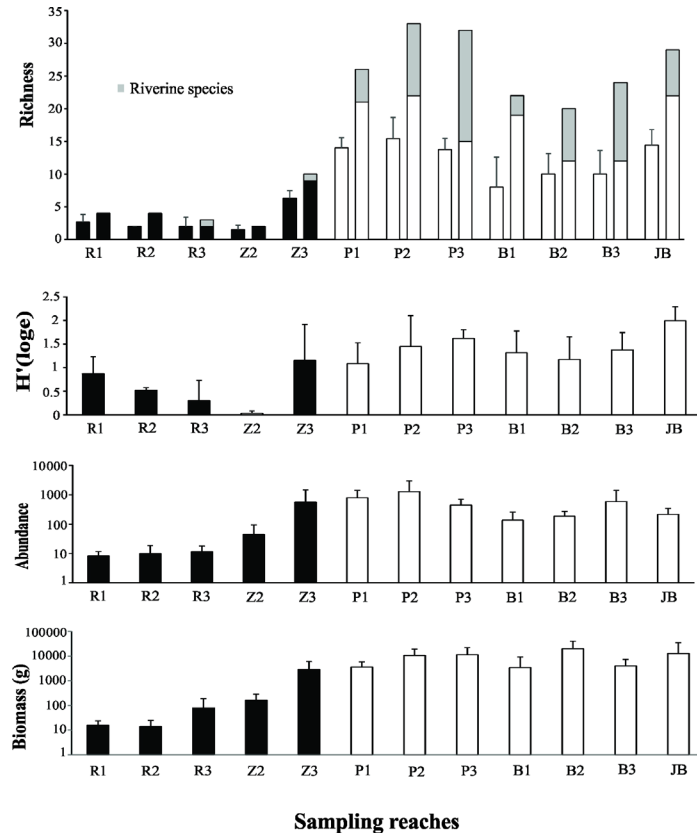

Figure 4. Mean species richness (first bar), total richness (second bar), Shannon diversity (H'), abundance and biomass, in all stream reaches of pampean streams, Buenos Aires province, Argentina. Black bars: MI reaches; white bars: LI reaches.
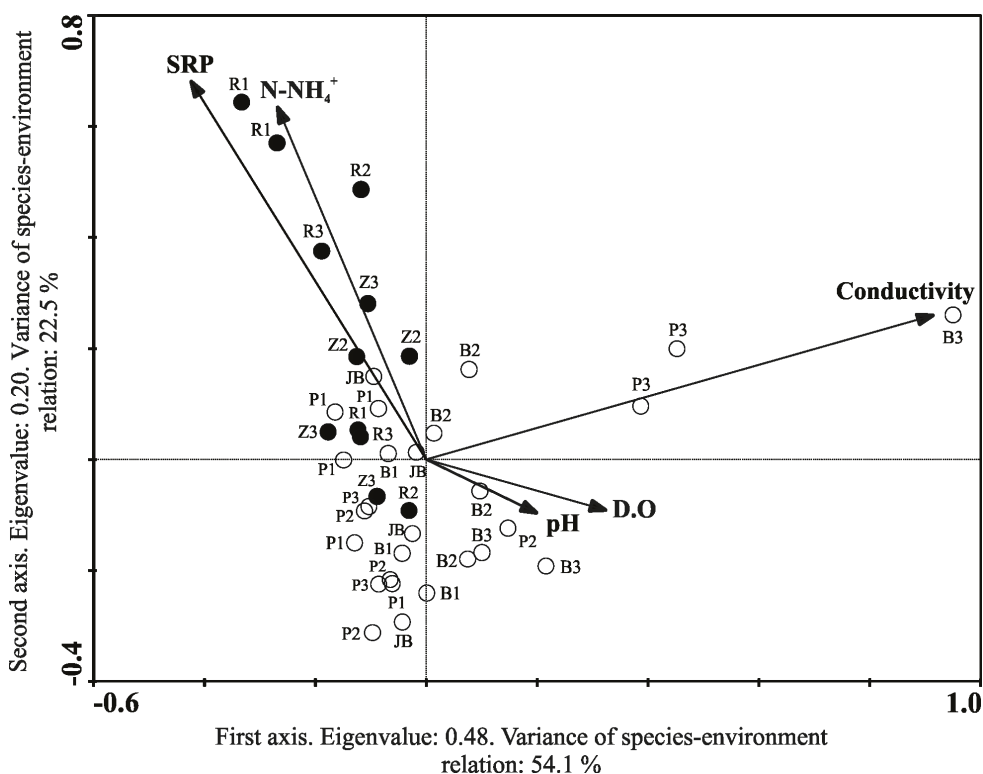
Figure 5. Canonical Correspondence Analysis. Biplot of stream reaches and the environmental variables measured in pampean streams, Buenos Aires province, Argentina. The LI stretches are represented by white dots and the MI stretches by black dots. The arrows point to the environmental variables.

