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RESEARCH ARTICLE

Chironomid genera distribution related to environmental characteristics of a highly impacted basin (Argentina, South America)

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Abstract

The objective of the present study was to investigate the responses of the chironomid communities (Diptera: Chironomidae) to environmental variables in four moderately and highly disturbed rivers located in one of the most degraded watersheds in South America. Sampling campaigns were carried out during 2014–2016 in four sites of the Matanza-Riachuelo basin. The physical-chemical and hydrological variables were measured and, the ecological indices were calculated and evaluated by ANOVA. The responses of Chironomidae to the environmental variables were evaluated by redundancy analysis (RDA), and the sampling sites were grouped according to the populations of chironomids and the main environmental variables. Finally, the Spearman correlation was made to determine which of these variables were significant. In total, 13 chironomid taxa were found in 36 samples during the study period. The greatest density registered belongs to *Rheotanytarsus* and *Cricotopus*. The ANOVA detected the greatest Chironomidae density and taxonomic richness in the sites with agricultural-urban impact. The changes in the distribution of *Rheotanytarsus*, *Thienemanniella*, and *Polypedilum* were mainly explained by the increase in current velocity, organic matter, and hardness, and the decrease of NH3 and BOD. On the other hand, *Goeldichironomus*, *Chironomus*, *Parachironomus*, *Dicrotendipes*, and *Cricotopus* were explained by the increase in conductivity, dissolved oxygen, and temperature, and the decrease of the variables NO3, BOD, and Cu. In addition to this, the sites with urban-agricultural impact were clearly separated from sites with urban-industrial impact. The last one was more related to the increase in BOD, Cu, and NO3 that indicates moderate to poor water quality. In conclusion, we can infer that the physical and chemical variables are correlated with changes in the structure and distribution of the chironomid community and there are genera that respond differently at high and intermediate situations of disturbances. This knowledge contributes to the execution of strategies for the conservation and restoration of the lotic ecosystems.

Keywords Chironomidae assemblages · Plain streams · Physical and Chemical parameters · Ecological indices

Introduction

Aquatic environments are among the most threatened natural resources of the world, since they are directly affected by what happens in their surroundings (Machado et al. 2015). These modifications affect the structure and composition of biological communities (Bortone 2005; Borja et al. 2009). In Argentina, the Pampean streams are naturally characterized by their low water flow, low slope (1 m/km), abundant clay and silt substrates, a riparian vegetation dominated by grasslands, and a diverse and abundant aquatic vegetation (Giorgi et al. 2005). However, lots of the watercourses in the Pampean ecoregion are degraded, mainly caused by urban and agricultural activities. The growing interest in evaluating the environmental impact has led us to consider the benthic macroinvertebrates as elements tending to evaluate the quality of water bodies (Rodrigues Capítulo et al. 2001; Paggi 2003). Within the macroinvertebrates, the chironomid faunistic assemblages are useful as bioindication of pollution in streams (Janssens de Bisthoven and Gerhardt 2003), because the

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larvae are affected by organic content and trace metal load in the sediments (Lafont and Durbec 1990).

It has been suggested that species identification of freshwater macroinvertebrates is essential for applied studies, since there can be considerable variation from species to species within a taxon with respect to their pollution tolerances (Resh and Unzicker 1975). However, identification of chironomids at the species level is not always feasible and today is a problem among non-specialist researchers because of limited taxonomic expertise, time, and (or) money, and biological features to identify the organisms collected at a given place and time (Furse et al. 1984). Also, there is little knowledge about the distribution of chironomid at genera level along watersheds with significant human settlements, industrial areas, and agricultural activities. At the same time, the influence of chemical inorganic, organic, and hydrological factors on the fauna has been little investigated. The objective of this study was to investigate how the structure and distribution of the chironomid assemblage is in situations of intermediate and high disturbance, and how changes in sites and environmental variables affect the community of chironomids. Our hypothesis was that the chironomid genera respond differently in situations of high and intermediate alterations, and the environmental variables determine the structure and distribution of the community in the Matanza-Riachuelo basin. This study was designed to generate information that could strengthen the management strategies of the river basin under study in particular and plain streams in general.

Material and methods

Study area

In South America, several rivers have suffered from environmental degradation due to excessive use of the lotic courses as receivers of industrial dumps and urban wastes. A very good example of this is the case of the Matanza-Riachuelo river basin, located in an area of NE plain in the province of Buenos Aires, Argentina. This basin is a typical lowland watercourse, with a 2034 km^2 watershed. It starts to flow in a rural area of the Buenos Aires province, continues through an industrial and urban area (one of the poorest urban regions in Argentina), and ends with its outlet on the Río de la Plata estuary. Furthermore, the upstream area is influenced by agriculture activities, the medium area by urban activities, and the downstream by punctual or diffuse domestic and industrial pollution. The surrounding area of the basin is one of the largest urban centers of Latin America, and has nearly ten million people living within the area of the basin (Conforti et al. 1995). For this reason, this is a fluvial system with one of the greatest anthropogenic impacts in the Pampean ecoregion of Argentina (Cattaneo and Sardi 2013).

