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Chironomidae (Diptera) diversity in extreme environments (Salar de Olaroz, Puna Desert, Argentina)

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Abstract. The Salar de Olaroz, located in the Argentine Puna, is one of the largest lithium deposits of the world. Lithium extraction requires large amounts of fresh and brackish water, creating pressure on wetlands of these desert environments. The knowledge of the aquatic fauna of the area is of interest to monitor impacts of these extractive activities. In this work, a study of the Chironomidae (Diptera) prior to mining is carried out in order to understand the structure of the Chironomidae assemblage at morphospecies level, with the aim of evaluating its spatial and seasonal variation, relating changes in the assemblage to some environmental variables. Quantitative biological samples and environmental variables of interest were taken and registered in three streams during four season in three consecutive years (2013-2015). Our results show that the Chironomidae assemblage could respond to variables related with discharge by decreasing its richness. Some morphotypes (e.g., *Podonomus*, *Parametriocnemus*, *Limnophyes* and *Polypedilum*) associated with changes in pH, decreases in dissolved oxygen and water velocity, and increases of finer sediments could disappear from the area.

[Keywords: non-biting midges, high altitude, benthic community, Salar de Olaroz]

Resumen. Diversidad de Chironomidae (Diptera) en ambientes extremos (Salar de Olaroz, Desierto de Puna, Argentina). El Salar de Olaroz, ubicado en la Puna Argentina, es uno de los depósitos de litio más grandes del mundo. La extracción de este elemento requiere grandes cantidades de agua dulce y salobre, lo cual presiona sobre los humedales de estos ambientes desérticos. Conocer la fauna acuática de la zona es de interés para monitorear los impactos de estas actividades extractivas. En este trabajo se realiza un estudio de los Chironomidae (Diptera) previo a la explotación minera, para determinar la estructura del ensamblaje de Chironomidae a nivel de morfoespecies, a fin de evaluar su variación espacial y estacional, relacionando cambios en el ensamblaje con algunas variables ambientales. Se tomaron y registraron muestras biológicas cuantitativas y variables ambientales relevantes, en tres arroyos durante tres años consecutivos (2013-2015), incluyendo cuatro temporadas cada año. Nuestros resultados muestran que el ensamble de Chironomidae podría responder a cambios en variables relacionadas con el caudal, disminuyendo su riqueza. Algunos morfotipos (e.g., *Podonomus*, *Parametriocnemus*, *Limnophyes* y *Polypedilum*) asociados con cambios en el pH, disminuciones en el oxígeno disuelto y la velocidad del agua, y aumentos de los sedimentos finos, podrían desaparecer del área.

[Palabras claves: mosquitos que no pican, gran altitud, comunidad bentónica, Salar de Olaroz]

Introduction

The Salar de Olaroz basin, one of the most important deposits of lithium salts, is located in the Argentine Puna (Morello et al. 2012; Izquierdo 2018). The Puna is one of the largest plateaus in the world, with an average height of 3800 m and extremely arid climatic conditions and temperature (Brown and Pacheco 2005). The salt flats are endorheic systems fed by streams, rivers and *vegas* (humid areas with water-saturated soils), whose fauna is little known. In general, small crustaceans dominate lotic communities (e.g., Ostracoda, Amphipoda), and among insects, Diptera, especially Chironomidae, stand out (Rodrigues Capítulo et al. 2014; Nieto et al. 2016).

Chironomids have a wide distribution and tolerance (Ashe et al. 1987), being able to survive in extreme environments. For example, they have been found in icy, hypoxic or saline environments, even in Antarctica (Lencioni et al. 2018). Both their immature stages (larvae and pupae) and adults make important contributions to trophic circulation (Armitage et al. 1995).

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The growing demand for lithium for the manufacture of batteries for automobiles and electrical devices has generated great interest in the Puna and its salt flats (Garcia et al. 2020). Lithium extraction uses large amounts of fresh and brackish water to sustain the evaporation processes of brine in pools, which creates pressure on wetlands (Flexer 2018; Maidana and Seeligmann 2014). The main impact related with this exploitation is the decrease in discharge, with the consequent impact on related variables (i.e., conductivity, pH, dissolved oxygen, granulometry). We sampled streams that feed the salar, so they are located up waters of the direct impacts of mining. Nevertheless, knowledge of the aquatic fauna of the area is of interest to monitor impacts of these extractive activities, that began in 2015 just after our last sampling. The surveys of this work were carried out prior to the start of the mining exploitation stage in three tributaries of the Olaroz salt flat. The benthos of these tributaries were studied by Rodrigues Capítulo et al. (2014), who reported five Chironomidae morphotypes from two sampling campaigns (autumn and spring). In this work, a study of the Chironomidae family is carried out from seasonal samplings (autumn, winter, spring and summer) for three consecutive years. Our objectives were a) to know the structure of the Chironomidae assemblage at the morphospecies level, b) to evaluate its spatial and seasonal variation, and c) to relate environmental variables with biological ones.

MATERIALS AND METHODS

Study area

The study was carried out in three tributaries of the Olaroz salt flat, Susques department, 270 km west of the city of San Salvador de Jujuy, Argentina (Figure 1). The salar is a plain of ~260000 ha that is at an average altitude of 3900 m a. s. l., surrounded by mountain ranges (Izquierdo et al. 2016). Two biogeographic provinces are represented in the area: Puna and Altos Andes (Brown and Pacheco 2005). The climate is arid, with a

Figure 1. Geographic location of the sampling points in the Salar de Olaroz, Susques, Jujuy province, Argentina.

