Acta Limnologica Brasiliensia, 2011, vol. 23, no. 4, p. 412-425 http://dx.doi.org/10.1590/S2179-975X2012005000020

Different levels of taxonomic resolution in bioassessment: a case study of oligochaeta in lowland streams

Diferentes níveis de resolução taxonômica em biomonitoramento: um estudo de caso de oligoquetados em rios de planícies

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Abstract: Aim: This study evaluated the use of oligochaetes at different levels of taxonomic resolution as environmental indicators in Argentine lowland streams affected by different land uses. **Methods:** Sampling sites were grouped based on the physicochemical and habitat characteristics (low-, moderate-, and high-impact disturbance). Collection of the oligochaetes samples was carried out seasonally in sediment and vegetation habitats. **Results:** The increases in nutrients and organic matter produced elevated densities of the Oligochaeta, but when the disturbance also involved changes in the physical habitat or enhancements in toxic substances, the abundance decreased significantly to values even lower than those of non-impacted environments. The responses of Naidinae and Tubificinae were similar. The density of the Pristininae decreased with increasing impact, but those of the Enchytraeidae and Rhyacodrilinae increased at the most highly impacted sites. The Opistocystidae were not recorded in high-impact sites. Species richness and diversity (H') were lower in high-impact sites and even lower in sediments. Some species presented no restrictions in the habitat type or with the contamination level: *Limnodrilus hoffmeisteri*, *Dero furcatus*, *D. digitata*, *D. pectinata*, *Pristina longiseta*, and *P. aequiseta*. Moreover, *Trieminentia corderoi*, *Slavina appendiculata*, and *Aulodrilus pigueti* exhibited the highest abundances at low-impact sites and were not registered in high-impact sites. **Conclusions:** The Oligochaeta show a relatively wide ecological valence through their extensive number of species. Although lower taxonomic levels can give information about environmental status, test-species' sensitivities to different types and degrees of contamination will be of utmost relevance to the evaluation of ecological quality.

Keywords: annelids, land use, habitat preferences, sediment, macrophyte.

Resumo: Objetivo: Este estudo analisou as uso de oligoquetos em diferentes níveis de resolução taxonômica como indicadores ambientais em rios de planície Argentina afetadas por diferentes usos da terra. **Métodos:** Os sítios de amostragem foram agrupados com base nas características físico-químicas e habitat (perturbação baixa, moderada ou alta). Amostras de oligoquetos foram coletadas sazonalmente em habitats de sedimentos e vegetação. **Resultados:** Os aumentos de nutrientes e matéria orgânica resultaram em densidades elevadas de Oligochaeta, mas quando a perturbação também envolveu mudanças no habitat físico ou incrementos em substâncias tóxicas, a abundância diminuiu de forma significativa para valores ainda mais baixos que os de ambientes naõ perturbados. As respostas dos Naidinae e Tubificinae foram semelhantes. A densidade de Pristininae diminuiu com o aumento da perturbação, mas as densidades de Enchytraeidae e Rhyacodrilinae aumentaram nos locais mais altamente perturbados. Os Opistocystidae não ocorreram em locais de alta perturbação. A riqueza de espécies e a diversidade (H') foram menores em locais de perturbação elevada e ainda mais baixos nos sedimentos. Algumas espécies não apresentaram restrições no tipo de habitat ou com o nível de contaminação: *Limnodrilus hoffmeisteri, Dero furcatus, D. digitata, D. pectinata, Pristina longiseta* e *P. aequiseta.* Além disso, *Trieminentia corderoi, Slavina appendiculata* e *Aulodrilus pigueti* exibiram uma maior abundância em locais de baixa perturbação e não foram registrados em locais com elevadas perturbações. **Conclusões:** Os Oligochaeta apresentaram uma valência ecológica relativamente ampla, através de seu extensivo número de espécies. Embora os níveis taxonômicos mais baixos podem dar informações sobre o status ambiental, testes com espécies com diferentes sesibilidades para diferentes tipos e graus de contaminação serão da maior relevância para a avaliação da qualidade ecológica.

Palavras-chave: anelídeos, uso da terra, as preferências de habitat, sedimentos, macrófitas.

1. Introduction

In freshwater systems, the oligochaetes are often the most diverse and/or abundant group of benthic invertebrates. From the 5,000 species described worldwide, 1,700 are aquatic with 1,111 being from continental aquatic environments, 100 from underground waters, and the rest from the oceans (Wetzel et al., 2006). These annelids participate in the trophic networks of the aquatic systems as a feeding resource of turbellarians, hirudins, chironomids Tanipodinae, crayfish, amphipods, amphibians, fish, and birds (Ezcurra de Drago et al., 2007). Oligochaetes inhabit all types of substrata, but reach a higher density and richness mainly in fine sediments (Marchese, 2009). Due to their ecological prevalence and presence in all environments, the oligochaetes are widely utilized as indicators of environmental conditions. Because of the difficulty of their taxonomic determination, however, even though they are present in samples of benthic macroinvertebrates, the Oligochaeta worms are generally referred down to only the class or family level, or even are omitted entirely from any analysis of the faunistic structure and composition of lotic environments (Alves et al., 2006).

Depending on the taxonomic level of oligochaete determination reached in a given study, their reported tally can be interpreted in different ways for the same particular situation. Howmiller and Beeton (1971), for instance, considered the high abundance of Oligochaeta as an indication of organic enrichment, whereas Martins et al. (2008) used the relative abundance of Tubificidae, rather than the Oligochaeta in their entirety, for the same purpose. Nevertheless, the Howmiller-Scott index (Howmiller and Scott, 1977) provided detailed information on the quality of an aquatic habitat because the means of evaluation relied not only on the full identification of all constituent species but also on the knowledge of the ecological demands of a reasonable number of the most abundant species in the environment.

