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ECOSYSTEMS

Spatial structure and composition of invertebrates in high altitude rivers of the central Andes (Olaroz Salar, Argentina)

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Abstract: This study aimed to examine the spatial variation in sets of micro and macroinvertebrates and to detect how physicochemical and environmental variables affect community structures in high Andean rivers. Six sites were sampled in three rivers of the Argentinian plateau, in altitudes between 3900-4400 masl during the dry season (May-October 2017). The variables that affected the structure of the micro and macroinvertebrate communities were: altitude, conductivity, turbidity, water temperature, hardness, oxygen, and lead. Sites with high levels of arsenic, lead and boron were identified. Assemblages of species common to high Andean courses were recorded on a north-south axis. The registered community structure has similarities with High Andean streams of Bolivia and rivers of the Catamarca plateau, increasing the differences in composition and assemblages towards the south (Mendoza and Patagonian Andes). Diptera was the best represented with Orthocladiinae and Podonominae, reaching better representativeness at higher altitudes. Together with them, *Austrelmis*, Hydracarina, Hirudinea, *Nais*, *Hyalella* constitute the dominant group. There is a trend towards a decrease in the richness of species with respect to altitude, related to the proximity of the Salar and the increase in conductivity, carbonates and hardness.

Key words: macroinvertebrates, microinvertebrates, diversity, altoandean rivers.

INTRODUCTION

The Atacama Plateau is one of the driest areas of the world, the water demand greatly exceeds its availability. This region is located between 3200 and 5000 m.a.s.l. in the Central Andes with high solar radiation, intense winds and daytime temperatures close to 0 °C (Ruthsatz 2012, Squeo et al. 2006). In High Andean ecosystems, the associated processes with the maintenance and perpetuation of limnic systems are very sensitive to changes produced by natural events such as variations in the rainfall regime (Elosegi & Sabater 2009) and anthropic disturbances (Paoli 2003). The loss of depth of the underground water layers, the changes in the flow of surface currents, the estimated reserve volume and the recharge rate is fundamental for the conservation of the systems (Sticco 2018, Mignaqui 2019). In Jujuy, an important lithium reserve is found in the Olaroz salar. Although this mineral represents an economic opportunity and a resource in the face of climate change, its extraction puts the High Andean water courses at risk. These ecosystems are fragile, not very resilient, have endemic biodiversity and are a source of life for indigenous communities (Cepeda Pizarro & Pola 2013). The extraction of lithium, especially by the evaporitic method, implies a huge loss of groundwater and produces a salinization of freshwater. However, little attention has been paid to the composition and structure of aquatic biological diversity and its association with the environmental variables of the water. This information is relevant if we consider that the assembly of species plays a fundamental role in the efficiency and stability of the functions of the ecosystems (Arzamendia et al. 2018, Everard 2016). Facing a rapid development of extractive industries such as mining, it is necessary to implement more integrated freshwater quality indicators (Mercado García et al. 2019). Biodiversity is an indicator of the health of the ecosystem; the mechanisms by which biodiversity produces a wide array of supporting services essential for the continuity of life and human wellbeing is poorly understood, but it is of vital importance. Invertebrates are good indicators of aquatic environment quality because they are taxonomically and ecologically diverse, the sampling is simple and its systematics is solid for the family and genus levels (Prat et al. 2009). Evaporation conditions and substrate mineral composition may be the determining factors in the salinity ranges in rivers (Elosegi & Sabater 2009). The importance of knowing the variability of physicochemical factors in rivers lies in the influence that they have on the biodiversity in different spatial levels and the lack of this knowledge makes it difficult to identify patterns of distributions of organisms (Jacobsen 2004). The importance of studies of biological diversity in aquatic environments of arid regions is that they can provide a baseline for future studies as well as document how climate change affects the conditions of water quality, habitat availability and species diversity. (Hankel et al. 2018, Rodrigues Capítulo et al. 2014, Scheibler & Debandi 2008, Scheibler & Ciocco 2013, Nieto et al. 2016). The objective of the study was to characterize, for the first time, the environmental conditions, the diversity of invertebrates and the physicochemical water of the main freshwater course, tributary to the Salar de Olaroz. For this, the spatial variability of the rivers and the structure and composition of the aquatic communities of invertebrates, the physicochemical of the water and the granulometry of the substrate were analyzed. It was also analyzed how abiotic variables influence the abundance of invertebrate species.

STUDY AREA

The Atacama Plateau is a high-altitude plain in western-central South America, and one of the most extensive high plateaus in the world. Its altitude is 3900 m (Márquez-García et al. 2009), and is one of the driest regions on the entire planet. The climate is dry and cold with average temperatures that daily fluctuate to a greater extent (up to 30°C) than the seasonal variation (Squeo et al. 2006). The rainfall shows a high degree of seasonality (200 mm- 800 mm) with a rainy period (November-April) and a dry one (June-October). The vegetation consists of scattered grasses, low shrubs, and thorny species such as cacti. In the higher-altitude areas the vegetation is sparse, adapted to radiation, dryness, severe cold, and winds (Cabrera & Willink 1973). The salar are considered to be the remnants of the extensive lakes that once occupied the high plains. The Salar de Olaroz is fed in the north by the Rosario river (Figure 1), in the West by the Toro river, and in the East by the Sierra de Tanques river. The vegetation in the alluvial valley of Rosario river is scarce, while, in the perimeter of the valley, the flora is xerophilous (Morello et al. 2018).