Figura 1. Ubicación geográfica de los puntos de muestreo en el Salar de Olaroz, Susques, provincia de Jujuy, Argentina.

high daily temperature range (>40 °C), low air density and high radiation. Precipitation is very scarce (100-500 mm/year) occurring mainly in summer (December to February) (Garreaud et al. 2003). The vegetation is xerophytic shrubbery formed by tufts of 80 to 150 cm in height, usually dominated by *Baccharis boliviensis*, *Fabiana densa* and *Adesmia horrida*.

The sampled sites were Rosario stream (RO, 3917 m a. s. l., 23°17′18.00′′ S - 66°37′51.91′′ W), Cerro Overo stream (CO, 3929 m a. s. l., 23°34′55.90′′ S - 66°40′25.20′′ W) and the Archibarca valley stream (AR, 4047 m a. s. l., 23°37′23.63′′ S - 66°51′15.52′′ W) (Figure. 1). One reach at each stream was sampled, with the easiest accessibility. The Archibarca stream channel is covered by aquatic vegetation and the margins by cespitose vegetation typical of *vegas* (Figure 2a-b). Cerro Overo stream presents aquatic vegetation and grasslands on the bank (Figure 2c-d). Rosario stream does not present aquatic vegetation and there are few grasslands in the riverbank (Figure 2e-f). Additional descriptions can be found in Rodrigues Capítulo et al. (2014).

Measurement of environmental variables

At each site, water temperature (°C), pH, conductivity (µS/cm) and dissolved oxygen (ppm) were measured *in situ* with a HI 9829 multiparametric probe (Woonsecket RI, USA). Depth of the stream was measured in the center of the channel using a ruler. In addition, sediment samples (500 mg) were taken with a PVC core (sample tube for soft sediments) (area 0.002 m^2) to make indirect measurements of total organic matter through total organic carbon content, following the method proposed by Nelson and Sommers (1982). The sediment was classified into three categories: sand, silt and clay, following Bouyoucos (1927) through the analysis of granulometry.

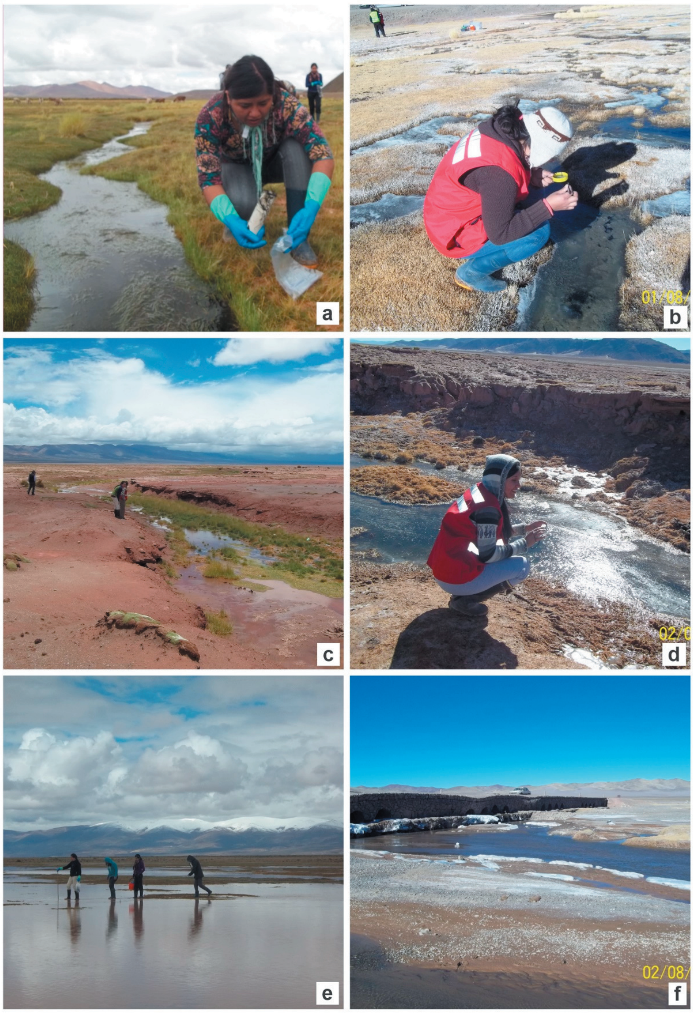

Figure 2. Sampling sites in Salar de Olaroz, Jujuy, Argentina. Archibarca: a) summer, b) winter. Cerro Overo: c) summer, d) winter. Rosario: e) summer and f) winter.

Figura 2. Sitios de muestreo en Salar de Olaroz, Jujuy, Argentina. Archibarca: a) verano, b) invierno. Cerro Overo: c) verano, d) invierno. Rosario: e) verano y f) invierno.