Although an increasing number of oligochaete studies have been conducted in streams and rivers of South America (Alves et al., 2006; Armendáriz, 2000; Armendáriz et al., 2011; Armendáriz and César, 2001; Dornfeld et al., 2006; Marchese and Paggi, 2004; Pavé and Marchese, 2005), the following questions still remain unanswered for the neotropical region in general:

1) What physical, chemical, and habitat changes of the type that could affect the normal development of oligochaetes are produced in lowland streams running through areas with different land uses?
2) How do the different taxonomic levels of oligochaetes respond to different types and degrees of contamination?
3) What oligochaete species can be identified as being relevant to the diagnosis of the different classes of deteriorating environmental quality?

The aim of this study was to evaluate the tolerance of oligochaetes at different taxonomic resolutions to diverse types of pollution and intensities of environmental impact (low, moderate and high) within lowland streams. We intended to utilize this more detailed information for employing these annelids as environmental indicators. We also evaluated the role of the main habitats available within pampean streams in determining the spatial distribution and abundance of the various oligochaete species.

2. Methods

2.1. Study area

The study area is located in Buenos Aires province (Argentina) within the Río de la Plata subcatchment (southeastern South America). Buenos Aires province has a surface area of 307,500 km^2 and is included in the pampean region, a vast grassy plain covering central Argentina. The lowland streams originate in small depressions and are characterized by a low flow rate as a result of the gradual slope of the surrounding terrain, by high levels of suspended solids, by silty sediment in the benthos, and by reduced rithron (Rodrigues Capítulo et al., 2010).

These systems also lack a forested riparian zone, which absence leads to an increased irradiation even in their upper reaches along with the development of diverse and dense macrophyte communities. The pampean lowland streams furthermore exhibit an autochthonous primary production relying on algal and macrophyte communities plus autotrophic production-respiration ratios (Vilches and Giorgi, 2008) and are characterized by high nutrient levels relative to the values found in forested streams (Binkley et al., 2004), even in sites with low or moderate cattle raising and agriculture (Feijoó et al., 1999; Bauer et al., 2002).

The three lotic systems selected for this study are small tributaries located in the surroundings of the city of La Plata, the capital of Buenos Aires province. These three streams—Don Carlos (DC), Martín (M), and Baldovinos (B)—traverse the pampean plain to empty into the Río de la Plata, and each is affected by a different set of anthropic activities. All are small shallow lotic systems of the first order and of lengths between 4 (DC) and 14.5 (Martin) km. We selected three sampling sites in each one: Site 1 (upstream section), Site 2 (midstream section) and Site 3 (downstream section; Figure 1).

The streams selected are subjected to low levels of perturbation stemming from human intervention throughout their upper courses, but in their middle and lower reaches they receive the discharges from urban or industrial areas. Martín stream, however, is less altered than the others: it flows through a developed area in its middle reach, which segment then crosses a nature reserve before flowing into the Río de la Plata. By contrast, Don Carlos stream receives the discharge from a textile plant right after the headwaters, and in addition to this input, major modifications have been made in its physical habitat through a clearing away of the macrophytes, dredging, and a straightening of the riverbed. In the middle sector the streambed consists in a consolidated bottom ($CaCO3$ concretions) having a greater proportion of sand and gravel, the surface of which benthos is carpeted with mats of filamentous bacteria and cyanophytes. In the lower reach the stream has been channellized and even given a cement bottom. Baldovinos stream, though remaining unaltered in its headwaters, thereafter flows through highly developed areas and thus is modified by continuous dredging and the discharges from the surrounding farmlands.

2.2. Water quality

At each site, the following physical and chemical variables were measured: dissolved oxygen (YSI 52 dissolved oxygen meter), temperature plus pH (Hanna HI 8633), conductivity (Lutron