Sampling Design

The basin of Rosario river (Susques department, Jujuy, Argentina) has an approximated surface of 1589 km^2 with wetlands occupying 1.8 % of the total area (Neme 2017). The study area

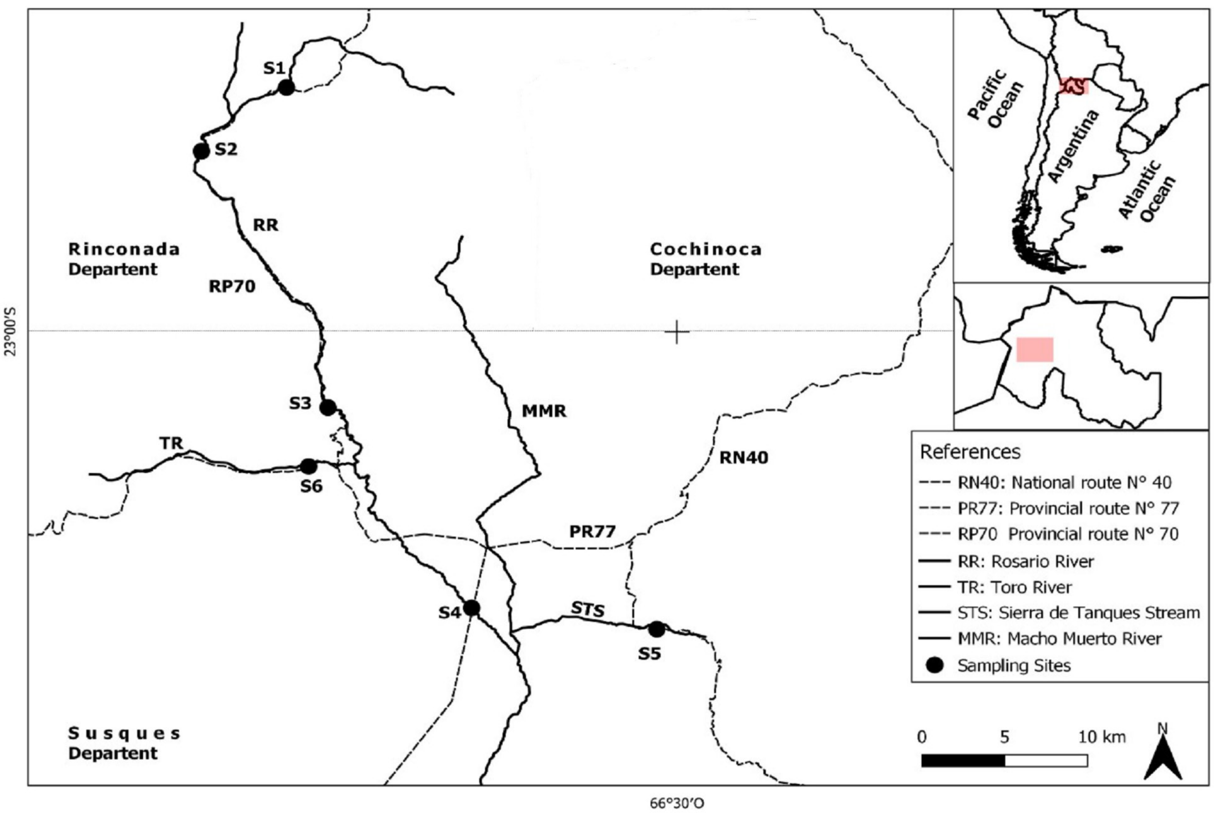

Figure 1. Location of Rosario, Sierra de Tanques and Toro rivers and sites.

was located in a hardly accessible region characterized by a pronounced seasonal climate, so two samplings were performed during the dry period (May-October 2017) at six sites located in the three rivers: Rosario river (S1-S4; upstream-downstream, respectively); Toro river (S5), and Sierra de Tanques (S6) (Figure 1, Figure 5, Table I). The hierarchy of the channels (number of order) was calculated according to the proposed scale by Sthraler (Angelier 2002). The samples for granulometry were collected with a sieve and the percentage composition of the fractions was determined (calcination method, APHA 19981):-medium gravel (25.0 mm-12.5 mm), fine gravel (4.76 mm), sabulo (4.00 mm–2.83 mm), coarse sand (2.00 mm–1.68 mm), medium sand (1.00 mm–0.42 mm), fine sand (0.25 mm–0.08 mm), silt (0.06 mm–0.03 mm) and clay (0.02 mm). The physicochemical parameters determined in situ with a probe (Cole Parmer PCD650 and Hanna HI96732) were: pH (SM 17th Ed. 4500H.B Electrometric); conductivity, Total Dissolved Solids (TDS), salinity (SM 17ºEd. 2510B. Conductimetry). Samples of two liter of water were extracted for other laboratory determinations: total hardness (SM 17th Ed. 2340 C-Titration EDTA); carbonates and chlorides (SM 17ºEd. 2320 B-Titration method); sulfates (SM 17ºEd. 4500-C-Gravimetric method); nitrates (SM 17th Ed.4500-B-UV spectrometric method); nitrites (Colorimetric-Sulfanilic-phenol Zambelli Method); ammonium (SM 17º Ed.4500 NH3-C Nesslerization Method); copper, lead, arsenic, iron, aluminum, boron and chromium (Atomic Emission by Microwave Plasma (MP-AES 4200); fluorine (SM 17th Ed.4500 – F- D SFADNS method). For the determination of salinity, the criterion of Dejoux (1993) was used. The depth, width, speed and flow of the channel were determined with a flowmeter (GW111). The macroinvertebrates

Table I. Values of the physicochemical variables registered at the sampling sites in rivers: Rosario, Sierra de Tanques, Toro (Salar de Olaroz, Jujuy, Argentina).