exhibited the highest positive correlation with the second axis (0.61 and 0.54 respectively), followed by the conductivity (0.20). In the CCA biplot of the environmental variables in the stream reaches, the sites related to the highest values on the first axis were the lower reaches of the streams draining livestock basins and in permanent connection with the Río de la Plata (Fig. 5).

The fish assemblage was characterized by a dominance of juvenile stages of the riverine species such as *Parapimelodus valenciennis*, *Iheringichthys labrosus*, *Pachyurus bonariensis*, and *Plagioscion ternetzi* (Fig. 6). The sites related to the higher values of the second axis belong the MI group and were associated with the worse environmental conditions characterized by high concentrations of ammonium, SRP and low dissolved oxygen (Fig. 5). The dominant species in these reaches were *Corydoras paleatus*, *Rhamdia quelen*, and *Cnesterodon decemmaculatus*.

Nevertheless, the LI sites were associated with lower nutrient and higher dissolved oxygen concentrations. With the exception of *Pimelodus maculatus* and *Prochilodus lineatus*, the assemblage was characterized by species typically recorded in pampean streams representing good environmental conditions (Fig. 6). Most of the assemblages were represented by species of the family Characidae: *Charax stenoperus*, *Bryconamericus iheringii*, *Astyanx rutilus*, *A. eigenmanniorum*, *Oligosarcus oligolepis*, *O. jenynsii*, and *Pseudocorynopoma doriae*. Other species associated with the LI sites belonged to other families, such as *Cyphocharax voga*, *Hoplias argentinensis*, *Pimelodella laticeps*, *Otocinclus arnoldi*, *Loricariichthys anus*, *Hypostomus commersoni*, *Jenynsia lineata*, and *Australoheros facetus*.
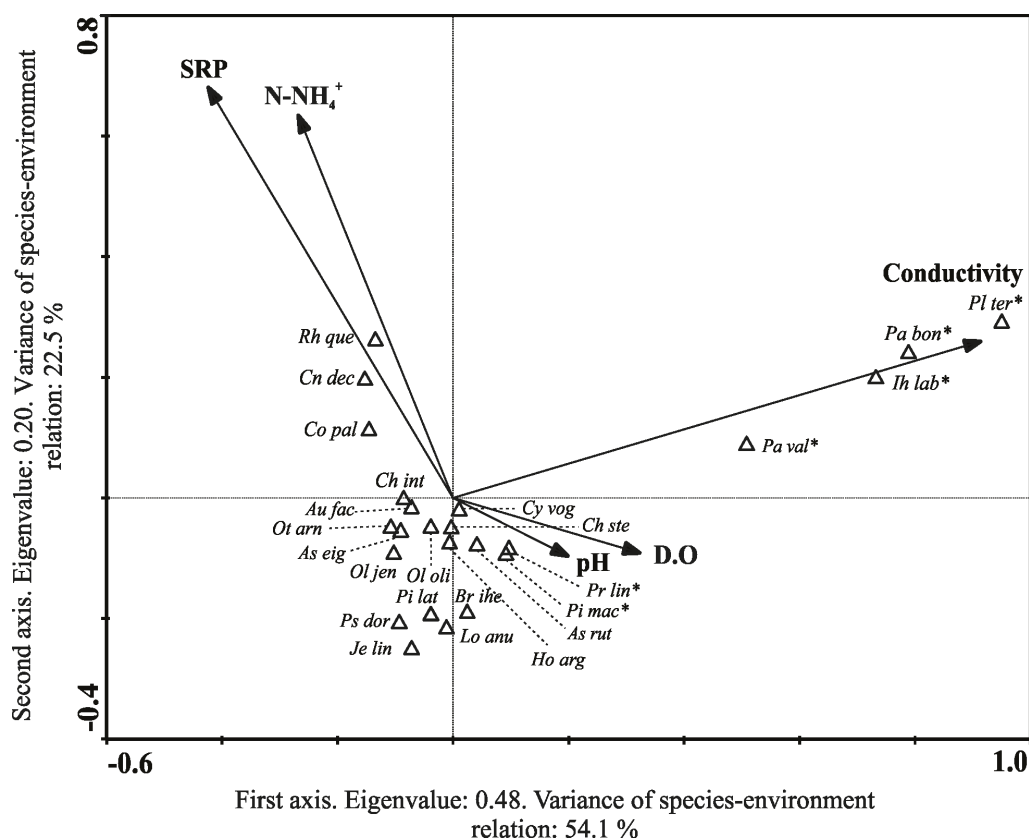