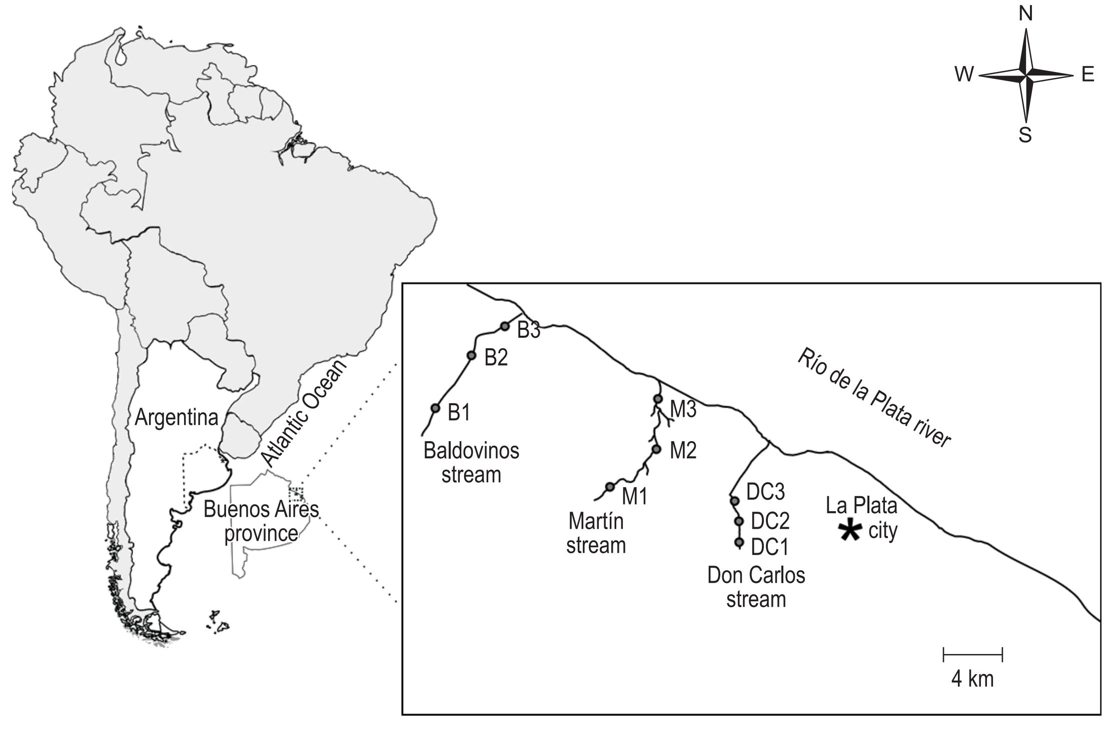

Figure 1. Map of the study area showing streams and sampling locations.

CD-4303), and turbidity (Turbidity Meter 800-ESD). Water samples were taken for analysis of phosphate ($P\text{-}PO_4^{-3}$), ammonium ($N\text{–}NH_4^{+1}$), nitrate ($N\text{-}NO_3^{-1}$), nitrite ($N\text{–}NO_2^{-1}$) and oxygen demand (BOD_5 and COD; Mackereth et al., 1978; APHA, 1995). The percentage of organic matter in the sediment was calculated by weight loss after ignition at 500 °C for 4 hours from a subsample (20 g net weight).

2.3. Oligochaete Assemblages

In lowland streams the sediment and the vegetation are the primary habitats for oligochaete residence and development. We therefore performed samplings seasonally (March, June, September, and December 2005) and collected samples of those two habitat types in triplicate at the three sampling sites of each stream. Samples of sediment were taken with an Ekman grab (100 cm^2). Samples of hydrophytes were collected within the area subsumed by a plexiglas square of 1,300 cm^2, while sieves of 250-μm mesh size were used to collect phytophilous oligochaetes. In the laboratory, the oligochaetes were stained with erythrosin B, separated under a stereomicroscope, and finally identified by light microscopy through the use of standard morphological keys (Brinkhurst and Marchese, 1992). Enchytraeidae and Megadrili were not identified at the species level since the appropriate identification keys were not available. The collected material was preserved in 70% (v/v) aqueous ethanol. The oligochaete numbers were counted and their density expressed as ind/m^2 for each sampling site as the average of the three replicates. The diversity index (Shannon and Wiener, 1949) and species richness (as number of taxa) were also calculated.

2.4. Statistical analysis

The sampling sites were arranged according to their physicochemical characteristics on the basis of the principal-components analysis (PCA) through the use of the statistical package CANOCO (Ter Braak, 1998). For this analysis we used the mean annual values. The physicochemical data were standardized with the Statistica program (STATISTICA for Windows 4.5 Soft Inc., 1993). To test whether differences existed between the sampling-site groups identified, multivariate analysis of variance (MANOVA, Wilk's lambda and Hotelling's Trace) was employed.

The Poisson distribution was used to model the distribution of the oligochaete counts categorized by two factors: the habitat (vegetation and sediment) and the degree of impact (low, moderate, and high). The PROC GENMOD of SAS (version 9.1) software was used to perform the Poisson-regression analysis of these data with a log-link function. Because of the occurrence of excessive zeros, the degree of overdispertion was taken into consideration and controlled. The rare species (frequency of occurrence at lower than 4) were excluded from the analysis.

Because the sample sizes were different in two habitats (sediment and vegetation), we used rarefaction methods for comparing the mean diversity and the mean richness. Rarefaction uses the probability theory to derive expressions for the expectation and variance of species diversity and richness for a sample of a given size. This method "rarefies" its samples down to a common abundance level and then compares species diversity and richness. The process was repeated 1,000 times to generate a mean and a variance of species diversity and richness. For this calculation, we used the EcoSim 7 software (Gotelli and Entsminger, 2004).

3. Results

3.1. Water and habitat quality

An initial exploratory PCA indicated the main differences between the sites with respect to the physicochemical parameters recorded. The first factor—determined by the conductivity, the turbidity, the dissolved oxygen, the NH_4^+, and the BOD_5—explained 51.4% of the variance, while the second factor—associated with the NO_3^-, the PO_4^{+3}, and the COD—explained 20.6% (Figure 2). The sampling sites were arranged in 3 main groups: In the first group, M1, M2, M3, DC1, and B1 had the highest levels of dissolved oxygen. This group was regarded as being in the category of low impact (LI) with respect to water quality. The second group consisted in sites B2 and B3, which pair contained the highest levels of nutrients (especially NO_3^-). This group was considered to be of moderate impact (MI). The DC2 and DC3 sites of the third group exhibited the highest levels of conductivity, COD, and NH_4^+. This group was classified at the level of high impact (HI) with respect to water quality.

The difference between these three groups (LI, MI, and HI) was highly significant in terms of the physical and chemical variables analyzed (Lambda Wilks p = 0.0002; Hotelling Trace p = 0.05; Table 1). The assumptions of normality and variance homogeneity were met for this analysis.

3.2. Biota quality

During this study, 13,800 individuals belonging to the families Naididae, Opistocystidae, Enchytraidae, and Megadrili were collected and identified. The family Naididae was represented by 39 species (19 Naidinae, 14 Pristininae, 5 Tubificinae and 1 Rhyacodrilinae). The Opystocistidae were represented by a single species (Table 2).

3.3. The oligochaetes

The mean density of total oligochaetes was higher at the sites with MI, where the values exceeded 10,000 ind.m^{-2}; and at those sites the organic matter reached mean values of 5.6%. At the sites with the highest percentage of organic matter (8.5%), but with physicochemical and habitat variables corresponding to the HI sites, the density did not exceed 5,000 ind.m^{-2} (Figure 3).