Biological sampling

The surveys were carried out in four seasons (summer, autumn, winter and spring) for a period of three years (2013-2015). In each site and season, 3 samples were taken in the superficial 5 cm of the bed sediments with the same PVC core used for sediment sampling. The three samples were taken along a 50 m stretch, in the middle of the stream, and were preserved with 76% alcohol. In the laboratory, the samples were studied using a stereomicroscopy at 40X, the material corresponding to Chironomidae was identified at the morphospecies level, and the specimens of the fourth larval stage were prepared with the standard methodology (Paggi 2009). The identification was carried out following Epler (2001), and later corroborated with taxonomic bibliography for the Neotropical region. The material is deposited in the Limnology and Aquatic Ecology laboratory of the Faculty of Agrarian Sciences of the National University of Jujuy (Argentina).

Data analysis

To evaluate whether the sampling effort was appropriate for each of the sites, the 'sample coverage' analysis proposed by Chao and Jost (2012) was carried out. For this, abundance data based on the total number of individuals was used (Hsieh et al. 2016).

Chironomid larval morphospecies diversity among the three sites was estimated and compared using diversity profiles based on Hill numbers (qD). These numbers depend on a parameter q, which determines the sensitivity of the diversity index to the relative abundances of morphospecies, presenting three widely used values: q=0 (which is equivalent to species richness), diversity of order q=1 (equivalent to the exponential of the Shannon index) and the diversity of order q=2 (equivalent to the inverse of the Simpson index) (Jost 2006). These analyzes were carried out using the iNEXT (version 2.0.12) and SpadeR (version 2.0.12; Hsieh et al. 2016) packages implemented in the R software (version 3.3.0; R Foundation for Statistical Computing, Vienna, Austria).

To study the spatio-temporal variation of the environmental parameters, Kruskal-Wallis tests were performed between sites and between seasons. To explore the relationship between the structure of the chironomid assemblage and environmental variables between sites and seasons, a canonical correspondence analysis (CCA) was performed. This direct gradient analysis technique assumes an unimodal model for the relationships between the responses of each species to the environmental gradient; the ordering axes are linear combinations of the environmental variables (ter Braak and Smilauer 1999). Three variables with high correlation (Spearman>0.7) were excluded from the analysis: silt and clay (highly correlated with sand) and air temperature (with water temperature). Other variables (e.g., DO and channel width) were not considered in the final analysis because they resulted not significant in the ordination process (Borcard et al. 2018). The analyses and graphs were performed using the ade4 (Dray and Dufour 2007), vegan (Oksanen et al. 2018) and ggplot2 (Wickham 2016) packages using R software (version 3.3.0, R Development Core Team 2016).

RESULTS

Environmental variables

The pH varied between neutral and alkaline; the maximum values were registered in the Rosario stream, which presented significant differences with the other two sites (Table 2), but did not vary between seasons. Total organic matter in the sediments varied between sites (H-KW=10.93, P<0.01), being higher for the Cerro Overo stream, which reached 4.5% during winter, but at a temporal scale there were no changes in this variable. Water temperature did not show significant differences between the sites however, significant differences were found among seasons, with minimum values in autumn and winter. The conductivity values were between the range 1.930 to 112.000 μS/cm, with significant differences at the spatial scale, but not temporal (Table 2). The dissolved oxygen concentration did not show significant variations at the spatial or temporal scales.

The average depth was different in the three sites and between seasons. The Archibarca stream was the deepest, similar to Rosario, while Cerro Overo was shallower. The granulometric composition at the three sites was similar: sand (>80%), silt (<8%) and clay (<12%).

Structure of the Chironomidae assemblage

A total of 2964 larvae from three subfamilies (Table 1) were collected: Orthocladiinae (7

Table 1. Mean density and standard deviation of the Chironomidae morphospecies of the three studied water courses during 2013-2015. Abbreviations: AR (Archibarca), CO (Cerro Overo), RO (Rosario).

Tabla 1. Densidad media y desviación estándar de las morfoespecies de Chironomidae de los tres cursos de agua estudiados durante 2013-2015. Abreviaturas: AR (Archibarca), CO (Cerro Overo), RO (Rosario).

	Summer			Autumn			Winter			Spring		
	AR	CO	RO	AR	CO	RO	AR	CO	RO	AR	CO	RO
Orthocladiinae (7)												
Genus 1	0	0	944 (2324)	667 (1414)	0	2889 (6689)	2500 (7500)	111 (220)	2056 (2256)	56 (167)	0	0
Cricotopus sp. 3	0	0	0	0	0	0	0	444 (1333)	0	0	444 (1333)	0
Cricotopus sp. 4	555 (882)	167 (354)	222 (441)	1056 (3167)	0	77167 (106645)	111 (333)	0	14722 (28388)	56 (167)	8778 (26333)	0
Cricotopus sp. 10	0	278 (833)	56	1667 (5000)	778 (1302)	500 (1500)	7722 (11189)	7500 (16277)	0	111 (220)	8722 (18123)	0
Parametriocnemus	0	0	0	0	0	111 (220)	56 (167)	0	611 (782)	0	0	0
Limnophyes	111 (220)	0	0	278 (565)	0	56 (167)	389 (821)	56 (167)	0	0	0	0
Paraphaenocladius	0	0	0	0	0	0	0	56 (167)	556 (167)	0	0	0
Chironominae (1)												
Polypedilum	444 (1333)	56 (167)	167 (354)	1667 (2806)	0	111 (333)	11667	0	0	1444 (2038)	111 (333)	0
Podonominae (1)												
Podonomus fastigians	0	0	0	56 (167)	0	278	0	0	1000 (1299)	0	56 (167)	0

morphotypes), Chironominae (1 morphotype) and Podonominae (1 morphotype). The sampling coverage values were higher than 90%, indicating that most of the expected morphotypes were collected.