Figure 6. Canonical correspondence analysis. Biplot of species and environmental variables in measured in pampean streams, Buenos Aires province, Argentina. Species with an asterisk are riverine. *Cn dec, Cnesterodon decemmaculatus; Rh que, Rhamdia quelen; Co pal, Corydoras paleatus; Ch int, Cheirodon interruptus; Ot arn, Otocinclus arnoldi; As eig, Astyanax eigenmanniorum; Ch ste, Charax stenopterus; As rut, Astyanax rutilus; Cy vog, Cyphocharax voga; Pr lin, Prochilodus lineatus; Pi mac, Pimelodus maculatus; Ol oli, Oligosarcus oligolepis; Ol jen, Oligosarcus jenynsii; Au fac, Australoheros facetus; Ho arg, Hoplias argentinenensis, Ps dor, Pseudocorynopoma doriae; Pi lat, Pimelodella laticeps; Je lin, Jenynsia lineata; Lo anu, Loricariichthys anus; Br ihe, Bryconamericus iheringii; Pa val, Parapimelodus valenciennis; Ih lab, Iheringichthys labrosus; Pa bon, Pachyurus bonariensis; Pl ter, Plagioscion ternetzi*

DISCUSSION

Nutrient concentrations were an order of magnitude higher in the reaches associated with the MI group than those of the LI group, thus, pointing to the effect on adjacent streams of contaminant loads from urban and land used by industry. Soluble reactive phosphorus concentrations reported in the MI group were also an order of magnitude higher than previously reported for other pampean streams. Feijoo & Lombardo (2007) studied 41 rural streams in the Buenos Aires province, and reported SRP values

in the range of 52-433 µg/l, which values overlap the concentrations measured in the present LI group. Likewise, Mugni et al. (2013) recorded SRP concentrations in the range of 144-456 µg/l in a pampean stream surrounded by land use involving livestock and agriculture. High nutrient concentrations have been repeatedly reported in urban streams. Loiselle et al. (2016) studied nutrient concentrations in 150 streams in South, Central, and North America and reported that the concentration of SRP correlated with urban land coverage and population density. In Midwestern agricultural basins, USA, urban areas

Table II. Means and range of variation in physical and chemical parameters recorded in all reaches of pampean streams, Buenos Aires province, Argentina. MI: more impacted sites, LI: less impacted sites.