Collection of chironomids

Sampling campaigns were carried out during three consecutive years: December 2014, October–November 2015, and March 2016. Four representative sites of the basin were selected with different types of environmental impact: Rodríguez stream (ROD) (34° 59′ 10.5″ S, 58° 53′ 3.48″ W) and Aguirre stream (AG) (34° 49′ 35.29″ S, 58°34′ 45.62″ W) with an agricultural-urban impact, Chacón 1 stream (CH1) (34°54′ 17.93″ S, 58°46′ 2.5″ W) and Depuradora Oeste (DEP) (34° 43′ 0.7″ S, 58° 30′ 28.51″ W) with an urban-industrial impact. Sampling sites in the Matanza-Riachuelo basin are shown in Fig. 1.

Three benthic samples were taken at each sampling site with the technique that best suited to the soil type of the region, which is an Ekman grab covering an area of 100 cm^2. In the laboratory, the samples were washed on a 500-μm-mesh sieve and stained with erythrosin B. All the samples were fixed in 5% (*v*/*v*) aqueous formalin. The preimaginal instars of chironomids were sorted out from the sediments under a stereoscopic microscope. The chironomids were mounted according to Paggi (2009) and identified up to genus or species level, depending on larval or the imago pharate pupal stage. The following identification keys were used: Wiederholm (1983, 1986); Wiedenbrug (2000); Epler (2001); Wiedenbrug and Ospina-Torres (2005); Merritt et al. (2008); Paggi (2009); Prat et al. (2014); and by other specific literature of the region (Paggi 1975, 1977a, b, 1978a, b, 1985, 1987, 1993, 2007; Donato and Paggi 2008; Tejerina and Paggi 2009).

Environmental variables

The physical-chemical variables and habitat characteristics measured were current velocity with a micro-correntimeter Multifuncion MiniAirWater 20, and conductivity, pH, temperature (T), dissolved-oxygen (DO), and turbidity with multiparametric sensor (Horiba U-10). The biochemical oxygen demand (BOD), chemical oxygen demand (COD), Cl, hardness, As, P PO4−, NO_2, NO_3, N Kjel, F, Cd, Pb, CN−, Cr, Cu, Hg, Ni, total solids, and organic matter (OM) follow standard methods (APHA 1998). The values of the metals in water were provided by the Matanza-Riachuelo Basin Authority (ACUMAR web 2018).

Statistical analyses

The data of species were analyzed in all the samples and then the following parameters were calculated: Chironomidae density (individuals/m^2), taxonomic richness (*S*), Shannon-Wiener diversity index (*H*'), and equitability index (*J*'). For this, the programs Biodiversity Pro (Mc Aleece 1997) and INFOSTAT Version 2011 (Di Rienzo et al. 2010) were used. To analyze the differences in the biological variables, a two-