Sites	S1	S2	S3	S4	S5	S6
Coordinates S	22°50´49.6"	22°53´12.4"	23°02´49.7"	23°10´20.5"	23°10´0.6	23°05´2.7"
W	66° 43´48.8"	66°46´51.5"	66°42´20.2"	66°37´15.4"	66°30´44.0"	66°43´3.6
Strahler order	1	2	2	3	1	1
Altitude (masl)	4446	4287	4103	3973	4126	4094
Water temperature (°C)	2,9	18,7	0,1	0,7	17	3,1
Environmental temperature (°C)	5	6	9	10	17	13.8
Width (m)	2.25	5.92	3.98	7.17	0.28	0.45
Mean depth (m)	0.1	0.15	0.11	0.07	0.02	0.04
Mean velocity (m/s)	1.28	2.51	1.93	2.89	<0.10	<0.10
Flow (m^3/s)	0.28	2.2	1.31	1.38	< 0.05	< 0.05
Dissolved oxygen (mg/L)	8	2.5	5.6	1.5	2.93	10
Conductivity (uS/cm)	92.1	2400	3100	2820	417	382
Salinity (mg/L)	70,0	1824,0	2356,0	2143,2	316,9	290,3
Turbidity (NTU)	1.8	4.7	2.8	2.6	2.3	1.46
pH	6.7	6.8	7.1	7.2	7.1	7
Total hardness (mg/L)	103.88	470.4	476.28	419.44	382.2	441
Carbonate (mg/L)	0	48	180	248	36	16
Clorhide (mg/L)	3.88	92.64	111.55	94.09	114.46	120.28
Sulfate (mg/L)	35.8	178.84	252.95	190.44	118.4	80.73
Nitrates (mg/L)	1.71	33.65	27.3	30.34	<0.01	<0.01
Nitrites (mg/L)	0.02	6.26	0.3	0.43	<0.02	<0.02
Ammonia (mg/L)	0.18	2.39	1.68	0.2	<0.05	<0.05
Copper (mg/L)	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006
Lead (mg/L)	< 0.0021	0.09	<0.0021	0.1	<0.0021	< 0.0021
Fluorine (mg/L)	<0.20	0.98	0.8	0.9	0.72	0.3
Arsenic (mg/L)	0.01	1.39	1.63	1.33	0.14	0.02
Iron (mg/L)	0.08	1.2	0.2	0.8	0.03	0.03
Aluminun(mg/L)	0.09	0.4	0.2	0.6	0.05	0.04
Boron (mg/L)	0.29	69.4	102.4	83.4	3.07	4.71
Crome (mg/L)	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004

were collected with Surber net (30x30 cm, 250 µm pore size), three samples per site, and fixed with 96° ethanol. The qualitative sampling was carried out with a D net with a fixed collection time (20 minutes). For the microinvertebrates, a handnet was used with 50 microns pore size, three samples per site and fixed with 4% formaldehyde (Epele & Miserendino 2016). For the identification of the organisms, general and specific identification keys for each group were used: Coscarón & Coscarón Arias (2007), Domínguez & Fernández (2009), Hamada et al. (2018), Lopretto & Tell (1995), and Merritt & Cummins (1996).

Data analyses

To estimate abundance and taxonomic richness for each sample, we developed a matrix of biotic (in m^2, per morphospecies) and abiotic data (physicochemical, morphometric, granulometric composition and environmental variables) per sampling site. To calculate diversity indices for each sampling site, we used the taxonomic richness, the Shannon-Wiener diversity (H'), the Simpson dominance (D) and the equitability indices (J), with PAST package (Hammer et al. 2001) version 3.02. To examine spatial variations in abiotic variables were used main components (PCA). To analyze the relationship between abiotic variables and morphospecies abundances per sampling sites, we performed a canonical correspondence analysis (CCA). Only those variables that presented low correlation with one another (based on the Spearman correlation analysis results; r<0,60) were taken into account.

RESULTS

Environmental characterisation

The analyzed bodies of water are shallow (mean: 0.08 m), slightly acid to neutral pH, transparent, with heterogeneous substrate with sand and fine gravel being predominant (Tables I, II). The average flow was 0.87 m^3/s with an average current of 1.55 m/s. The Rosario river has a tendency from the headwaters to the S3 to increase the values of conductivity, dissolved oxygen, hardness, chloride, sulfates, nitrates, arsenic and boron. After the contribution of the Toro river, this trend changed, decreasing the values of the variables analyzed. The S2 has thermal characteristics, while S4 is the drainage of the Rosario river and discharges into the Salar. The highest salinity values were recorded in the Rosario river, evidencing an inverse relationship to altitude. Approximately ten times less saline were the rivers Sierra de Tanques y Toro, while S1 was the least saline of those analyzed. The analyzed sites were unpolluted –reflecting the physicochemical registers and natural conditions of the water. The concentration of dissolved oxygen in S2, S4 and S5 is below the recommended for the maintenance of aquatic life in shallow freshwater and saline mirrors (Table I). The concentration of carbonates in S3 and S4 exceed the limits suggested by the Argentine regulations (use II) (Table I). According to provincial regulations, the Rosario river presented a high concentration of boron conditioning the uses I, II, VI (Table I). The headwaters of the Rosario river (S1) is a shallow course, with low flow and turbidity and with a

Table II. Granulometry.

Components/Sites	Ø(mm)	S1	S2	S3	S4	S5	S6
medium gravel	25-12.5	0,00	0,00	0,00	6,83	0,00	0,00
fine gravel	12-4.5	22,41	0,00	41,18	30,07	16,43	25,32
sabulo	4-2.8	8,26	0,00	14,79	6,69	13,41	16,47
gross sand	2-1.7	11,61	2,12	10,11	11,07	10,12	16,28
medium sand	1-0.42	51,71	7,41	24,32	37,12	31,94	31,67
fine sand	0.25-0.09	5,29	59,22	8,30	6,64	27,22	9,59
silt	0.06-0.03	0,61	30,77	0,27	1,28	0,76	0,38
clay	0.002	0,11	0,48	0,02	0,5	0,12	0,29

predominance of medium-fine sands (Table I, II). In S1, the low conductivity qualifies the water as freshwater, with moderately hardness and low boron and arsenic content. However, for this same river, the arsenic values in S2, S3, S4 and S5 (Sierra de Tanques) increase and exceed the concentrations according to national and provincial regulations for human drinking. As the Rosario river approaches the mouth of the salar, the river loses depth and becomes wider, increasing the concentration of borates, lead, fluorine, aluminum and boron. The water temperature was low except for S2, which has thermal characteristics, and S5 due to the shallow depth and high insolation during the sampling. The rivers tributaries to the Rosario, analyzed (S5: Sierra de Tanques; S6: Toro river) are shallow, permanent and narrow courses in relation to the Rosario. Medium and fine sands predominate in the substrate, with very low flow rates and speeds. The conductivity, hardness, nitrites, nitrates, ammonium, fluorine, iron, aluminum and boron in these tributary rivers are lower than the Rosario. Possibly, due to these characteristics, the contribution of the Toro river causes a decrease in the values of the parameters of the Rosario river. Downstream of the sampling site in the Toro river, prior to entering the Rosario river, there is a town which uses surface water as a supply for a water treatment plant.