		O_2 (mg/l)	Cond. (µS/cm)	Temp (°C)	pH	$N-NH_4^+$ (µg/l)	$N-NO_3^-$ (µg/l)	PRS (µg/l)
MI	R1	1.6 (0.3 - 4)	986 (904 - 1,055)	23.7 (23 - 24)	7.5 (7.4 - 7.6)	8,192 (1,746 - 15,008)	402 (45 - 884)	4,125 (2,434 - 5,333)
MI	R2	3.5 (3 - 4)	1,519 (1,509 - 1,530)	22.9 (22.5 - 23.3)	7.6 (7.3 - 7.8)	7,331 (377 - 14,285)	3,046 (2,813 - 3,279)	2,582 (1,784 - 3,381)
MI	R3	9 (8.6 - 9.4)	1,305 (1,234 - 1,376)	26.8 (22.1 - 31.5)	8.2 (8 - 8.3)	6,230 (1,350 - 11,113)	3,056 (2,354 - 3,758)	2,537 (1,843 - 3,232)
MI	Z2	14.4 (13.7 - 15)	2,165 (2,050 - 2,280)	26.1 (22 - 30.2)	8.8 (8.4 - 9.2)	4,802 (1,667 - 7,936)	984 (893 - 1,075)	2,381 (1,913 - 2,849)
MI	Z3	8.8 (0.5 - 14.8)	1,590 (1,030 - 2,300)	26.9 (21 - 30)	8.5 (7.7 - 8.8)	455 (37.6 - 867)	116 (14 - 272)	2,240 (1,700 - 2,675)
LI	P1	7.0 (3.8 - 9)	320 (190 - 450)	25.8 (19 - 29.2)	7.3 (7.2 - 7.8)	117 (9 - 255)	177 (5 - 428)	677 (360 - 931)
LI	P2	9.4 (8.5 - 12)	1,590 (563 - 3,480)	28.1 (24 - 31)	8.5 (7.7 - 9)	34 (5 - 78)	84 (5 - 266)	932 (679 - 1,408)
LI	P3	10.8 (8.7 - 15)	2,941 (974 - 5,195)	26.8 (22.1 - 30)	8.2 (7.6 - 8.6)	82 (5 - 232)	37 (5 - 103)	451 (268 - 721)
LI	B1	6.0 (2.8 - 10)	362 (214 - 744)	22.5 (19 - 27)	6.9 (6.7 - 7.2)	748 (50 - 2,175)	116 (20 - 225)	220 (25 - 385)
LI	B2	12.3 (10.8 - 15)	1,880 (1,180 - 2,500)	22.8 (15 - 30)	7.9 (7.3 - 8.6)	169 (5 - 524)	163 (42 - 487)	142 (51 - 251)
LI	B3	9.2 (8.7 - 10.2)	5,070 (1,640 - 9,050)	20 (14 - 28)	7.8 (7.4 - 8.1)	751 (339 - 1,027)	486 (160 - 828)	181 (160 - 191)
LI	JB	7.4 (4 - 9.7)	755 (170 - 1,286)	23.7 (20 - 27)	7.4 (6.5 - 8.1)	101 (5 - 250)	144 (65 - 303)	276 (168 - 388)

were found to strongly influence the dissolved-P concentrations in streams despite representing only 5% of the area of the basin (Osborne & Wiley 1988). In Great Britain, even sparsely populated rural settlements have been reported to cause significant nutrient enrichment in lowland streams (Jarvie et al. 2010).

In the present study, occasional peaks of non-ionized ammonia in the Zapata Stream of the MI Group (0.8 and 0.9 mg/l) were higher than the lethal concentrations reported in the literature, with fish mortality starting at roughly 0.6 mg/l (Durborow et al. 1997). The reported 96-h-LC50 of non-ionized ammonia for freshwater fish species ranges between 0.068 and 2 mg/l (Eddy 2005).

Dissolved oxygen concentrations occasionally dropped to quite low values in the Rodríguez and Zapata streams of the MI Group (0.3 and 0.5 mg/l, respectively). Rimoldi et al. (2018), in a study of the urban El Gato Stream located close (3.5 km) to the Rodríguez Stream, likewise had recorded similarly low dissolved oxygen concentrations (0.5-1.3 mg/l). Minimum oxygen concentrations fell below the LC50 of the common pampean stream species *Pimelodella laticeps* and *Corydoras paleatus* reported by Gómez 1993 (0.88 and 0.72 mg/l, respectively). In the same study, the author also reported sublethal effects such as equilibrium loss in the 0.26-1.53 mg/l range for several Neotropical-fish species. Smale & Rabeni (1995) in Missouri, USA demonstrated that the ventilation and opercular movement in 35 stream species of fish ceased when the dissolved oxygen concentration decreased below 0.49-1.6 mg/l. *Corydoras paleatus* and *C. decemmaculatus*, the dominant species at the most impacted sites in the present study are comparatively tolerant to hypoxia. *Corydoras paleatus* makes use of the caudal portion of the intestine as an accessory air-breathing organ (Plaul et al. 2016),