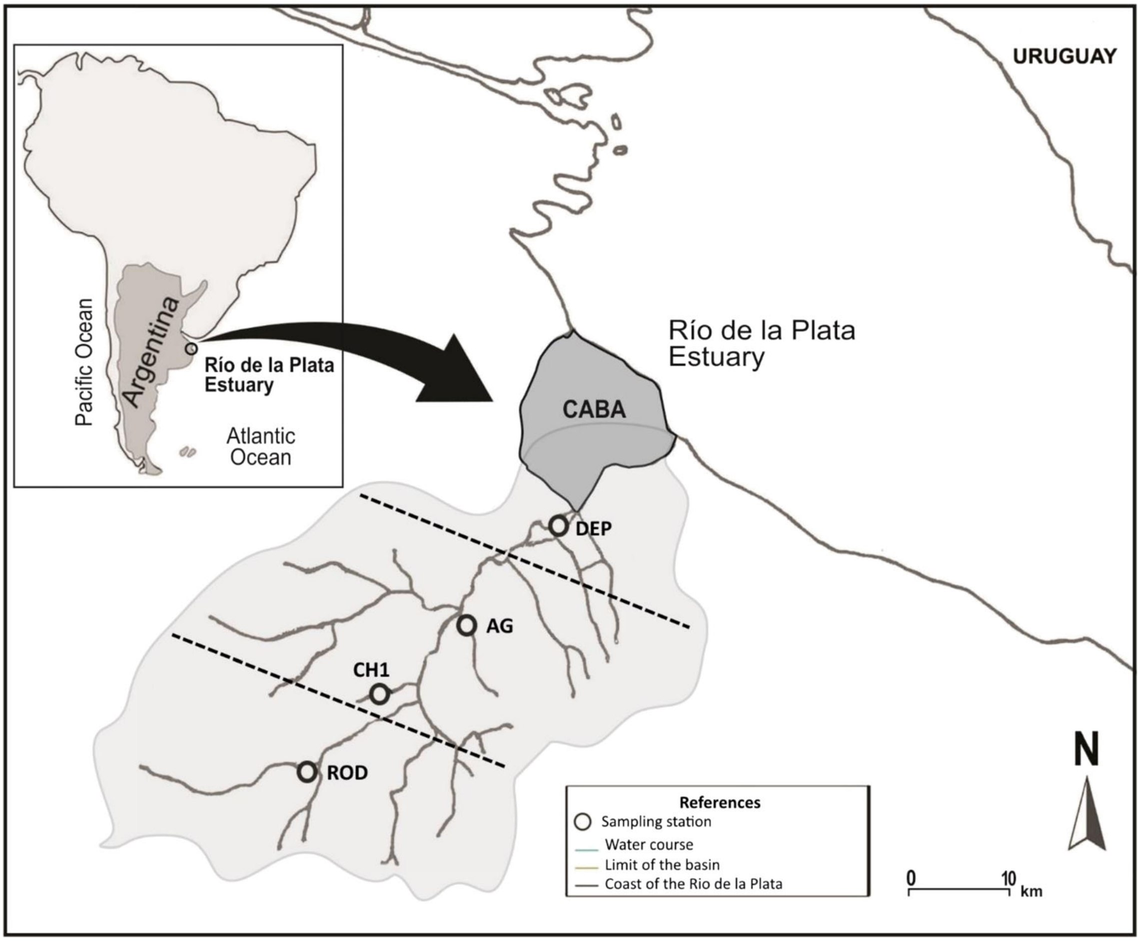

Fig. 1 Matanza-Riachuelo river basin and the 4 sampling sites considered in the analysis: Rodríguez stream (ROD), Aguirre stream (AG), Chacón1 stream (CH1), and Depuradora Oeste (DEP). The dotted lines represent the division of the basin between the upper (represented by ROD), medium (represented by CH1 and AG), and low (represented by DEP)

way factorial ANOVA was performed (factors: site and year). The data of abundance and taxonomic richness were transformed with square root (x + 1). The Shapiro-Wilk test was carried out to evaluate the normality of the residues and the Levenne test for homogeneity of variance of the model. To analyze the differences in the physico-chemical variables, a one-way ANOVA test was also performed. For the variables that did not meet the assumptions, the data was transformed with Log10 $(x + 1)$. In addition to this, nonparametric tests of Kruskal-Wallis were performed on the variables that did not meet the ANOVA assumptions after the transformation. Multivariate analysis is often used to analyze environmental preferences of macroinvertebrate communities (Verdonschot et al. 1992; Ter Braak and Verdonschot 1995; Cao et al. 1997; Verdonschot 2000).

A detrended correspondence analysis (DCA) by segments was performed to determine if the taxa analyzed had responded linearly to gradients (if the maximum gradient length is less than 4 SD) or whether had done so according to some environmental optimum indicating a unimodal response (if the maximum gradient length exceeds 4 SD) (Ter Braak 1986; Ter Braak and Smilauer 1998). The maximum length of the gradient obtained in this analysis was less than 4 (standard deviation units), a value which indicated a linear response. A redundancy analysis (RDA) was thus performed in order to explore the relationship between the abundance of taxa and the environmental variables registered at the study sites. The abundance values of the individuals and environmental data were transformed to $\log(x + 1)$ in order to reduce the weighting of the dominant groups. We only included in the analysis taxa that have a relative abundance of more than 1%. Upon standardization of the physico-chemical variables registered, the inflation values obtained proved to be less than 20. Those variables pass the test of significance (i.e., NH3, T, DO, conductivity, hardness, current velocity, OM, NO3, Cu, and BOD) and were selected from analysis. The statistical significance of the model with respect to the first axis as well as the canonical axes was evaluated by the Monte Carlo test (499 permutations under the reduced model, $p < 0.05$). The first two axes of ordination were selected for graphical representation. Finally, a

Spearman correlation was made between the genera and the variables used in the RDA to determine which were the factors that significantly affect ($p < 0.05$) the distribution of the genera in the basin.

Results

Chironomid biodiversity and biological assessment

In total, 13 chironomid taxa were found in 36 samples during the study period. Within the subfamily Chironominae, seven genera were identified, in Orthocladiinae five genera, and in Tanypodinae one genus. The total relative density was dominated by the Chironominae (79.01%), continuing with the Orthocladiinae (20.97%) and Tanypodinae (0.02%). The high density of the Chironominae subfamily was represented by the genus *Rheotanytarsus* (220,134 ind/m^2), and in the subfamily Orthocladiinae, the best represented genus was *Cricotopus* (58,966 ind/m^2). For the ROD site, the most abundant genus was *Cricotopus* (49,633.33 ind/m^2), and for the AG was *Rheotanytarsus* (196,000 ind/m^2). For CH1, it was *Goeldichironomus* (2466.67 ind/m^2), and for DEP, it was *Chironomus* (2533 ind/m^2) (Table 1).