3.4. Oligochaeta families and subfamilies

The Tubificinae subfamily was more abundant at sites with low impact, whereas the Naidinae dominated at the moderate and high impacted sites. The Pristininae were registered in minor proportions and decreased in abundance along the gradient of environmental degradation. The Rhyacodrilinae, the Enchytraeidae, and the Opistocystidae were the taxa with the lowest densities. Among these three, the Enchytraeidae dominated at the high impacted sites (Figure 4).

Table 1. Result of the Hotelling test: Alpha = 0.05; Error: common covariance matrix; df: 33. Different letters (A,B,C) indicate significant differences (p ≤ 0.05).

Impact	Conductivity	DO	NO_3	NH_4	PO_4	BOD_5	COD	Turbidity	n			
L I	537.2	4.8	2.2	0.14	0.68	6.9	21.5	25.7	20	A		
M I	692.6	4.2	4.6	0.10	1.08	9.9	29.5	19.4	8		B	
H I	973.0	3.1	0.9	0.71	0.24	20.4	29.2	14.4	8			C

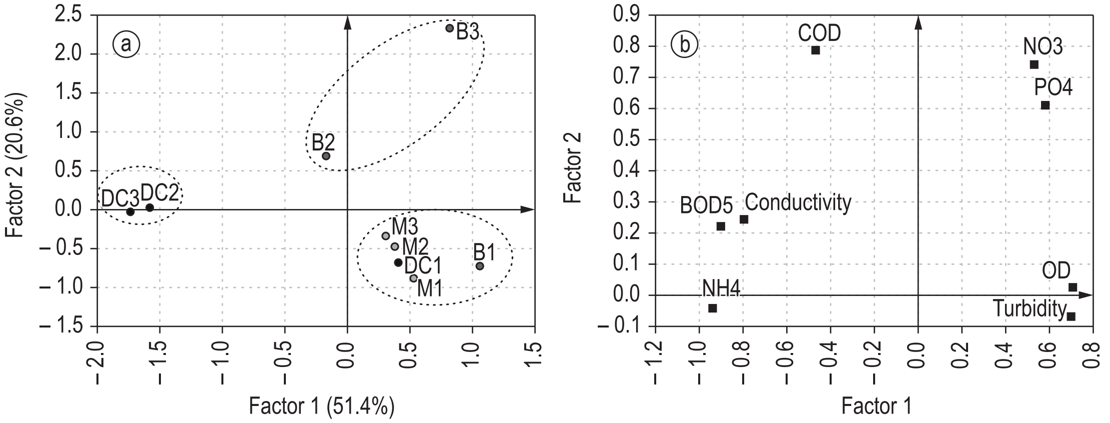

Figure 2. PCA-ordination diagram showing a) environmental variables and b) sampling sites.

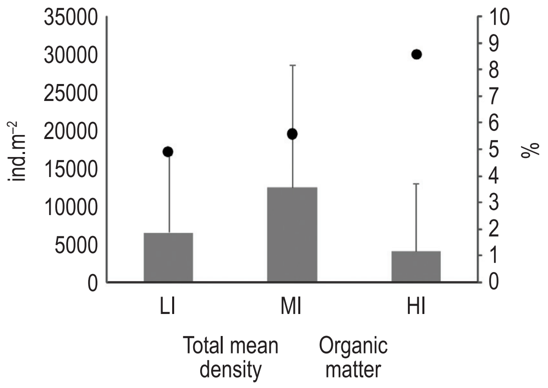

Figure 3. Total density of oligochaetes and percentage of organic matter in low-, moderate- and high-impact sites.

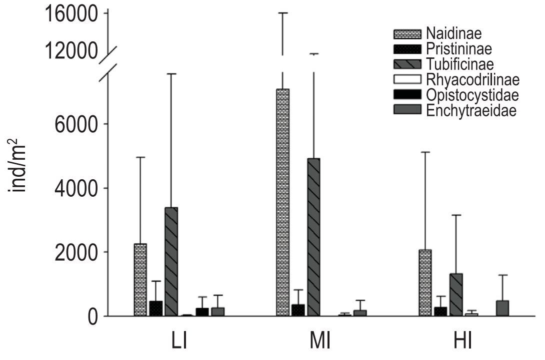

Figure 4. Relative abundances and standar error of the Naidinae, Tubificinae, Pristininae, and Rhyacodrilinae subfamilies and the Enchytraeidae and Opistocystidae families in low-, moderate- and high-impact sites.

Table 2. The species of Oligochaeta registered in this study.