The structure of the assemblage was different between sites and between seasons (Table 1). In Archibarca, during winter, *Polypedilum* (11667 individuals/m^2) and *Cricotopus* sp. 10 (7722 individuals/m^2) density peaks were recorded, while in summer, *Cricotopus* sp. 4 (166 individuals/m^2) and *Polypedilum* (55 individuals/m^2) were important. In Cerro Overo, during winter and spring, an unique morphotype was present: *Cricotopus* sp. 3 (444 individuals/m^2 for each season). *Cricotopus* sp. 10 presented very different densities in the four seasons, being higher in spring (7500 individuals/m^2). In the Rosario River, during the summer, only the following morphotypes were present: Genus 1 (944 individuals/m^2), *Cricotopus* sp. 4 (222 individuals/m^2) and *Polypedilum* (166 individuals/m^2), while in autumn and winter, the diversity and density increases. In spring, this river dried up superficially and no organisms were recorded.

The diversity profiles (Figure 3a-b) of the three sites did not show significant differences at the level of diversity of order q=0. The richness of morphotypes in each tributary was 7 in Archibarca, 8 in Cerro Overo and 8 in Rosario (Figure 3a, Table 1). Regarding the estimated diversity, there were significant differences between the sites. Thus, for q=1, Archibarca reached a diversity of 3.41 effective species, followed by Cerro Overo of 2.36 and Rosario of 1.47. Diversity of the order q=2 followed a similar pattern to the previous one (Figure 3a).

When observing the diversity profiles for each of the seasons (Table 1), significant differences were found in terms of diversity of the order q=0 (Figure 3b), where the richness was higher in winter (9 morphotypes), followed by autumn (7), spring (6) and summer (5). The diversity of the order q=1 was 4.60 effective species in winter, 4.17 effective species in summer, 2.67 effective species in spring and

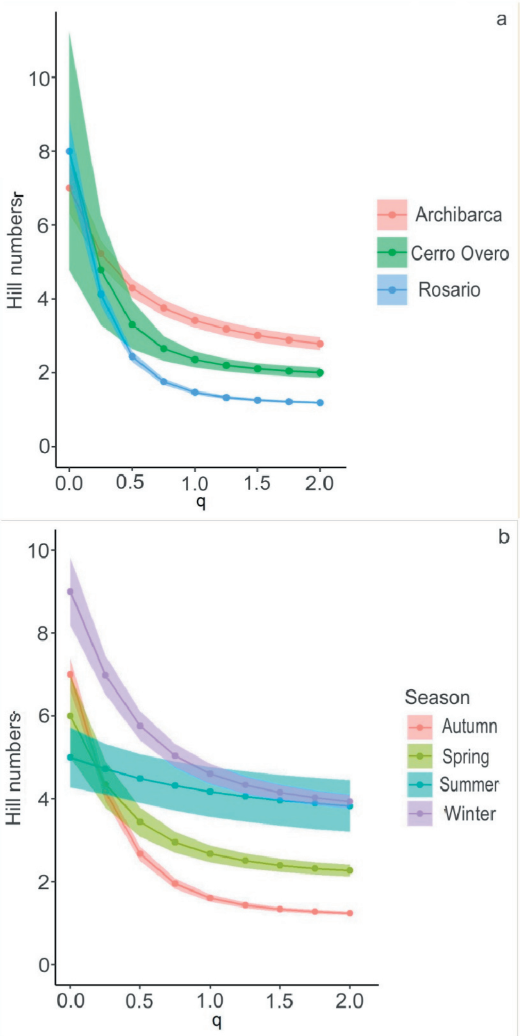

Figure 3. Profiles diversity Chironomidae based on Hill numbers in three tributary streams of the Salar de Olaroz, Jujuy, Argentina (lines, shaded area corresponds to 95% confidence intervals). a) spatial (all seasons together), b) temporal (all sites together).

Figura 3. Perfiles de diversidad de Chironomidae basados en números de Hill en tres corrientes tributarias del Salar de Olaroz, Jujuy, Argentina (líneas, área sombreada corresponde a intervalos de confianza del 95%). a) espacial (todas las temporadas juntas), b) temporal (todos los sitios juntos).

1.6 effective species in autumn. Regarding diversity of order q=2, it behaved similarly to richness (Figure 3b).

Orthocladiinae (Figure 4a) was the most abundant in the three sites, reaching values between 50% and 100% relative abundance. In the Archibarca stream, the relative abundances of Orthocladiinae and Chironominae were similar, while in the remaining sites, Chironominae did not exceed 1%. In the case of Podonominae, the abundances were very low: 1.3% in Rosario, 0.2% in Cerro Overo and 0.2% in Archibarca.

Table 2. Environmental variables in the sites (mean and standard deviation of all samplings) and seasons (mean and SD of all sites). H and P are the values of statistic and probability (Kruskal Wallis). At each variable, different letters (a, b, c) indicate significant differences.