The analysis of the two-way variance with interaction (ANOVA) detected statistically significant differences between sites with respect to the Chironomidae density (df 3; F 40.02; $p < 0.0001$), where ROD and AG site (with agricultural-urban impact) recorded the greatest density (Fig. 2 A). The taxonomic richness (S) (Fig. 2 B) also showed statistically significant differences according to the sites, these being the AG and ROD sites have the highest value (df 3, F 24.10, $p < 0.0001$). Besides, the diversity of Shannon (H') demonstrated statistically significant interaction between the sites and years (df 3, F 4.02; p 0.0063), which shows that the sites with urban-industrial impact had the lowest value in DEP 2014 and 2015, and the CH1 site in the year 2014 (Fig. 2c). Finally, differences were also found between years on equitability (J) (df 3, F 4.14, p 0.0286), having the highest value in 2016 and the lowest value in the year 2014 (Fig. 2d).

Environmental variables

The physical-chemical variables recorded in the studied sites are presented in Tables 2 and 3. The sites with urban-agricultural impact presented in general the highest values of As, Pb, and current velocity, and the lowest values of N and NH3. On the other hand, the urban-industrial sites presented the highest values of BOD, COD, Cl, and total solids, and the lowest in As and current velocity (Tables 4 and 5).

Multivariate analyses of the Matanza-Riachuelo basin data

The output of the DCA analysis revealed that the accumulated explained variance of the first two axes was 41.6%. The gradient length of the first DCA axis was 3.772 and therefore a redundancy analysis (RDA) was chosen. The cumulative variance of species-environment relation on the first two axes in the RDA analysis, which explained the role of the environmental variables in the structure of the chironomid assemblages, was 84.4%. Therefore, it can be said that the measured environmental variables are important parameters determining the structure of the chironomid assemblages. The Monte Carlo test gave significance (≤ 0.05) to both the first axis (p value = 0.002) and for the second (p value = 0.002).

The genus *Rheotanytarsus*, *Thienemanniella*, and *Polypedilum* were strongly related to axis I, and this was mainly explained by the increase in current speed, organic matter, and hardness, and the decrease of NH3 and BOD (Fig. 3). On the other hand, the genus *Goeldichironomus*, *Chironomus*, *Parachironomus*, *Dicrotendipes*, and *Cricotopus* were related to axes II, which were explained by the increase in conductivity, DO, and temperature, and the decrease of the variables NO3, BOD, and Cu.

In addition to this, the sites with urban-agricultural impact (AG and ROD) were clearly separated from sites with urban-industrial impact (CH1 and DEP). The last one was more related to the increase in BOD, Cu, and NO3 that indicates moderate-to-poor water quality.

Spearman correlation

Table 6 shows the statistical values of the Spearman correlation ($p \leq 0.05$) between the chironomid genera and the environmental variables, where it can be observed that, for all the genera analyzed in the RDA (except *Chironomus*), there are significant correlations with the variables. In some cases, these correlations are positive and in others negative (Table 6).

Discussion

Industrialization and economic growth have led to environmental problems due to the increasing contamination of water and the modification of the surrounding environment. In biomonitoring programs of the Pampean rivers, there are few published studies on the use of aquatic organisms. Furthermore, it is not commonly used to the chironomid genera in the biomonitoring of aquatic ecosystems due to the lack of sufficient data on their ecology and taxonomy (Paggi 2003). Therefore, our study is the first contribution on the relationship of chironomids at the genus level with environmental variables used in biomonitoring programs.

Table 1 Average density and standard deviation of the three samples of chironomids (ind/m^2) found in each of the four sites of the basin, during the three years of study ($n = 36$)

		ROD									AG							
		2014			2015			2016			2014			2015			2016	
	Acronyms	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$	
Chironominae																		
Chironomus	Chir	0	±	0	10,667	±	88.30	8600	±	77.38	33	±	0.58	233	±	4.04	133	±
Dicrotendipes	Dicro	2467	±	40.13	2433	±	21.08	3200	±	28.84	333	±	3.21	1033	±	12.34	1033	±
Goeldichironomus	Goel	0	±	0	0	±	0	13,667	±	119.57	67	±	1.15	0	±	0	0	±
Parachironomus	Par	0	±	0	2900	±	25.12	8000	±	74.73	0	±	0	1367	±	23.67	1800	±
nr_Pelomus		0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	67	±
Polypedilum	Poly	200	±	2.65	0	±	0	733	±	12.70	1067	±	5.03	17,233	±	43.13	1600	±
Rheotanytarsus	Rheo	22,667	±	180.88	1167	±	11.06	0	±	0	78,800	±	620.00	67,033	±	421.39	50,167	±
Orthocladiinae																		
Corynoneura	Cory	0	±	0	0	±	0	0	±	0	0	±	0	133	±	2.31	0	±
Cricotopus	Cric	11,900	±	107.06	37,200	±	184.79	533	±	9.24	100	±	1.73	633	±	10.97	8300	±
Nanocladius	Nan	0	±	0	0	±	0	0	±	0	233	±	2.52	233	±	2.08	0	±
Pseudosmittia		0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	0	±
Thienemanniella	Thien	400	±	6.93	100	±	1	0	±	0	3900	±	31.58	6600	±	26	15,233	±
Tanypodinae																		
Tanypus	Tany	0	±	0	67	±	1.15	0	±	0	0	±	0	0	±	0	0	±