Oligochaete	Taxa	Abbreviation
Naididae Naidinae	*Chaetogaster diaphanus* (Gruithuisen, 1828)	Chae dip
	Chaetogaster diastrophus (Gruithuisen, 1828)	Chae dis
	Dero (Dero) sawayai Marcus, 1943	Dero saw
	Dero (Dero) digitata (Müller, 1773)	Dero dig
	Dero (Dero) pectinata Aiyer, 1929	Dero pec
	Dero (Dero) multibranchiata Steiren, 1892	Dero mul
	Dero (Dero) botrytis Marcus, 1943	Dero bot
	Dero (Aulophorus) costatus (Marcus, 1944) emm. Harman, 1974	Dero cos
	Dero (Aulophorus) furcatus (Müller, 1773)	Dero fur
	Allonais lairdi Naidu, 1965	Allo lai
	Stephensoniana trivandrana (Aiyer, 1926)	Step tri
	Nais communis Piguet, 1906	Nais com
	Nais variabilis Piguet, 1906	Nais var
	Nais bretscheri Michaelsen, 1899	Nais bre
	Paranais frici Hrabé, 1941	Para fri
	Slavina appendiculata d'Udekem, 1855	Slav app
	Slavina isochaeta Cernosvitov, 1939	Slav iso
	Slavina evelinae (Marcus, 1942)	Slav eve
	Stylaria lacustris (Linnaeus, 1767)	Styl lac
Pristininae	*Pristina jenkinae* (Stephenson, 1931)	Pris jen
	Pristina aequiseta Bourne, 1891	Pris aeq
	Pristina osborni (Walton, 1906)	Pris osb
	Pristina synclites Stephenson, 1925	Pris syn
	Pristina leidyi Smith, 1896	Pris lei
	Pristina longisoma Harman, 1977	Pris lsm
	Pristina longidentata (Harman, 1965)	Pris lon
	Pristina proboscidea Beddard, 1896	Pris pro
	Pristina macrochaeta Stephenson, 1931	Pris mac
	Pristina breviseta Bourne, 1891	Pris bre
	Pristina americana Cernosvitov, 1937	Pris ame
	Pristina acuminata Liang, 1958	Pris acu
	Pristina sima (Marcus, 1944)	Pris sim
	Pristina notopora Cernosvitov, 1937	Pris not
Tubificinae	Tubificinae inmature	Tubi inm
	Aulodrilus pigueti Kowalewski, 1914	Aulo pig
	Limnodrilus hoffmeisteri Claparede, 1862	Limn hof
	Limnodrilus udekemianus Claparede, 1862	Limn ude
	Limnodrilus claparedianus Ratzel, 1868	Limn cla
	Tubifex tubifex (Müller, 1774)	Tubi tub
Rhyacodrilinae	*Bothrioneurum americanum* Beddard, 1894	Both ame
Opistocystidae	*Trieminentia corderoi* (Harman, 1969)	Trie cor
Enchytraeidae		Ench
Megadrili		Mega

3.5. Oligochaeta species and habitats

Both the diversity and richness of the taxa decreased throughout the environmental-quality gradient in the direction of low to high impact, but were more plentiful in the vegetation habitat for all types of sites. At the LI sites, a richness of more than 30 taxa was registered with mean-diversity values of 2.6 in the vegetation. At sites with the highest impact, the richness in the vegetation habitat exceeded an average of 22 taxa, whereas the diversity reached only values of 2.2 (H'). Those HI sites evinced a clear distinction between the richness and the diversity-rarefaction curves between the sediment and the vegetation. This observation also applied to the range of sites with LI, while the MI sites exhibited overlapping values between the two habitats (Figure 5).

Most of the species analyzed showed significant differences in density ($p < 0.05$) between the three