Tabla 2. Variables ambientales en los sitios (media y desviación estándar de todos los muestreos) y de las épocas (media y desviación estándar de todos los sitios). H y P son el estadístico y la probabilidad (Kruskal Wallis). En cada variable, letras diferentes (a, b, c) indican diferencias significativas.

Environmental variables	Sites					Season					
	Archibarca N=12	Cerro Overo N=12	Rosario N=12	H	P	Summer N=9	Autumn N=9	Winter N=9	Spring N=9	H	P
Water temperature (°C)	11.67 (5.63) ab	15.75 (3.47) b	9.71 (7.76) a	5.53	0.03	16.67 (4) b	8.22 (3.96) a	5.83 (5.02) a	11.44 (8.82) ab	12.75	0.005
PH	7.61 (0.25)	7.46 (0.37)	6.32 (3.82)	5.36	0.06	7.98 (0.38) b	7.81 (0.54) ab	7.66 (0.68) ab	5.07 (3.80) a	7.85	0.04
Conductivity (µS/cm)	4588.75 (1792.41) a	20757.75 (30158) b	2878.36 (2878.36) a	9.34	0.009	8911.44 (8802.70)	7542.78 (6677.67)	7225.56 (7049.60)	14580.00(36580.73)	4.48	0.21
Total organic matter	1.4 (0.75) b	2.65 (1.60) b	0.50 (0.62) a	15.23	0.0005	1.75 (1.43)	1.30 (1.27)	1.88 (1.66)	1.14 (1.21)	1.82	0.61
Dissolved oxygen (ppm)	5.48 (1.20)	5.19 (2.73)	4.46 (3.26)	0.62	0.73	5.11(2.44)	6.11 (1.63)	5.44 (2)	3.5(3.30)	4.83	0.18
Depth (cm)	22.24 (7.11) b	14.11 (7.38) a	12.27 (11.88) a	8.47	0.01	23.76 (9.12) b	15.33 (8.48) ab	18.94 (7.08) b	6.8 (6.70) a	14.5	0.002
Channel width (m)	0.64 (0.51) a	2.13 (1.87) b	10.28 (24.71) b	6.17	0.04	12.21 (28.54)	1.49 (2.50)	2.64 (2.87)	1.07 (1.49)	6.94	0.07
Sand (%)	89.86 (4.69)	79.45 (10.51)	68.09 (42.48)	5.76	0.05	86.13 (13.30)	89.54 (7.40)	86.13 (13.30)	57.49 (43.33)	6.23	0.09
Clay (%)	6.26 (4.42) a	11.73 (5.92) b	3.05 (4.22) a	15.65	0.0004	8.05 (7.02)	5.38 (4.77)	9.07 (7.35)	5.55 (4.49)	1.38	0.7
Silt (%)	3.33 (1.27) a	8.75 (4.94) b	4.24 (7.50) a	10.01	0.003	8.51 (8.02)	4.35 (3.48)	5.28 (5.51)	3.61 (8.02)	5.02	0.12

Regarding the temporal pattern (Figure 4b), Orthocladiinae was the best represented during the four seasons, but it reached its maximum abundance in autumn (98% of the total). Chironominae and Podonominae reached maximum values in winter, with 24% and 2%, respectively.

Relationship between environmental variables and the Chironomidae assemblage

The environmental variables that presented a significant relationship with the structure of Chironomidae assemblage (F=5.99, P=0.001) were total organic matter, conductivity, sand, pH and depth. This analysis showed that the first two axes of the explained 50.81% of the accumulated variability. The variables that were significantly correlated with the CCA1 axis were pH, total organic matter and average depth. The variables that were related to the CCA2 axis were: sand and conductivity. The morphospecies *Podonomus* sp. and *Cricotopus* sp. 4 showed preference for sites with neutral pH. *Paraphaenocladius* sp. and *Cricotopus* sp. 3 were present in samples with high conductivity (Cerro Overo). *Parametriocnemus* sp. was associated with Rosario samples where the conductivity was lower. *Limnophyes* sp. and *Polypedilum* sp. were associated with Archibarca, a site with greater depth. *Cricotopus* sp. 10 and Genus 1 sp. did

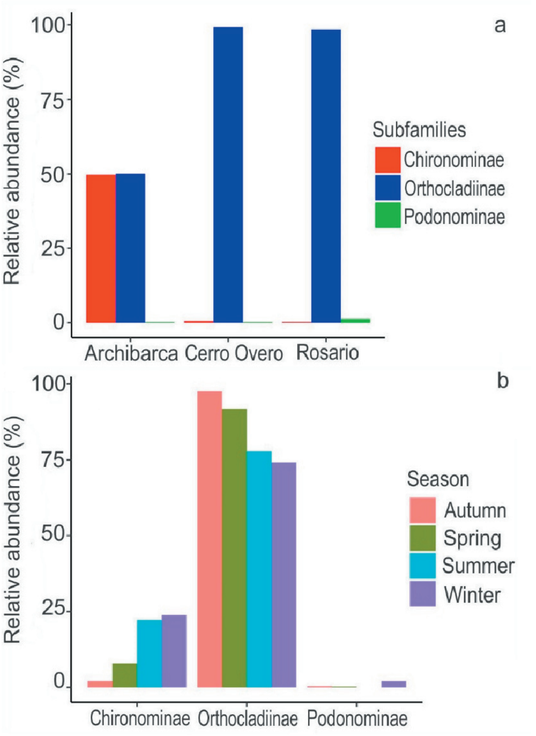

Figure 4. Relative abundance (%) of the Chironomidae subfamilies in the different sites of the Salar de Olaroz (a) and in the seasons (b).