	AG	CH1									DEP									
	2016	2014			2015			2016			2014			2015			2016			
	SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	
Chironominae																				
Chironomus	2.31	0	±	0	0	±	0	167	±	0.58	267	±	2.31	2233	±	21.50	33	±	0.58	
Dicrotendipes	3.51	133	±	2.31	100	±	1	0	±	0	0	±	0	33	±	0.58	0	±	0	
Goeldichironomus	0	1867	±	32.33	600	±	2	0	±	0	0	±	0	0	±	0	0	±	0	
Parachironomus	19.29	0	±	0	300	±	2	0	±	0	0	±	0	0	±	0	0	±	0	
nr_Pelomus	1.15	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	
Polypedilum	21.17	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	
Rheotanytarsus	281.04	0	±	0	300	±	2	0	±	0	0	±	0	0	±	0	0	±	0	
Orthocladiinae																				
Corynoneura	0	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	
Cricotopus	54.53	0	±	0	0	±	0	33	±	0.58	0	±	0	0	±	0	0	±	0	
Nanocladius	0	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	0	±	0	
Pseudosmittia	0	0	±	0	0	±	0	0	±	0	33	±	0.58	67	±	1.15	0	±	0	
Thienemanniella	125.09	0	±	0	0	±	0	0	±	0	0	±	0	33	±	0.58	0	±	0	
Tanypodinae																				
Tanypus	0	0	±	0	0	±	0	33	±	0.58	0	±	0	0	±	0	0	±	0	

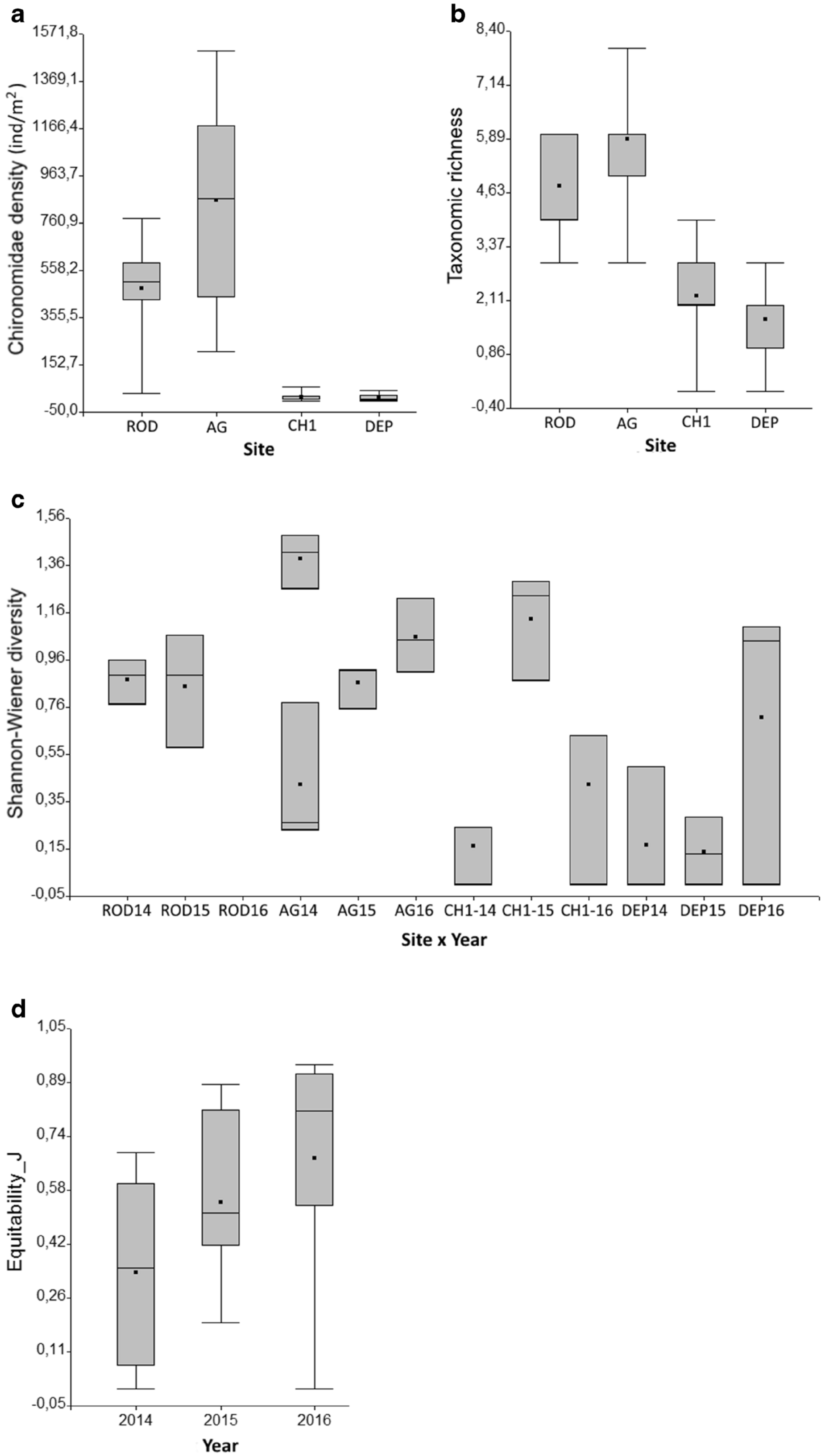

Fig. 2 Boxplot of the biological variables in which ANOVA detected significant differences. **a** Chironomidae density, **b** taxonomic richness, **c** Shannon-Wiener diversity, and **d** equitability