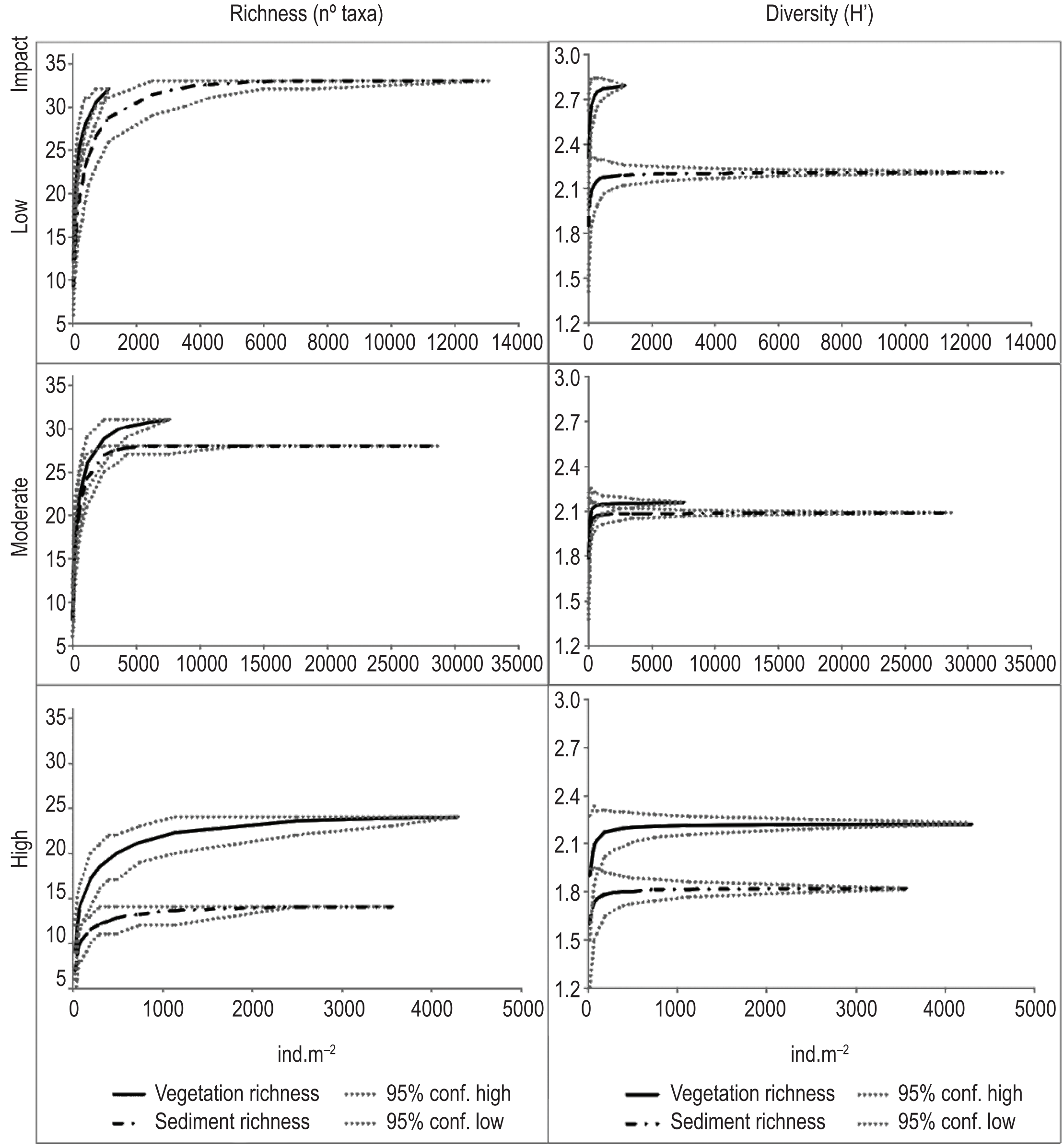

Figure 5. Species-rarefaction curves of richness (number of taxa) and Shannon diversity index (H') based on the number of individuals in the sediment and vegetation habitats. The individual means (and 95% CI) expected (based on 1,000 simulations) are considered different if the CIs do not overlap.

groups of sites formed from water quality and habitats of LI, MI, and HI (Table 3). The density of *Dero furcatus* increased at the HI sites, whereas *Aulodrilus pigueti* and *Trieminentia corderoi* exibited high densities at the LI sites and disappeared entirely at sites with HI. The densities of *Dero digitata*, *Dero pectinata*, and *Limnodrilus hoffmeisteri* significantly increased at sites with MI despite being present in all the habitats and sites recorded. Likewise, *Dero sawayai* and *Limnodrilus claparedianus* were more abundant at sites with MI but decreased in density or else were absent at the HI sites. Finally, *Chaetogaster diaphanus*, *Nais communis*, *Nais variabilis* were absent in the sediment from HI sites, but were present at a significantly increased density in the vegetation of those sites.

4. Discussion and Conclusions

The streams selected for this study exhibited different levels of pollution depending on the use of the land in the area analyzed. Bauer et al. (2002) pointed out that since the urban streams of the pampean plain receive insufficiently treated wastewater and are affected by inputs

Table 3. The Poisson distribution of species densities in the sediment and vegetation at sites with low impact (LI), moderate impact (MI), and high impact (HI). Different letters (A, B, C) indicate significant differences ($p \leq 0.05$) in the density of the species analyzed at sites characterized by the three types of impact (LI, MI, and HI).

	Sediment			Vegetation		
	L I	**M I**	**H I**	**L I**	**M I**	**H I**
Chae dia	17.9	**57.1**	0	22.7	5.5	**87.4**
	A	B		A	B	C
Dero dig	684.6	**2957.1**	57.1	153.7	**912.6**	81.6
	A	B	C	A	B	C
Dero fur	41.0	71.4	**664.3**	29.0	48.7	**1408.3**
	A	B	C	A	B	C
Dero pec	1176.9	**4928.6**	342.9	86.9	**1109.9**	173.9
	A	B	C	A	B	C
Dero saw	1374.4	**1685.7**	0	130.2	**418.6**	1.9
	A	B		A	B	C
Allo lai	0	0	8.1	0	4.4	**8.7**
		not estimable			A	B
Nais com	166.7	**285.7**	0	42.2	76.0	**381.7**
	A	B		A	B	C
Nais var	82.0	86.7	0	19.7	12.2	**730.4**
	A	A		A	A	B
Slav app	30.8	29.6	0	**10.7**	0.56	0
		not estimable		A	B	
Slav iso	**110.3**	28.6	57.1	26.5	**38.71**	3.9
	A	B	C	A	B	C
Styl lac	15.1	29.6	0	104.8	**119.9**	0
		not estimable		A	B	
Pris jen	**461.5**	35.7	0	12.8	**23.3**	7.8
	A	B		A	B	C
Pris aeq	20.5	**85.7**	7.1	33.2	21.1	**95.2**
	A	B	C	A	B	C
Pris lei	**107.7**	28.6	85.7	12.2	11.1	**34.0**
	A	B	C	A	A	B
Pris lon	56.4	**314.3**	0	3.8	20.9	**35.0**
	A	B		A	B	C
Pris pro	17.4	0	0	2.1	5.5	**15.5**
		not estimable		A	B	C
Pris mac	0	58.1	0	0.4	**97.7**	0
		not estimable		A	B	
Pris osb	97.4	14.3	**185.7**	**14.5**	1.7	10.7
	A	B	C	A	B	C
Pris not	0	0	0	1.3	0	**48.6**
		absent in sediment		A		B
Tubi inm	1451.3	**1564.3**	142.9	**172.0**	28.3	92.3
	A	B	C	A	B	C
Aulo pig	**333.3**	157.1	0	**41.2**	10.0	0
	A	B		A	B	
Limn cla	682.0	**2057.1**	0	13.3	**337.9**	0
	A	B		A	B	
Limn hof	3679.5	**4750.0**	1607.1	168.3	**935.6**	312.7
	A	B	C	A	B	C
Limn ude	48.1	0	8.1	1.3	0	**8.7**
		not estimable		A		B
Both ame	30.8	0	29.6	21.8	0	**406.9**
		not estimable		A		B
Trie cor	**433.3**	57.1	0	**39.1**	2.78	0
	A	B		A	B	
Ench	479.5	28.6	**750.0**	27.7	**326.4**	235.0
	A	B	C	A	B	C