Spatial variability of the physicochemical composition of the water

The physicochemical (ammonia, arsenic, aluminum, boron, carbonate, fluorine, nitrate, pH, environmental temperature), morphometric (width, depth, flow) and granulometric variables (sand, sage, silt, clay) showed a high Spearman correlation (r> 0.6); therefore, they were excluded from the multivariate analyzes. The first component (PC1) explained 50.7% of the variance from dissolved oxygen (e =0.45), conductivity (e =-0.44), turbidity and lead (e =-0.43). The second component (PC2) explained 25.0% of the variance with altitude (e =0.60), water temperature (e =0.57) and hardness (e =-0.31). The maximum values of dissolved oxygen and altitude characterized mainly the headwaters of the Rosario and Toro rivers, while the highest turbidity and temperature of the water correspond to S2, with thermal characteristics; additionally, a tendency to increase the hardness towards the mouth of the salar (S3-S4) was observed. The highest concentrations of lead were registered in S2 and S4 (Figure 2).

Micro and macroinvertebrates assemblage composition

The microinvertebrates presented a specific composition of 17 taxa: five rotifers, five amebozoans, one cercozoan and copepod and four ostracods (Table III). The combination of factors such as the shallowness of the water courses, the high temperatures during the day and the presence of winds, exert a mixing effect on the scarce vertical profile. A spatial variability was observed with respect to the composition of the microinvertebrate community. The Rosario river registered the highest richness, amoebozoans reaching the highest representation (53.8%) followed by rotifers (13.6%), ostracods (12.3%) and cercozoans and tardigrades (1, 3%). In the Toro river, rotifers (75%) were dominant over cercozoans (12.5%), while in Sierra de Tanques no organisms were recorded. The ostracods had its maximum representativeness and richness in S1, related to soft water with low registers in conductivity, bicarbonates and sulphates. The maximum representativeness of amebozoans was registered in S4 –near the salt pan and lowest drainage point in the Rosario river- with predominant gravel and fine sand (Table II).

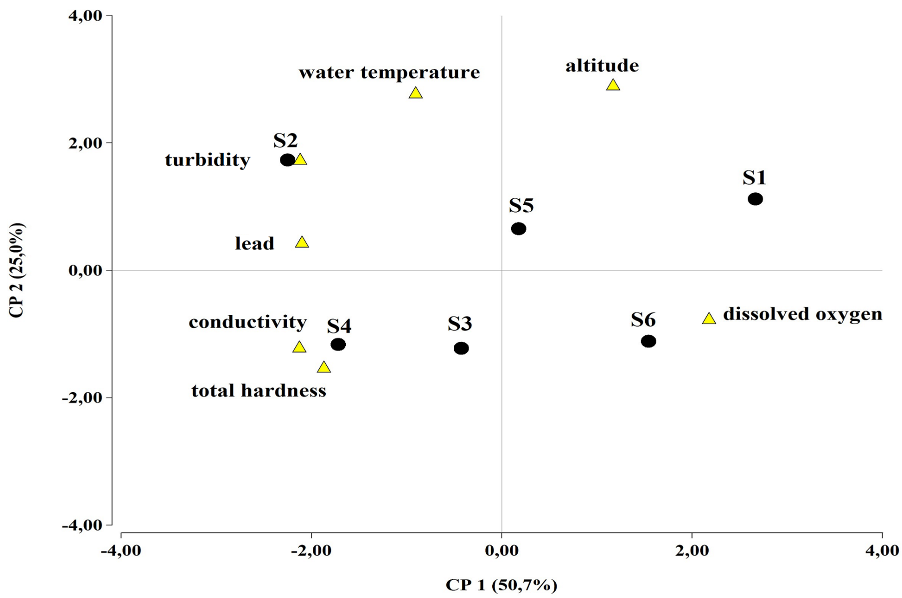

Figure 2. Spatial variability S1-S6 respect to: physical-chemical parameters and altitude.

Trinema was registered in S1 and S6, sharing both sites similar granulometric–composition (Tables II, III). The maximum representativeness of rotifers was registered in S6, associated with clear water, maximum concentration of dissolved oxygen conditions and water temperature (Tables I, III). The presence of Tardigrada under a thick layer of ice that characterized S2 during monitoring, is an indicator of its adaptation to extreme environmental conditions. The quantitative analyses have determined a total microinvertebrate density of 2375 ind/L in S1 and no registers in S5 (Table III). Comparing the density between components, the macroinvertebrates one was higher, in a range between 6777.8 (S2) and 33.3 ind/m^2 in S5. In relation to taxonomical composition of the macroinvertebrate community: 8410 organisms were collected, 80% of which (n=6726) were insects. 43 taxa that belong to 12 orders, 26 families and 32 genera were identified. The most abundant Insecta orders were Diptera (70.9%) and Ephemeroptera (15.9%), having the other orders a representativeness below 10%. The genera best represented belong to the Diptera order: *Genus 1* (Chironomidae: Orthocladiinae) and *Simulium* (P) *horcochuspi (*Simuliidae). The order with the greatest richness of families (8) and genera (17, and four morphotypes) was Diptera. Coleoptera was represented by four families, five genera and two morphotypes. The principal tolerant orders: Ephemeroptera (E), Plecoptera (P) and Tricoptera (T) obtained low representativeness (E: 15.9%, P: 0.02%, T: 0.6%) and richness (E: two species, one genera, P:one species, T: two genera, one inmature stage) (Table IV). The trophic structure was complex and the following functional groups were distinguished: chewers (*Hidroptilidae*, *Metrichia, harpacticoida*, *amebozoans*, *cercozoans*), shredders (*C. tigrina, Antarctoecia, H. puna)*, filterers (*Simuliidae*: *G. cilicinus, S. horcohuspi)*, gatherers (*chironomids,* Baetidae*, Austrelmis, Neolemis,* Ceratopogonidae, Ostracods, rotifers, Naididae). Predators were represented by Athericidae, *Tabanus, Tipula, L.n. nordenskjoldi, L. flavofasciatus, Ectemnostega*, *Thinobius*, Acari, Hirudinea. New records of families, genera and species in Argentinean high Andean rivers were obtained, above 3900-4400 m.a.s.l. For Insecta: *Baetodes* (Baetidae); *M. tintinnabula* (Leptophlebiidae); *Metrichia* (Hydroptilidae),

Table III. Microinvertebrates in Rosario basin (Salar de Olaroz, Jujuy, Argentina). Taxa specific abundances in percentage (%). S1 and S4 were placed at Rosario river; S5 at Sierra de Tanques stream; while S6 at Toro river. Abundance (N, ind /L), R (richness); D (diversity Shannon Wiener, H´); E (Equitability, J).