Table 2 Average ($\overline{X}$) and standard deviation (SD) of the organic parameters of the four sites in the 3 years of study

	ROD			CH1			AG			DEP		
	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD
COD (mg O2/l)	63.00	±	10.12	150.00	±	35.84	51.56	±	23.06	67.47	±	4.17
BOD (mg O2/l)	7.33	±	2.51	9.33	±	2.51	8.33	±	2.08	22.33	±	1.52
PO4 (mg PO4-P/l)	2.83	±	1.17	1.52	±	1.51	0.567	±	0.15	2.20	±	1.22
Cl (mg Cl/l)	68.53	±	21.50	526.78	±	237.95	25.3	±	11.01	119.57	±	4.03
DO (mg DO/l)	5.29	±	3.01	6.06	±	2.93	5.05	±	3.37	3.26	±	1.53
NO3 (mg NO3-N/l)	1.43	±	0.49	0.84	±	0.13	1.5	±	0.29	3.85	±	3.27
NO2 (mg NO2-N/l)	0.18	±	0.05	0.17	±	0.14	0.22	±	0.11	0.31	±	0.32
N Kjel (mg N Kjel/l)	11.50	±	4.72	8.85	±	2.15	2.23	±	0.26	11.85	±	3.25
P (mg P/l)	3.10	±	0.96	2.32	±	1.10	0.67	±	0.14	2.90	±	1.31
N (mg N/l)	12.95	±	4.54	9.87	±	2.41	3.96	±	0.55	16.28	±	3.25
NH3 (mg NH3/l)	9.28	±	5.20	4.42	±	2.88	0.50	±	0.03	9.20	±	2.17
Organic matter (%)	6.82	±	5.05	7.06	±	3.46	7.38	±	4.46	6.53	±	3.64

In the present work, 13 genera were found in the Matanza-Riachuelo river basin. The quantity of genera was different according to each area of the basin. In the upper basin, most *Rheotanytarsus* and *Cricotopus* were detected; in the middle basin, most *Goeldichironomus*; and in the lower basin, *Chironomus* was mostly found. However, in one of the first works carried out in the same sampling sites on the basin, only four genera were found: *Chironomus*, *Goeldichironomus*, *Tanypus*, and *Coelotanypus* in the upper and middle basin, while, in the lower basin, no chironomids were recorded at any time (Paggi 2003). Other authors have cited the same genera that we have found in other lotic systems of the Pampean region of Argentina (Paggi 2003; César et al. 2000; Rodrigues Capítulo et al. 2001, 2004; Paggi et al. 2006; Cortelezzi et al. 2011; Ocon and Rodrigues Capitulo 2012; Rodriguez Catanzaro et al. 2018; Zanotto Arpellino et al. 2018), all qualified as cosmopolitans and euritopics (Coffman and Ferrington Jr 1996; Epler 2001).

Our results of ANOVA detected that the structure and distribution of the chironomid community differs between streams with different anthropogenic activities. The greatest diversity, density, and taxonomic richness were registered in ROD and AG, which corresponded to the stations with agricultural-urban impact. ROD station recorded the highest

Table 3 Average ($\overline{X}$) and standard deviation (SD) of the inorganic and hydrologic parameters of the four sites in the 3 years of study

	ROD			CH1			AG			DEP		
	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD	$\overline{X}$		SD
Cr (mg/l)	0.008	±	0.000	0.007	±	0.004	0.011	±	0.005	0.022	±	0.013
Cu (mg/l)	0.008	±	0.003	0.010	±	0.005	0.012	±	0.003	0.02	±	0.01
Total solids (mg TSD/l)	48	±	22.716	58.33	±	26.312	145	±	52.048	12	±	2.828
Current velocity (cm/seg)	7	±	1	0.19	±	0	15	±	1	11	±	1
Conductivity (μs cm^{-1})	1521.08	±	228.58	821.52	±	298.59	1183.88	±	96.10	937.66	±	79.08
pH	8.04	±	0.80	8.10	±	0.48	8.02	±	0.815	7.4	±	0.410
T (°C)	15.0	±	10.3	21.9	±	9.2	16.7	±	10.2	18.9	±	10.8
Hardness (mg/l)	157.12	±	12.02	196.45	±	71.02	107.33	±	9.65	114.28	±	107.51
As (mg/l)	0.032	±	0.004	0.006	±	0.000	0.015	±	0.003	0.004	±	0.003
Cd (mg/l)	0.000	±	0.000	0.000	±	0.000	0.000	±	0.000	0.000	±	0.000
Pb (mg/l)	0.005	±	0.003	0.005	±	0.003	0.014	±	0.001	0.005	±	0.002
CN− (mg/l)	0.002	±	0.000	0.002	±	0.000	0.002	±	0.000	0.002	±	0.000
Hg (mg/l)	0.001	±	0.000	0.001	±	0.000	0.001	±	0.000	0.001	±	0.000
Ni (mg/l)	0.009	±	0.002	0.009	±	0.001	0.013	±	0.004	0.013	±	0.004
Turbidity (NTU)	73.92	±	63.09	364.06	±	317.43	46.23	±	31.96	110.60	±	127.30