while *C. decemmaculatus* takes advantage of the higher dissolved oxygen concentration in the uppermost layer of the water without needing to alter its swimming posture as a result of an upward orientation of its mouth and a flattening of its head (Lewis 1970, Kramer & Mehegan 1981). Rimoldi et al. (2018) reported mortalities of up to 60% for *C. decemmaculatus* in laboratory exposures to the urban El Gato Stream water. Furthermore, several other contaminants have been determined in the El Gato Stream, such as metals. The present evidence suggests that the overall effect of the combined contaminant loads results in low species richness, as determined in the Rodríguez and Zapata streams. In the present study, the downstream R3 site evidenced low richness at only 3 species, of which one was riverine. In 1999, 19 species had been registered throughout the Rodríguez stream (Remes Lenicov et al. 2005). Those authors had observed an increase in richness downstream, with 16 species had recorded at the downstream site, nine of which were pampean and seven riverine. The present evidence suggests that increased water quality deterioration caused the disappearance of sensitive species and affected the entrance of riverine species from the Río de la Plata into that lower stretch of the Rodríguez Stream. Fish assemblages in the Cahaba River, Alabama, USA, evidenced changes in the relative abundance, the disappearance of two species was registered between 1984 and 1995-1997, in accordance with increased urbanization and water quality deterioration (Onorato et al. 2000). Wang et al. (2000) studied 47 streams in southeastern Wisconsin, recorded decreases in the number of species, the density, and the biotic integrity at sites where urbanization had increased by only 10% between 1970 and 1990. Weaver & Garman (1994), at the Tuckahoe Creek watershed, Virginia, USA, reported a lower abundance and diversity and 6 fewer species in 1990, compared with the

fish composition reported in 1958 as a result of increased urbanization. The authors concluded that urban land use was related to the increase in toxic and nutrient loads, removal of the riparian areas, and increased sedimentation. Changes in the fish assemblages were related to the decrease in the species sensitive to contamination along with dominance of trophic generalists.

The three dominant species at the MI sites in the present study (*C. decemaculatus*, *C. paleatus* and *R. quelen*) have been reported previously as dominant in contaminated environments. *Corydoras paleatus* and *C. decemmaculatus* were abundant downstream in the Suquía River of Córdoba city, Argentina, where high nutrients and low dissolved oxygen concentrations were recorded (Hued & Bistoni 2005). Similarly, both species were also abundant in accordance with high nutrients and low dissolved oxygen concentrations at contaminated streams adjacent to cultivated plots and dairies in the basin of the Santa Lucía River, Uruguay (Chalar et al. 2013). *Rhamdia quelen* attained the highest biomass in urban streams in Maringá city, Brazil (Cunico et al. 2006) and was the most abundant species in the most urbanized areas around Toledo city, Paraná, Brazil (Daga et al. 2012). All three dominant species at the MI sites are omnivores, likely profiting from the increased loads of allochthonous organic matter. Cunico et al. (2011) reported that benthic omnivores predominated in fish assemblages in urban streams in the USA and Brazil.