Figura 4. Abundancia relativa (%) de las subfamilias Chironomidae en los diferentes sitios del Salar de Olaroz (a) y en las diferentes estaciones del año (b).

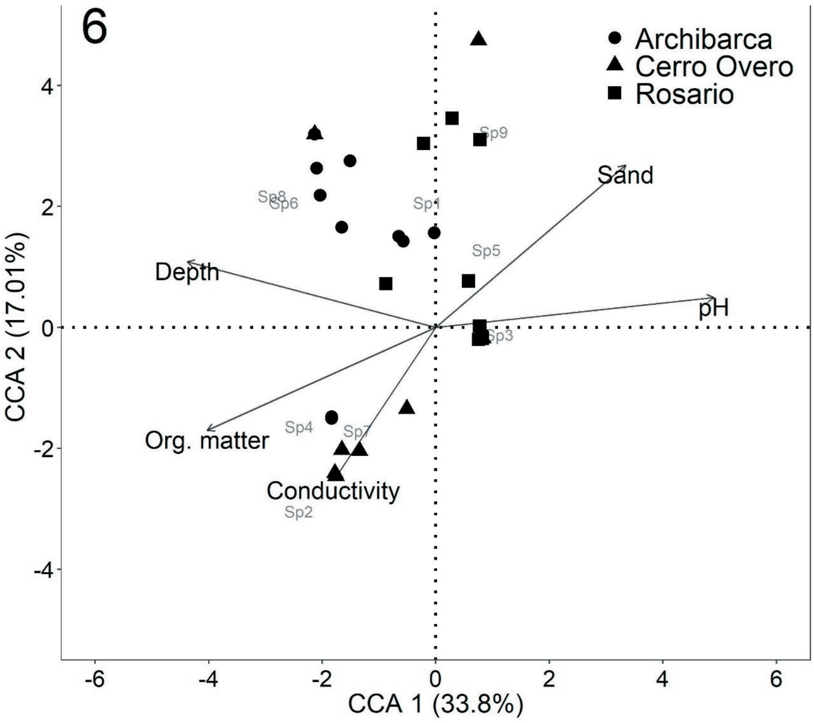

Figure 5. Ordination diagram of the canonical correspondence analysis showing the distribution of the sites based on the average abundances of Chironomidae and their relationships with environmental variables. Sp1: Genus 1; Sp2: *Cricotopus* sp. 3; Sp3: *Cricotopus* sp. 4; Sp4: *Cricotopus* sp. 10; Sp5: *Parametriocnemus* sp.; Sp6: *Limnophyes* sp.; Sp7: *Paraphaenocladius* sp.; Sp8: *Polypedilum* sp.; Sp9: *Podonomus fastigians*.

Figura 5. Diagrama de ordenación del análisis de correspondencia canónica que muestra la distribución de los sitios con base en las abundancias promedio de Chironomidae y sus relaciones con las variables ambientales. Sp1: Género 1; Sp2: *Cricotopus* sp. 3; Sp3: *Cricotopus* sp. 4; Sp4: *Cricotopus* sp. 10; Sp5: *Parametriocnemus* sp.; Sp6: *Limnophyes* sp.; Sp7: *Paraphaenocladius* sp.; Sp8: *Polypedilum* sp.; Sp9: *Podonomus fastigians*.

not show an association with any particular variable (Figure 5).

Discussion

The environmental variability of the three tributaries of the Salar de Olaroz determines the spatial and temporal distribution of the Chironomidae assemblage, as was also highlighted by Rodrigues Capítulo et al. (2014) in their study of this salar, and Scheibler et al. (2014), Nieto et al. (2016) and Rodríguez Garay et al. (2020) for other Andean systems (not salars) in Argentina.

The richness of chironomids found in the present study was higher than that reported by Rodrigues Capítulo et al. (2014) for the same streams, who found 5 morphotypes. *Cricotopus* sp., *Orthocladius* sp. 1, *Orthocladius* sp. 2, *Polypedilum* sp. and *Podonomus* sp. In our study the following are added: Genus 1, *Parametriocnemus* sp., *Limnophyes* sp., *Paraphaenocladius* sp. and 3 different morphotypes of *Cricotopus* are recognized. The greater richness that we find is surely due to the greater sampling effort, including 4 seasons for three consecutive years. We do not attribute this difference to the sampler used (Ekman dredge in the cited work), since the core we used is also a sediment sampler.

Other studies carried out in arid and semi-arid high Andean zones (Medina and Paggi 2004; Scheibler et al. 2008, 2014; Rodríguez Garay et al. 2015, 2020) registered a greater richness than that found by us. This could be related to the granulometry of the sediments, since in the aforementioned works it was composed not only of fine sediments (as in our sites), but also of gravels and rocks of different sizes, causing greater environmental heterogeneity. At the temporal scale, the richness and diversity pattern were similar to that observed in these studies and in others on the complete benthic community (Rodrigues Capítulo et al. 2014; Nieto et al. 2016).The values of richness and diversity were higher in winter (dry season) due to the stability of the wetland bed, while during the summer, the flow of the streams increases due to rains and spates, removing the substrate and increasing the suspended solids, which decreases the richness and diversity of chironomids as found by Rossaro et al. (2006) in Alpine rivers.