	Rosario river				Sa. Tanques	Toro river
Taxa	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Ostracoda	21.1	5.3	0.0	7.1	0.0	0.0
Cypridopsidae	0.0	5.3	0.0	0.0	0.0	0.0
Cyprideis	5.3	0.0	0.0	0.0	0.0	0.0
Ilyocypris	5.3	0.0	0.0	0.0	0.0	0.0
Copepoda						
Godetella	5.3	31.6	33.3	0.0	0.0	12.5
Amebozoa						
Arcella sp.	10.5	5.3	33.3	14.3	0.0	0.0
Bullinaria	0.0	0.0	0.0	7.1	0.0	0.0
Centropyxis	15.8	5.3	0.0	0.0	0.0	0.0
Cyclopyxis	5.3	15.8	0.0	57.1	0.0	0.0
Difflugia	0.0	5.3	33.3	7.1	0.0	0.0
Cercozoa						
Trinema	5.3	0.0	0.0	0.0	0.0	12.5
Rotifera						
Abrochtha	5.3	10.5	0.0	0.0	0.0	12.5
Ascomorpha	0.0	10.5	0.0	0.0	0.0	0.0
Brachionus plicatilis	21.1	0.0	0.0	7.1	0.0	25.0
Keratella cochlearis	0.0	0.0	0.0	0.0	0.0	25.0
Platyias	0.0	0.0	0.0	0.0	0.0	12.5
Tardigrada	0.0	5.3	0.0	0.0	0.0	0.0
N (ind/l)	2375.0	2.6	0.6	2.0	0.0	1.0
R	10	10	3	6	0	6
D (H´)	2.114	2.059	1.099	1.352	0	1.733
E (J)	0.9126	0.8869	1.0	0.7500		0.9708

Antarctoecia (Limnephilidae); *Lopescladius, Reocricotopus, Pentaneura, Paramectriocnemus, Nanocladius, Thienemanniella, Orthocladiinae Genus 1, Parakieferella, Tanytarssus* (Chironomidae); *Tabanus* (Tabanidae); *Tipula* (Tipulidae); *L. (n) nordenskjoldi*, *L. flavofasciatus* (Dytiscidae); *Neoelmis* (Elmidae). For Phyla Annelida: *Nais* (Naididae); Ph. Amebozoa: *Arcella, Bullinaria, Centropyxis Cyclopyxis, Difflugia* and Ph. Cercozoa: *Trinema*. For rotiferans: *Abrotcha, Ascomorpha, K. cochlearis, Platyias*.

Community of ecological attributes

The Kruskall Wallis test was applied to the ecological attributes ($H_{microinv.}$ =8.03; p =0.0443, $H_{macroinv}$ =20.75; p =0.0001) and significant differences between sites for abundances and equitability were identified.

Recorded values for ecological attributes represent natural environmental conditions or minimal human intervention. The microinvertebrates showed a tendency to decrease in abundance and richness with respect to altitude; S3, the site with the lowest

Table IV. **Benthic invertebrates in Rosario basin (Salar de Olaroz, Jujuy, Argentina). A: abundance (ind/m^2) from quantitative method; B: taxon specific abundances in percentage (%) from qualitative method. S1- S4 were placed at Rosario river; S5: Sierra de Tanques stream; S6: Toro river. N (total abundance, ind/m^2); R (richness), D (diversity Shannon Wiener, H´); E (Equitability, J).**

	S1		**S2**		**S3**		**S4**		**S5**		**S6**	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Insects												
Ephemeroptera												
Andesiops peruvianus	1470,4	24,6	3,7	4,5	22,2	27,6	122,2	17,2			7,4	
Baetodes	1607,4	30,2			11,1							
Meridialaris tintinnabula	140,7	5,1		4,5								
Plecoptera												
Claudioperla tigrina	3,7											
Trichoptera												
Hydroptilidae	22,2	0,5										
Antarctoecia	100,0	1,9										
Metrichia		0,5										
Diptera												
Athericidae	3,7				3,7							
Orthocladiinae. *Cricotopus*	137,0	1,0		2,3	37,0	0,2				5,9	74,1	
Orthocladiinae. *Lopescladius*	7,4											
Orthocladiinae. *Nanocladius*							7,4					
Orthocladiinae. *Genus 1*	44,4	1,2	5107,4	9,1	1118,5	6,7	233,3	5,2				2,0
Orthocladiinae. *Parakieferella*					63,0	3,8						
Orthocladiinae. *Paramectriocnemus*	37,0	0,5			29,6		48,1	10,3	3,7	35,3	18,5	15,0
Orthocladiinae. *Rheocricotopus*										23,5		1,0
Orthocladiinae. *Thienemanniela*					3,7	0,2		1,7				
Orthocladiinae			244,4	18,2	3,7				3,7		174,1	
Podonominae. *Podonomus*	3,7	0,2			37,0	3,6	66,7	27,6	14,8	5,9	666,7	27,0
Tanypodinae. *Pentaneura*	81,5	2,4				0,2						
Chironominae. *Polypedilum*										5,9	7,4	5,0
Chironominae. *Tanytarssus*	22,2	0,5			7,4							
Ceratopogonidae											37,0	9,0
Ephydridae			92,6	13,6					3,7	5,9	11,1	
Muscidae. *Limnophora*		0,5					7,4				25,9	
Simuliidae. *S.(P) horcochuspi*	100,0		3,7		6481,5	51,3	37,0	12,1	3,7			
Simuliidae. *G. cilicinus*	14,8											
Tabanidae. *Tabanus*	11,1		3,7			0,2	3,7				3,7	
Tipulidae. *Tipula*		0,5										
Coleoptera												
Elmidae *Austrelmis*	277,8	10,0	337,0	9,1	48,1	4,9	88,9	6,9		5,9	177,8	7,0
Elmidae. *Neoelmis*	25,9											
Lancetes nigriceps nordenskjoldi										5,9	3,7	
Liodessus flavofasciatus									3,7			1,0
Dytiscidae								1,7			11,1	1,0
Hydrophilidae											237,0	3,0
Staphilinidae. *Thinobius*											511,1	9,0
Hemiptera												

Table IV. Continuation.