$p < 0.05$, **not estimable = low number of samples** from nonpoint-source runoffs, an increase in almost all the physicochemical variables would be expected; though most consistently an elevation in conductivity, NH_4^+, BOD_5, and COD. This conclusion is consistent with the results of the present study because these variables were seen to increase at the sites of greatest impact. The physicochemical variables analyzed reflected changes in water quality between the sites with exclusively urban and suburban living (*i. e.*, of LI), the sites with suburban living and extensive agriculture (*i. e.*, of MI), and the highly urbanized sites with intensive industrial activity (*i. e.*, of HI). In addition to the conditions resulting from the surrounding land use, changes also occurred in habitat quality as a result of the deliberate anthropic influences on the streams. The dredging of urban systems in the pampean plain is frequently carried out with the intention of increasing their discharge into the Río de la Plata estuary. The inappropriate use of the land, the inadequacy of urban planning, and the input of contamination frequently accelerate the siltation, thus leading to the need of dredging and mud extraction (Licursi and Gómez, 2008). These physical disturbances were reflected here in the middle and lower reaches of the Don Carlos Stream. In agreement with our study, Goldstein et al. (2002), in an investigation of the biotic integrity and the physical characteristics of habitats employing the Visual Environmental Quality Index, concluded that most of the disturbed sites were associated with channelization and concrete stone facing with respect to the bed as well as the banks. These interventions resulted in a decline or loss of sinuosity and an alteration of the width-to-depth ratio that, in turn, perturbed the processes that dissipated the flow force and modified the associated biotic substrates.

Physicochemical variables and substrate characteristics exert a profound influence on the distribution and composition of the oligochaete community (Alves et al., 2006; Lin and Yo, 2008). Moreover, features such as a pollution by heavy metals (Chapman, 2001), the prevalence of a gravelly sediment (Lin and Yo, 2008), and a low availability of organic matter (Schenková and Helesic, 2006) along with competition and predation (Martins et al., 2008) may interfere negatively in the abundance of the Oligochaeta. In our study case, the exclusively urban sites presented the lowest habitat-quality characteristics including, among other features, an increase in coarse sediment and a lack of vegetation as a result of the continuous dredging—as stated above, a process that can lead to the loss of substrate habitats for the establishment of the benthic species. This finding agrees with the studies realized by Berrío-Cárdenas and Vélez (2007), who determined that the absence of aquatic oligochaetes could be attributed to the lack of specific habitat features (*e. g.*, substrate, vegetation). Moreover, according to Ciborowski (2003), sediments severely polluted with toxic materials may be degraded to the point where even the survival of oligochaetes become less likely and their densities become low for this reason. In the middle and lower reaches of the Don Carlos Stream, the amount of Pb, Ni, Cu, Cr, Cd, phthalates, and phenols registered in the streambed sediments resulted from the proximity of a textile plant (Gómez et al., 2008). We conclude that an increase in nutrients and organic matter in streams will, in general, result in an increase in the density of the oligochaetes. When, however, an anthropic disturbance also involves changes in the physical habitat or the added presence of toxic substances such as heavy metals; the oligochaete abundance will decrease significantly, and even drop down to values lower than those of nonimpacted environments.

At the family and subfamily levels, the Tubificinae are considered indicators of soft sediments rich in organic matter since most are deposit feeders, subsisting on organic detritus and its associated microflora (Paoletti and Sambugar, 1984). This subfamily also exhibits an aggregated distribution in benthic habitats, particularly since the members are unable to make extensive movements; so that their populations, living buried in the sediments, may reach high densities (Sampons, 1989). In contrast, coarse substrates (medium-sized grains of sand) as well as shallow environments allowing the development of the periphyton exhibit a greater richness of Naidinae and Pristininae. In our study, these two subfamilies were present in high abundance at the MI sites, thus indicating an affinity for an environment rich in nutrients and organic matter; but their abundance decreases significantly when the environmental impact is high (*e. g.*, through industrial contamination and habitat destruction). The Pristininae likewise decreased in abundance with diminished environmental quality as did the Opistocystidae, though this latter subfamily was underrepresented in our study. In contrast, the densities of the Enchytraeidae and the Rhyacodrilinae became increased in the impacted sites. The former are common in streams with coarse granulometry, rapid currents, and high oxygen content (Maiolini and Lencioni, 2002).

In the present study, the species richness and the diversity (H') were low at the HI sites and even lower in the sediment than on the macrophytes. The central area of a riverbed is less rich in microhabitats and is subjected as well to disturbances from the high current velocities that cause changes in the structure of the sediment and the quantity of the organic matter (Paoletti Di Chiara, 1981)—disturbances that often affect the density of the associated species. Moreover, the heterogeneity within the class of streams studied here results not only from the type and size of the substrata present but also from the nature of the submerged vegetation, which plant life plays a consequential role in the structuring of the biological communities (Giorgi et al., 2005). The presence of a greater variety of fauna on the macrophytes results from the complex characteristics of the habitat itself, in that a highly rich assortment of microhabitats are present (Paoletti and Sambugar, 1984; Rooke, 1984; Pujals, 1989; Stacey and Coates, 1996). Furthermore, species richness and diversity were always higher in the vegetation, regardless of the degree of disturbance within the general stream system. At the HI sites, the macrophytes acted as a refuge and provided a less perturbed habitat—one that was less affected by the variation in water flow and whose granulometric texture was constant—where the species could sequester themselves from the contaminants in the sediment and water. At these HI sites, the difference between richness and diversity in the sediment and in the vegetation was more pronounced than at the LI sites.