On the other hand, in the present study, the fish assemblages at the LI sites surrounded by pastures devoted to livestock raising, evidenced a greater number of species belonging to several taxonomic and ecological groups. Species of the orders Characiformes and Siluriformes were predominant in the assemblage. Although omnivorous species were also present, different

trophic groups were well represented, *i. e.,* the piscivorous by *Oligosarcus jenynsii, O. oligolepis*, and *Hoplias argentinensis* (Barla et al. 2003); the invertivorous by *Pseudocorynopoma doriae* (Ferriz et al. 2012, Brancolini et al. 2015); and the detritivorous by *Cyphocharax voga* (González Sagrario & Ferrero 2013). *Loricariichthys anus* and *Hypostomus commersoni* were also common in the LI streams. This pattern of Characiformes and Siluriformes dominance is consistent with the expected composition in the Neotropical region (Lévêque et al. 2008, Reis 2016). Several authors reported that the dominance of those two orders with a broad trophic spectrum are accordingly indicators of balanced assemblages associated with good environmental conditions (Araujo et al. 2003, Ferreira & Casatti 2006, Pinto et al. 2006, Bastos dos Santos & Esteves 2015).

The number of riverine species in the LI streams in permanent contact to the Río de la Plata was significantly higher in the downstream than in the upstream reaches. The most abundant fish at these sites were the juveniles of species from the Río de la Plata, such as *Parapimelodus valenciennis*, *Iheringichthys labrosus*, *Pachyurus bonariensis*, and *Plagioscion ternetzi*.

The increased conductivity recorded at the downstream sites of the Buñirigo and Pescado streams (Figs. 5 and 6) was produced by the higher groundwater contribution during dry periods (Mugni 2009, Bazán et al. 2011). Close to the mouth of the Río de la Plata, the Buñirigo Stream of the LI group receives loads from two industries. The different composition of the benthic-invertebrate assemblages at this site have been interpreted as the result of deterioration in the sediment quality (Ocón & Rodrigues Capítulo 2012). Nevertheless, in the present study, no effect was observed on the fish assemblages presumably because of the attenuating effect of the Río de la Plata. A high proportion of riverine juveniles were recorded in

the lower stretches of the Buñirigo and Pescado streams (Fig. 5), pointing to the influence of the Río de la Plata close to the mouths of those streams. Hitt & Angermeier (2008) studied 308 wadeable streams in the Mid-Atlantic Highland region, USA and observed that sites near the confluences of mainstream rivers supported a greater species richness along with an abundance of riverine species of the catostomid, cyprinid, and ictalurid families than did sites farther upstream from those confluences. The authors emphasized the significant role of stream-river connectivity in structuring the richness and abundance of those families owing to their movement from the rivers to the streams during seasonal spawning migrations. Juveniles of the riverine *Micropogonias furnieri* were by far the most abundant species in the lower stretches of the Pando (Acuña-Plavan et al. 2010, Gurdek & Acuña-Plavan 2016) and Solís Chico (Acuña-Plavan et al. 2017) streams and the Ajo River (Solari et al. 2015) close to the mouths of those rivers on the Río de la Plata. The high abundance of juvenile riverine species underscores the essential function of the tributaries as nurseries of riverine assemblages. Therefore, those sites play a major role in the population dynamics of several species that inhabit the Río de la Plata and as such represent priority areas for protection and conservation.

CONCLUSIONS

This study demonstrated that streams running through land used by industry and urbanized land were characterized by higher nutrient and low oxygen concentration and a significantly lower species richness and abundance of fish because of the disappearance of the most sensitive species. By contrast, streams surrounded by land devoted to livestock

breeding evidenced good water quality and fish assemblages that were characterized by a higher species richness and abundance. The evidence garnered in our study suggests that a deterioration in water quality is the cause of the observed impoverishment of fish assemblages in the urban pampean streams.

The downstream sites in the less impacted streams contained fish assemblages in which the juvenile stages of riverine species were dominant, pointing to the significance of the preservation of those habitats in the maintenance of the fish fauna in the Rio de la Plata.

Acknowledgments

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SUPPLEMENTARY MATERIAL

Table SI. List of species, abundance and standard length (cm) recorded in pampean streams, Buenos Aires province, Argentina. P: pampean species, R: riverine species.

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Author contributions

AP, HM and CB made substantial contributions to conception, design and acquisition of data, as well as, analysis and interpretation of data and intellectual contribution to manuscript drafting. NM and IG participate actively of the samplings, data acquisition in the field, chemical determinations of nutrients in the laboratory and made contributions to the draft. TM and PC participate in the final edition of the text and reviewed critically the final version of the text adding a relevant intellectual contribution to the draft.