Corixidae. *Ectemnostega*			911,1	36,4	29,6	0,4	18,5	1,7			7,4	
No Insects												
Collembola Arthropleona										5,9		
Amphipoda. *Hyalella puna*	29,6	2,9									100,0	16,0
Acari	7,4											
Acari. *Torrenticola*	166,7	0,5									3,7	
Naididae *Nais*	640,7	2,4	63,0	2,3	25,9	0,9	22,2	15,5			625,9	4,0
Naididae	100,0	6,1	11,1									
Hirudinea	203,7	8,5										
N	5259,3	100,0	6777,8	100,0	7922,2	100,0	655,6	100,0	33,3	100,0	2703,7	100,0
R	25	20	10	9	15	12	11	10	6	9	19	13
S	2,089		0,878		0,665		1,884		1,603		2,046	
E	0,649		0,381		0,245		0,786		0,894		0,695	

water temperature and high conductivity, showed a drop in richness, with the dominance concentrated in three tolerant species (*Godetella*, *Arcella* and *Difflugia*) (Table I, III). High spatial variability was recorded -with a single species in common between the Rosario (*Arcella*) river sites- and four species between the Rosario and Toro (67% complementarity). Macroinvertebrates showed an inverse relationship between abundance and altitude, with a strong decrease in S4. Richness behaved in the opposite way, decreasing with altitude. The Toro registered 53% greater richness than Sierra de Tanques. The Rosario was the one that registered the highest number of taxa (35) followed by the Toro river (22) and finally Sierra de Tanques (12). Regarding the composition of macroinvertebrates, an important spatial variability was observed, with a single common species, *Austrelmis* (Coleoptera: Elmidae) among all the sites. The Rosario river sites presented 19 exclusive taxa with an indicator value, Ephemeroptera: Baetidae (one), Leptophlebiidae (one); Plecoptera: Gripopterygidae (~~a~~ one); Trichoptera: Hydroptilidae (two), Limnephilidae (one); Coleoptera: Elmidae (one); Diptera: Athericidae (one), Chironomidae (six), Simuliidae (one), Tipulidae (one); Acari (one), Naididae (one), Hirudinea (one). The rivers Sierra de Tanques and Toro increase their gamma diversity with nine taxa: Chironomidae (two: *Rheocricotopus* and *Polypedilum*), Ceratopogonidae (one), Dytiscidae (two: *L. (n.) nordenskjoldi*, *L. flavofasciatus*), Hidrophilidae (one), Staphilinidae (one), Collembola (one) (Table IV). Comparing the richness of macroinvertebrate taxa has always been greater (>50%) than microinvetebrates in all the sites, not registering a pattern regarding the behavior of diversity and equitability (Figure 3a, 3b).

Influence of environmental variables on species distribution

The correspondence analysis of the taxa abundance (micro and macroinvertebrates) in relation to the environmental and physicochemical variables is shown in Figure 4. The ostracods were only recorded in the Rosario river showing a preference for substrates with a predominance of medium to fine sand. The highest abundance was associated with the highest altitude site, showing tolerance to variations in water temperature (0.7-18.7 °C) and high concentrations of boron, lead and conductivity (Table I, II, III, Figure 4). *Cyprideis* and *Ilyocypris* were exclusive to the Rosario river and showed a preference for high sites, cold, oxygenated waters, with low conductivity and