At the species level, the oligochaetes are sufficiently sensitive to enable their utilization as water-quality indices (Lin and Yo, 2008). Some species seem to present no restrictions with respect to a compatible type of habitat and are thus present in both the sediments and in the associated aquatic vegetation. In our study *Limnodrilus hoffmeisteri* was present at high densities in both types of habitats, although this species is widely distributed worldwide and is commonly found at high densities in organically enriched environments (Pavé and Marchese, 2005; Alves et al., 2006; Lafont and Vivier, 2006). This species has respiratory pigments (hemocyanin) that improve respiration in environments with low levels of dissolved oxygen (Miserendino, 1995) and has also been recorded at sites contaminated with metals (Rosso et al., 1994; Zilli and Gagneten, 2005). Another species with broad habitat preferences—and one that can tolerate varied environments—was *Dero furcatus* (Zilli and Gagneten, 2005), though some authors consider that this species is usually dominant in coarse substrates (Lin and Yo, 2008). *Dero digitata* was likewise abundant in both the sediment and the vegetation and had been previously recorded at sites rich in nutrients and with low levels of disolved oxygen (Krodkiewska and Michalik, 2008) along with high concentrations of heavy metals (Rosso et al., 1994), such as Cu and Pb (Zilli and Gagneten, 2005). *Dero pectinata* was also present in both habitats and at the three types of sites (LI, MI, and HI), but with a much greater abundance at the MI sites. Marchese et al. (2005) had also found this species associated with environments containing fine sediment, a high organic-matter content, and a low flow rate. *Pristina longiseta* and *P. aequiseta* likewise had been found to exhibit a tolerance to organic pollution (Lafont and Vivier, 2006; Lin and Yo, 2008) and heavy metals (Rosso et al., 1994). *Bothrioneurum americanum* presented its greatest abundance in the HI vegetated environments. According to Rosso et al. (1994), this species exhibits a strong resistance to metals probably because of its affinity for organic matter. In addition, *Stylaria lacustris* also showed a greater affinity for vegetated environments (Strayer et al., 2003). While some authors state that this species can tolerate wide organic pollution (*e. g.*, Arimoro et al., 2007), in the present investigation *S. lacustris* was present in those sections with low to moderate impact. Other authors (Krodkiewska and Michalik, 2008) nevertheless argued that this species preferred environments with a low nutrient loading and a high content of dissolved oxygen. *Nais communis* was recorded in both sediments (at LI and MI sites) and vegetation (at all three types of sites). Whereas this species had been cited by some authors as being pollution-intolerant (Lin and Yo, 2008), other studies referred to it as being associated with organic matter (Arimoro et al., 2007) and resistant to heavy metals (Rosso et al., 1994; Zilli and Gagneten, 2005). Finally, *Trieminentia corderoi*, *Slavina appendiculata*, and *Aulodrilus pigueti* manifested the highest levels of abundance at the LI sites, decreased in number at the MI sites, and were not recorded at the HI sites. This observation would point to the sensitivity of these species to organic and/or industrial pollution as well as to the deterioration of habitat quality. Future studies on these various species are needed to confirm the above conclusions.

In summary, the Oligochaeta show a relatively wide ecological valence as a result of the large number of species within the class. According to Verdonschot (2006), the use of higher taxonomic levels for assessing ecological water quality may yield skewed results. The application of the Oligochaeta as an indicator taxon should be coupled with a taxonomic analysis of the other members of the benthic community (Uzunov et al., 1988). The families and subfamilies of oligochaetes could be used to determine sites of organic pollution in the absence of heavy metals and/or severe habitat physical disturbance. This level of classification is widely employed in biotic indices such as the Iberian Bio-monitoring Working Party or BMWP (Alba-Tercedor and Prat, 1992), the Macroinvertebrate Index for Pampean Rivers or IMRP (Rodrigues Capítulo, 1999), and the Biotic Index for Pampean rivers and streams or IBPAMP (Rodrigues Capítulo et al., 2001); where in all three the benthic communities are analyzed in their entirety. At the species level, the oligochaetes are sufficiently sensitive to enable their implementation as indicators of water-quality indices (Lin and Yo, 2008). According to Verdonschot (2006), ecologists should extract detailed information from the species they collect in order to determine the precise condition of a given site. Further studies on the tolerance of local species after subjection to different types of pollutants will, however, be required in order to complete the spectrum of bioindication for the oligochaetes.

Finally, the continual hydrologic modifications that occur in lotic systems (*e. g.*, dredging, channelling, weed-cutting) in the urban lowlands cause profound changes in the characteristics of both the sediment and the vegetation present in those ambiences. Such influences at the same time produce alterations in the benthic populations as well as in the biotic diversity in general. Our findings here underscore the necessity of conserving the natural sediments and vegetation in such lotic systems since the continued well-being of those bodies of water is a s*ine qua non* for the sustainability of the local fauna and the degree of biodiversity in general.

We conclude from the results of this study that aquatic oligochaetes are differentially sensitive at the species level to a sufficient extent for their use as environmental indicators for aquatic systems affected by different types of land use and forms of contamination. These annelids are a significant component within the aquatic community since they are ubiquitous, are responsible for a large portion of the secondary productivity, and constitute a vital link in the food chain. As a result of all these characteristics, oligochaetes possess the capability of becoming a key diagnostic tool for aquatic ecologists.

Acknowledgements

This research has been financed by a grant from CONICET and PICT Nº 33939 (FONCYT). The authors would like to thank Jorge Donadelli, from the Laboratory of Chemistry of the ILPLA, for the nutrient- and oxygen-demand analyses of the water samples and are grateful to Dr. Donald F. Haggerty, a retired career investigator and native English speaker, for editing the final version of the manuscript. We also thank Dr. Nora Gómez for her constructive comments on the general approach, Mónica Caviglia for final observations, and Dr. Manuel Graça for the corrections of Portugese abstract. We are grateful to Claudia Marinelli for the statistical analyses of the data. This manuscript constitutes scientific contribution Nº 824 from the Instituto de Limnología Dr. Raúl A. Ringuelet.

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Received: 28 December 2011
Accepted : 07 May 2012