Orthocladiinae was the most diverse and abundant of the three reported subfamilies, which also occurs in other studies (Tejerina and Malizia 2012; Scheibler et al. 2014; Rodrígues Capitulo et al. 2014; Rodríguez Garay et al. 2015, 2020). The low diversity of Chironominae, represented only by *Polypedilum* sp., could be explained considering that it is a warm eurythermic subfamily, more diverse in lower altitude environments (Medina et al. 2008). Podonominae was rare, perhaps because these streams have a low current speed and high conductivity, unfavorable characteristics for this group (Paggi 2009).

The association between chironomid morphotypes in the Salar de Olaroz and total organic matter, conductivity, pH, percentage of sand and depth was important, which coincides with Rodrigues Capítulo et al. (2014). We did not measure vegetation cover, suspended solids, water discharge and current velocity, variables that would be important to understand changes in aquatic assemblages. We suggest incorporating them in future studies.

The results of this study regarding the response of chironomids to spatio-temporal variations in the Olaroz salt flat for three consecutive years, prior to the establishment of mining ventures, set a precedent to interpret the potential impact represented by the great demand for water from these activities. If flow rates are reduced, other variables could be affected (e.g., increments in pH, salinity and conductivity, and decreases in dissolved oxygen, turbulence and particle size). Our results show that the Chironomidae assemblage could respond to this impact by decreasing its richness, mainly due to the disappearance of the morphotypes associated with these variables (e.g., *Podonomus*, *Parametriocnemus*, *Limnophyes* and *Polypedilum*). For these reasons, we think Chironomidae assemblage will be useful to monitor environmental quality in the studied streams, which show a rather poor benthic community (Rodrigues Capítulo et al. 2014).

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References

Armitage, P., P. S. Cranston, and L. C. V. Pinder. 1995. The Chironomidae. The biology and ecology of non-biting midges. Chapman and Hall, Londres. https://doi.org/10.1007/978-94-011-0715-0.

Ashe, P., D. A. Murray, and F. Reiss. 1987. The zoogeographical distribution of Chironomidae (lnsecta: Diptera). Annls Limnologica 23:27-60. https://doi.org/10.1051/limn/1987002.

Bouyoucos, G. 1927. A Rapid Method for Mechanical Analysis of Soils. Science 65(1692):549-551. https://doi.org/10.1126/science.65.1692.549.

Borcard, D., F. Gillet, and P. Legendre. 2018. Ecología numérica con R (2ª ed.). Publicaciones internacionales de Springer.

Brown, A. D., and S. Pacheco. 2005. Propuesta de actualización del mapa ecorregional de la Argentina. Pp. 28-31 *in* A. D. Brown, U. M. Ortiz, M. Acerbi and J. Corcuera (eds.). La situación ambiental argentina 2005. Fundación Vida Silvestre, Buenos Aires.

Chao, A., and L. Jost. 2012. Coverage-based rarefaction and extrapolation: standardizing samples by completeness rather than size. Ecology 93(12):2533-2547. https://doi.org/10.1890/11-1952.1.

Dray, S., and A. Dufour. 2007. The ade4 Package: Implementing the Duality Diagram for Ecologists. Journal of Statistical Software 22(4):1-20. https://doi.org/10.18637/jss.v022.i04.

Epler, J. H. 2001. Identification Manual for the Larval Chironomidae (Diptera) of North and South Carolina. A guide to the taxonomy of the midges of the southeastern Unites States including Florida. Special Publication SJ2001-SP13. North Carolina Department of Environment and Natural Resources, Raleigh, NC, and St. Johns River Management District, Palatka, FL.

Flexer, V. 2018. El potencial tecnológico alrededor del litio. Pp. 422-423 *in* H. R. Grau, M. J. Babot, A. Izquierdo and A. Grau (eds.). La Puna argentina: naturaleza y cultura. Serie Conservación de la Naturaleza Nro. 24. Fundación Miguel Lillo. Ministerio de Educación de la Nación.

García, M. G., L. G. Borda, L. V. Godfrey, R. L. López Steinmetz, and A. Losada-Calderón. 2020. Characterization of lithium cycling in the Salar De Olaroz, Central Andes, using a geochemical and isotopic approach. Chemical Geology 531:119340. https://doi.org/10.1016/j.chemgeo.2019.119340.

Garreaud, R., M. Vuille, and C. Clement. 2003. The climate of the Altiplano: Observed current conditions and mechanisms of past changes, Palaeogeography, Palaeoclimatology. Palaeoecology 194:5-22. https://doi.org/10.1016/S0031-0182(03)00269-4.

Hsieh, T. C., K. H. Ma, and A. Chao. 2016. iNEXT: un paquete R para la rarefacción y extrapolación de la diversidad de especies (números de Hill). Methods Ecol Evol 7:1451-1456. https://doi.org/10.1111/2041-210X.12613.

Izquierdo, A. E., R. Aragón, C. J. Navarro, and E. Casagranda. 2018. Humedales de la Puna: principales proveedores de servicios ecosistémicos de la región. Pp. 96-111 *in* H. R. Grau, M. J. Babot, A. Izquierdo and A. Grau (eds.). La Puna argentina: naturaleza y cultura. Serie Conservación de la Naturaleza Nro. 24. Fundación Miguel Lillo. Ministerio de Educación de la Nación.