Table 4 One-way ANOVA test on the physico-chemical and hydrologic variables of the currents of the Matanza-Riachuelo river basin. In italics, the significant *p* values ($p \leq 0.05$) and the corresponding post hoc test

	df	*F*	*p*	Post hoc test
Conductivity	3	3.12	0.0881	
pH	3	0.53	0.6761	
T	3	0.01	0.9982	
COD	3	12.67	*0.0021*	*ROD-AG-DEP < CH1*
BOD	3	30.83	*0.0001*	*ROD-AG-CH1 < DEP*
As	3	39.14	*0.0000*	*CH1-DEP < AG < ROD*
DO	3	0.33	0.8065	
Pb	3	10.46	*0.0038*	*ROD-CH1-DEP < AG*
Cr	3	2.87	0.1036	
Cu	3	3.59	0.0659	
Hg	3	1.00	0.4411	
Ni	3	1.17	0.3794	
NO2	3	0.67	0.5944	
Log_{10} (N Kjel +1)	3	12.07	*0.0024*	*AG < ROD-CH1-DEP*
P tot	3	2.83	0.1063	
Log_{10} (Turb. + 1)	3	0.15	0.9295	
Log_{10} (Sol tot +1)	3	4.59	*0.0376*	*AG-DEP < CH1*
N	3	6.67	*0.0144*	*AG < ROD-DEP*
OM	3	0.45	0.7242	

abundance and diversity of chironomids especially *Cricotopus*, member from the subfamily Orthocladiinae which have been earlier classified as facultative species usually absent from heavily polluted streams (Arimoro et al. 2007). Agricultural activities, through the use of fertilizers, often lead to the enrichment of nutrients from water and sediments, as well as the entry of treated and untreated domestic waste (Harding et al. 1999). Therefore, the ROD and AG sites were dominated by species facultative and tolerant to pollution, such as *Polypedilum*, *Rheotanytarsus*, and *Thienemanniella* (Merritt et al. 2008). According to Wright and Burgin 2009, the sites with industrial impact are usually dominated by chironomids within the macroinvertebrate assemblage. In our study, *Chironomus* was the most dominant genus in sites with urban-industrial impact (CH1 and DEP), although its abundance showed rather low values. Its dominance may be due to the fact that this genus is highly tolerant and adaptable to extremely contaminated conditions and usually shows deformities in response (Bhattacharyay et al. 2005; Al-Shami et al. 2010; Cortelezzi et al. 2011). In addition to this, other authors have reported that *Chironomus* and

Table 5 Kruskal-Wallis non parametric test on the physico-chemical and hydrologic variables of the streams of the Matanza-Riachuelo river basin. In italics, the significant p values ($p \leq 0.05$) and the corresponding post-hoc test

	H	*p*	Post hoc test
Hardness	1.97	0.5777	
Cl	10.38	*0.0156*	*ROD-AG-DEP < CH1*
Cd	5.17	0.1593	
CN −	4.71	0.1939	
NO3	3.25	0.3546	
NH3	8.15	*0.0428*	*AG < ROD-DEP*
PO4	6.17	0.1031	
Current velocity	8.73	*0.0331*	*CH1 < ROD-DEP < AG*

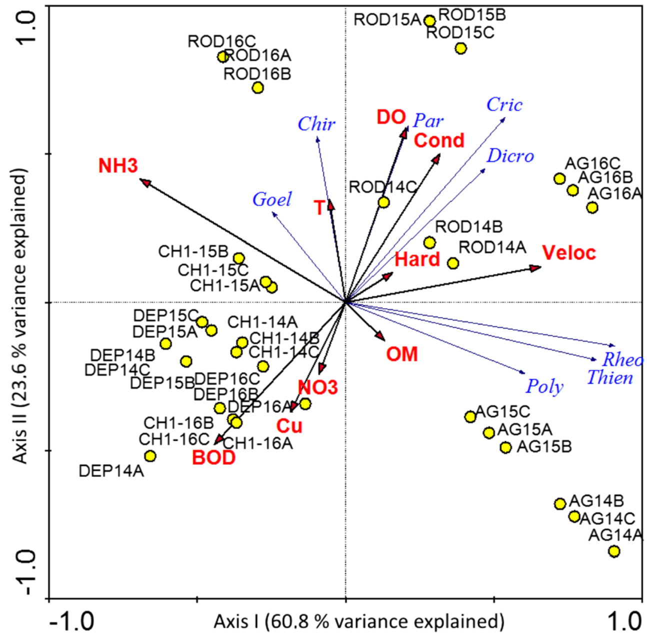

Fig. 3 Redundancy analysis (RDA) between the chironomid genera, the physico-chemical variables, and the sites of the basin during the 3 years of study. The scale in SD units is − 1 to 1 for the chironomid, station, and environmental variable scores. Full names for abbreviation codes of invertebrate taxa are given in Table 1