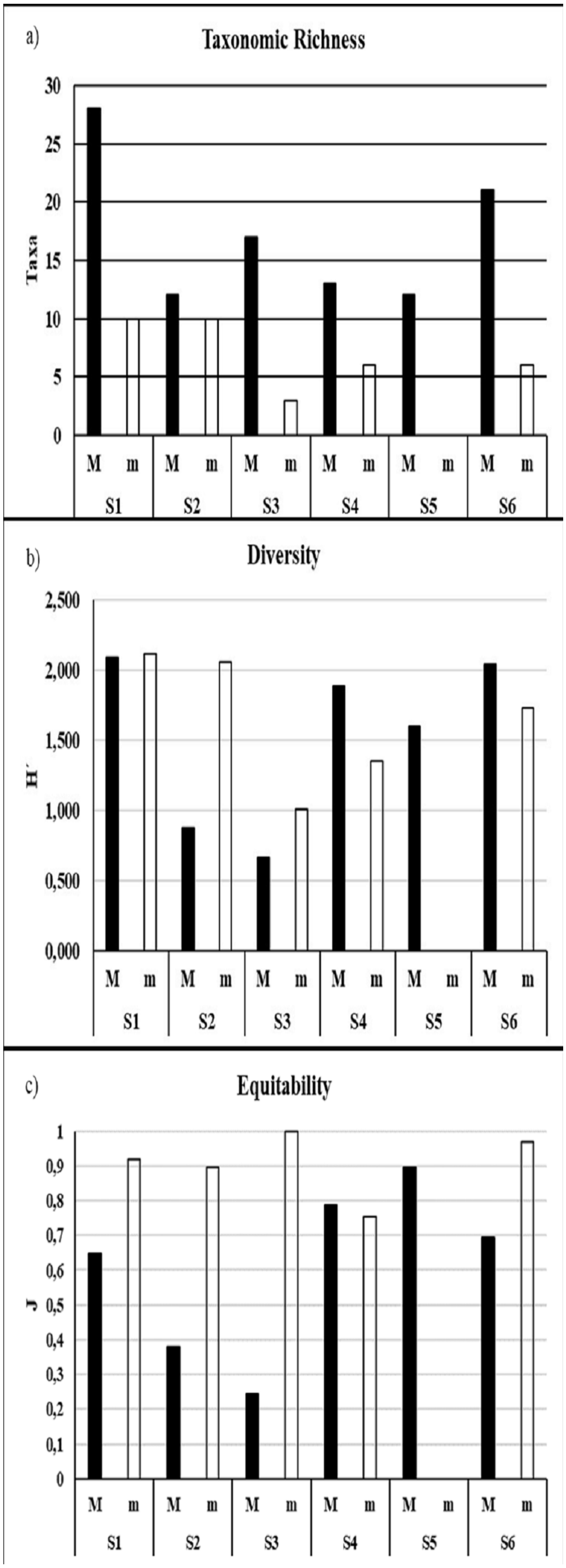

Figure. 3. a) Taxonomic richness (Taxa) b) Shannon diversity (H´) c) Equitability (J) calculated for the six sampling sites analyzed in this investigation (S1-S6). Macroinvertebrates (M); microinvertebrates (m).

concentrations of sulfate, fluorine and boron (Table I, III, Figure 4). *Godetella* was recorded in the Rosario river and Sierra de Tanques, associating the highest abundance with hard water, high chlorides and showing tolerance to high boron concentrations (Tables I, III). Amoebozoa were only recorded in Rosario and only *Arcella* was common to all sites, showing tolerance to increases in conductivity, turbidity, lead, nitrates, sulfates and boron. *Cyclopyxis* registered the maximum abundance in S4, showing tolerance to conditions towards the Salar (Table I, III, Figure 4). The rotifers with the highest representation: *B. plicatilis*, *K. cochlearis, Platyias* and *Abrotcha* registered the highest abundances in sites with dissolved oxygen records >8 mg/L, wide conductivity range (92- 2400 uS/cm), hardness (104- 470 mg/L), turbidity (1.5- 4.7 NTU) and water temperature (0.7- 18.7 °C) (Table I, III, Figure 4). Tardigrada was only recorded at the site with thermal characteristics and the presence of filamentous algae. They showed tolerance to conductivity, turbidity, lead, ammonium, boron, and sulfates (Table I, III). Mainly, the environmental variables that affected Chironomidae family were water temperature, altitude, conductivity, oxygen, sulfate and type of substrate. Depending of the taxa, Orthocladiinae subfamily was influenced in different manner by environmental variables (Table I, IV). While *Cricotopus* and *Paramectriocnemus* exhibited preferences for low temperatures, fine substrate and oxygen, *Thienemanniela* and *Genus 1* were sensitive to sulfate concentration, conductivity, and water temperature. Orthocladiinae morphotype was tolerant to increases in temperature and oxygen concentration.

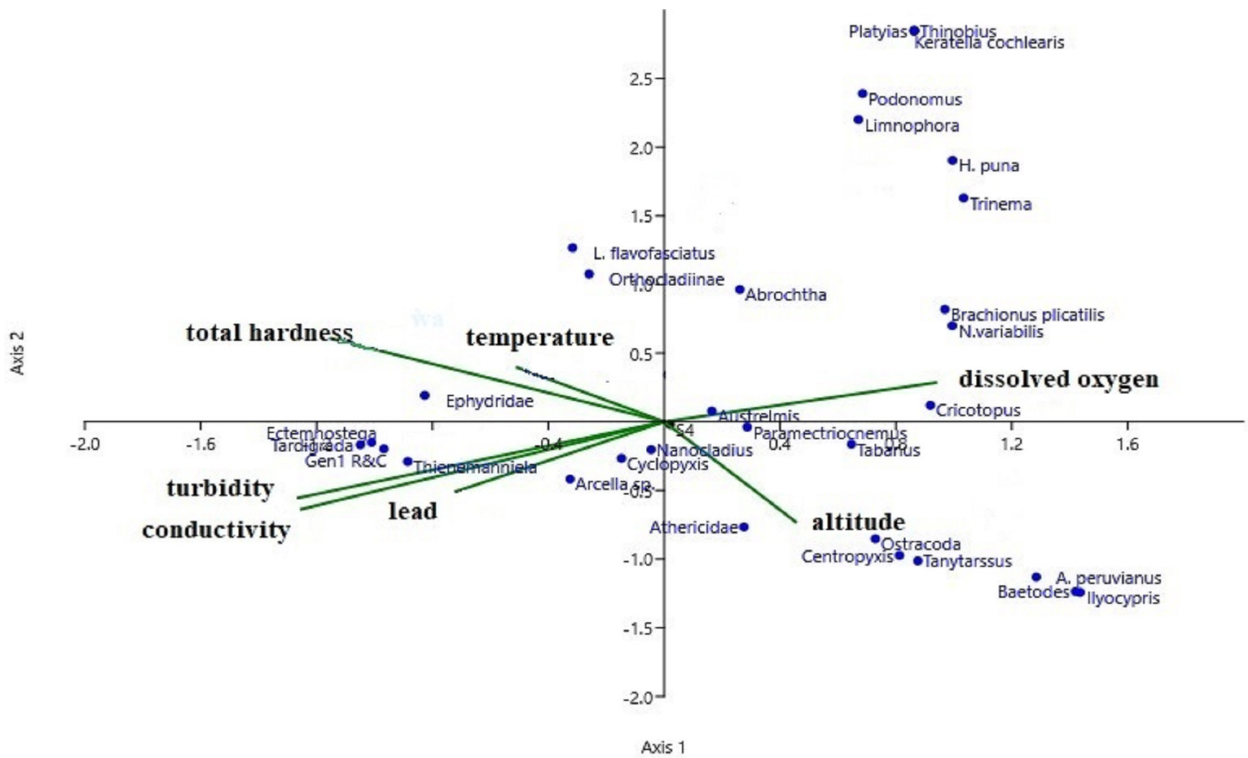

Figure 4. Correlation analysis showing the ordination of the micro and macroinvertebrates taxa registered and the sampling sites with respect to principal physical-chemical, morphometric and granulometric variables. S1-S6 Rosario basin (Salar de Olaroz, Jujuy. Argentina). Canonical correspondence, Past.