Izquierdo, A. E., J. Foguet, and H. R. Grau. 2016. Hidroecosistemas de la Puna y Altos Andes de Argentina. Acta Geológica Lilloana 28:390-402.

Jost, L. 2006. Entropy and diversity. Oikos 113(2):363-375. https://doi.org/10.1111/j.2006.0030-1299.14714.x.

Lencioni, V., P. S. Cranston, and E. A. Makarchenko. 2018. Recent advances in the study of chironomidae: An overview. Journal of Limnology 77(1):1-6. https://doi.org/10.4081/jlimnol.2018.1865.

Maidana, N. I., and C. T. Seeligmann. 2014. Phytoplankton in high mountain wetlands of Argentina. *In* G. Tell, I. Izaguirre and I. O´Farrell (eds.). Freshwater Phytoplankton from Argentina. Phytoplankton diversity and ecology in different aquatic systems. (Adv. in Limnology, 65). https://doi.org/10.1127/1612-166X/2014/0065-0032.

Medina, A. I., and A. C. Paggi. 2004. Composición y abundancia de Chironomidae (Diptera) en un río serrano de zona semiárida (San Luis, Argentina). Rev Soc Entomol Arg 63:107-118.

Medina, A. I., E. Scheibler, and A. Paggi. 2008. Distribución de Chironomidae (Diptera) en dos sistemas fluviales ritrónicos (Andino-serrano) de Argentina. Rev Soc Entomol Argent 67(1-2):69-79.

Morello, J., S. D. Matteucci, A. F. Rodríguez, and M. F. Silva. 2012. Ecorregiones y complejos ecosistémicos argentinos. Orientación Gráfica Editora, Buenos Aires. Pp. 752.

Nelson, D. W., and L. E. Sommers. 1996. Carbono total, carbono orgánico y materia orgánica. *In* D. Sparks, A. Page, P. Helmke, R. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston and M. E. Sumner (eds.). Methods of Soil Analysis. https://doi.org/10.2136/sssabookser5.3.c34.

Nieto, C., A. Malizia, J. Carilla, A. Izquierdo, J. Rodríguez, S. Cuello, M. Zannier, and H. R. Grau. 2016. Spatial patterns in communities of aquatic macroinvertebrates of Argentinean Puna. Revista de Biología Tropical 64(2):747-762. https://doi.org/10.15517/rbt.v64i2.18801.

Oksanen, J., F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. Henry, H. Stevens, E. Szoecs, and H. Wagne. 2019. vegan: Community Ecology Package. R package version 2.5-6. URL: CRAN.R-project.org/package=vegan.

Paggi, A. C. 2009. Diptera. Chironomidae. Pp. 383-409 *in* E. Domínguez and H. R. Fernández (eds.). Macroinvertebrados bentónicos sudamericanos. Sistemática y Biología. Fundación Miguel Lillo. Tucumán. Argentina.

Rodrigues Capítulo, A., F. Spaccesi, and L. Armendáriz. 2014. Stream zoobenthos under extreme conditions in the high Andean plateus of Argentina (South America). Journal of Arid Environments 108:38-42. https://doi.org/10.1016/j.jaridenv.2014.04.008.

Rodríguez Garay, G. N., A. C. Paggi, and E. E. Scheibler. 2020. Chironomidae assemblages at different altitudes in Northwest Argentina: the role of local factors. An Acad Bras Cienc 92:e20190953. https://doi.org/10.1590/0001-3765202020190953.

Rodríguez Garay, G. N., and A. C. Paggi. 2015. Chironomidae (Diptera) en cursos de agua de Puna y Chaco Serrano de Catamarca (Argentina): primeros registros y distribución de géneros y especies. Rev Soc Entomol Arg 74:15-25.

Rossaro, B., V. Lencioni, A. Boggero, and L. Marziali. 2006. Chironomids from Southern Alpine running waters: ecology, biogeography. Hydrobiologia 562:231-246. https://doi.org/10.1007/s10750-005-1813-x.

Scheibler, E. E., S. A. Roig-Juñent, and C. M. Claps. 2014. Chironomid (Insecta: Diptera) assemblages along an Andean altitudinal gradient. Aquatic Biology 20:169-184. https://doi.org/10.3354/ab00554.

Scheibler, E. E., V. Pozo, and A. C. Paggi. 2008. Distribución espacio-temporal de larvas de Chironomidae (Diptera) en un arroyo andino (Uspallata, Mendoza, Argentina). Rev Soc Entomol Arg 67(3-4):45-58.

Tejerina, E. G., and A. Malizia. 2012. Chironomidae (Diptera) larvae assemblages differ along an altitudinal gradient and temporal periods in a subtropical montane stream in Northwest Argentina. Hydrobiologia 686:41-54. https://doi.org/10.1007/s10750-011-0984-x.

ter Braak, C. J. F., and P. Smilauer. 1999. CANOCO for Windows (vers. 4.02). A FORTRAN program for canonical community ordination. Wageningen, the Netherlands: Centre for Biometry, Wageningen.

Wickham, H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. https://doi.org/10.1007/978-3-319-24277-4.