Table 6 Statistically significant Spearman correlation ($p \leq 0.05$) between chironomid genera and environmental variables

	Valid	Spearman	t ($N-2$)	p level
Cric and BOD	12	− 0.615960	− 2.47257	0.032959
Cric and Cond	12	0.562948	2.15392	0.056688
Dicro and Cond	12	0.761915	3.72005	0.003975
Dicro and Cu	12	− 0.578491	− 2.24271	0.048780
Dicro and BOD	12	− 0.693806	− 3.04655	0.012324
Goel and Cu	12	− 0.741860	− 3.49855	0.005740
Par and BOD	12	− 0.603620	− 2.39418	0.037688
Par and DO	12	0.687427	2.99321	0.013499
Poly and Veloc	12	0.714421	3.22873	0.009040
Rheo and NH3	12	− 0.620653	− 2.50314	0.031278
Rheo and Veloc	12	0.568002	2.18241	0.054025
Thien and NH3	12	− 0.669258	− 2.84831	0.017300
Thien and Veloc	12	0.771267	3.83176	0.003309

Cricotopus are dominant in the most contaminated sites (Ahmad et al. 2002; Azrina et al. 2006; Marziali et al. 2010). Among the adaptations that would explain this tolerance is the hemoglobin present in the *Chironomus* larvae, which allows physiological functions in the transport and storage of oxygen that allows it to survive extreme contamination conditions (Osmulski and Leyko 1986). Other adaptations to contaminants may involve detoxification, transport, regulation of essential elements, and behavior (Newman 1995).

In relation to the values of heavy metals, with the exception of Cd and Hg, the rest were close to constituting pollution or environmental health risks because, in most of the sampling sites, they exceeded the specified limits as the maximum allowed by the Law Argentina of Dangerous Residues, N° 24051 (1993) for the protection of the life of freshwater.

The redundancy analysis (RDA) shows a clear separation between the sites of the basin according to their type of impact, and these results are similar to those found by Cochero et al. 2016 who classified the same sampling sites in the same basin as water bodies with moderate-to-poor habitat quality. Moreover, the results of the RDA show that the community of chironomids responded through structural changes to environmental variables. Biochemical oxygen demand, conductivity, Cu concentration, dissolved oxygen, current velocity, and NH3 concentration were the main factors that determined the distribution and abundance of chironomids in the Matanza-Riachuelo river basin.

The genera *Cricotopus*, *Dicrotendipes*, and *Parachironomus* were low-BOD indicators, as well as *Dicrotendipes* of low Cu concentration and high conductivity, *Parachironomus* of high dissolved oxygen, *Polypedilum* and *Thienemanniella* current velocity and finally *Rheotanytarsus* and *Thienemanniella* of NH3 low concentration indicators. Ikomi et al. (2005), Arimoro et al. (2007), and Arimoro and Ikomi (2008) previously reported the great abundance of *Cricotopus*, *Polypedilum*, and *Chironomus* in some forest streams in the Delta State (Nigeria), in relation to the amount of detritus that is abundant in forest streams from assigned inputs and also in highly polluted basin sources. On the other hand, Mousavi et al. (2003) and Al-Shami et al. (2010) consider the genus *Polypedilum* to be very tolerant to contamination by heavy metals in the course of water and to low amounts of dissolved oxygen.

Conclusion

The present work demonstrated how dynamic the assembly of chironomids is in relation to the change of environmental variables in the different sampling stations. We can infer that there are significant correlations between the physical-chemical variables with the genera of chironomids that determined changes in the structure and distribution of the assembly. When the taxonomic description is analyzed in detail, it can be observed that there are genera that respond differently in high and intermediate situations of disturbances. In our study, the genera *Rheotanytarsus*, *Thienemanniella*, and *Polypedilum* were indicators of less contaminated sites, while *Chironomus* and *Goeldichironomus* proved to be more tolerant to contamination. Nevertheless, to obtain even more accurate results, it is recommended to collect samples at different seasons of the year and in lotic systems with different water qualities.

The use of the Chironomidae family to evaluate the quality conditions of the river has been recommended for several years. A better understanding of the ecological preferences of taxa and ecological studies is essential to allow the understanding of the dynamics of their populations in the Neotropical region. It is necessary to deepen this type of study to expand the knowledge of the adaptive and ethological adjustments that determine the responses of each population in prevailing conditions in their environment. The knowledge generated in the present study has a potential utility for the improvement of biomonitoring in the lotic ecosystems, which can be used as a tool for the execution of strategies for the conservation and restoration of river basins.

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