Athericidae, *Tabanus* and baetids were specimens from headwaters and fine substrate. Ephydridae presented its maximum density at the thermal site with the presence of abundant filamentous algae, high hardness, nitrites and nitrates (Table I, IV, Figure 4). *Ectemnostega* exhibited tolerance to the presence of dissolved ions and preference for low current flow. While among the Coleoptera, *L., flavofasciatus* showed correlation with higher temperature records, *Austrelmis* is tolerant to lower values and concentrations of oxygen.

DISCUSSION

This study analyzes the spatial structure and community composition of the aquatic invertebrates of the high Andean rivers in the northern tributary basin of the Salar de Olaroz, above 4000 m.a.s.l. and describes the main environmental, physicochemical and morphometric characteristics of rivers. The substrate -with a predominance of sand-, the morphometric measurements of the channel –width, depth and flow-, were similar to rivers of the Catamarca plateau, of order 2 and 3 (Rodríguez et al. 2020). The pH records were similar to those found in rivers of the Catamarca plateau: Del Cazadero and Punilla (Rodríguez Garay et al. 2020). Nevertheless, they differ from those registered for other fluvial rhitronic systems of Mendoza and rivers of the Catamarca pre-plateau 11 (Medina et al. 2008, Hankel et al. 2018), as they are more alkaline. The range of water temperatures recorded in this study are similar to those obtained for the season of high flows in rivers of Catamarca plateau (Rodríguez Garay et al. 2020). The dissolved oxygen records of the Catamarca (Hankel et al. 2018) and Jujuy plateaus (Rodrigues Capítulo 2014) rivers for

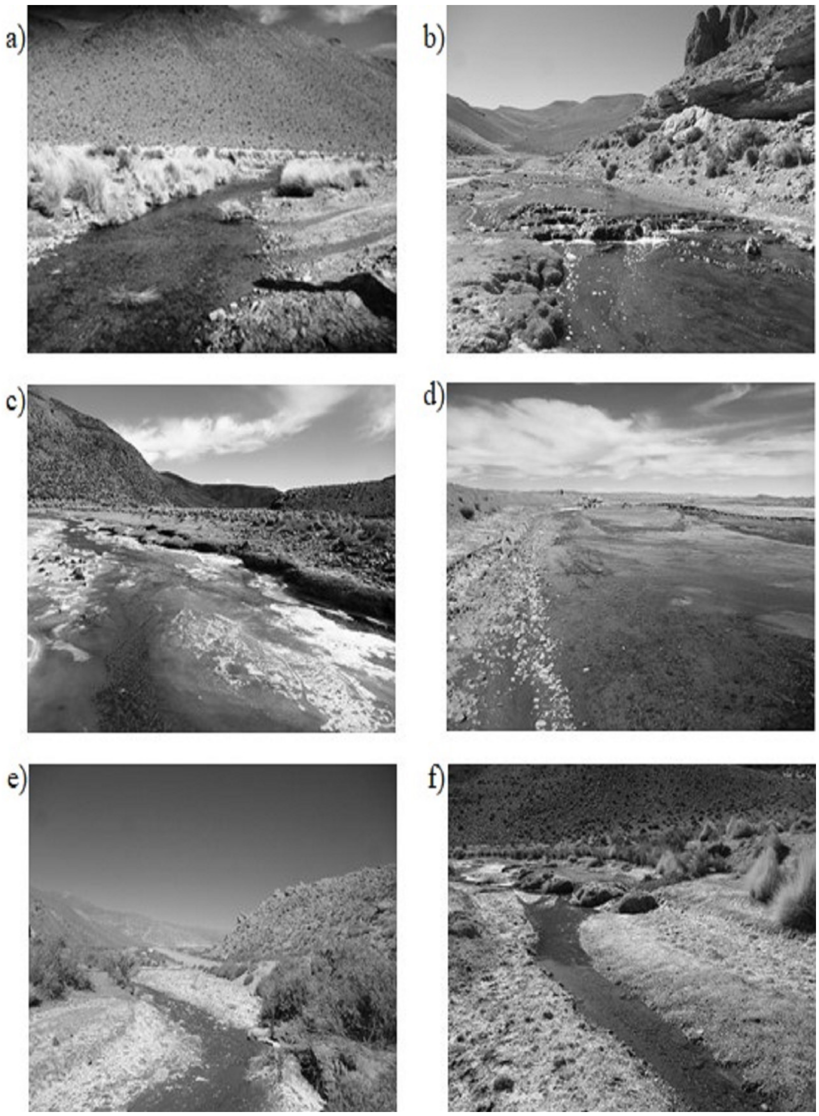

Figure 5. Photographs of the sampled sites, Rosario river: a) S1, b) S2, c) S3, d) S4, Sierra de Tanques river: e) S5, Toro river: f) S6

the same station are similar to those obtained in the present study. The conductivity values recorded in S2, S3 and S4 are similar to those recorded by Dejoux (1993) in bodies of water associated with the Salares de Pastos Grandes and Chalviri (Bolivia) and in meandering streams close to Salar de Olaroz by Rodrigues Capítulo et al. (2014). Previous studies referring to the concentration of arsenic in natural waters and the sanitary risk in the department of Susques, Jujuy (Steinmetz & Díaz 2018), cite concentrations similar to those obtained for the Rosario river and Sierra de Tanques. The origin of natural arsenic and hydrothermalism, both registered in the analyzed basin (S2, S3 & S4) is related with volcanism and is registered for extensive zones in the Jujuy plateau (Galindo et al. 2005). With the present work, new rivers and areas of influence are incorporated for the province of Jujuy, affected with high arsenic. For rivers in the Jujuy plateau, high concentrations of fluoride are cited (Avila Carreras et al. 2008) in the present study; the range of values registered in the Rosario, Toro and Sierra de Tanques rivers do not present a sanitary risk. Aluminium concentrations increase in the entrance of the Salar, which results in a similar range to the ones obtained in pristine rivers of the Rímac basin in

Peru (Tapia et al. 2018). The hardness recorded in the Rosario -except for the headwaters-, the Sierra de Tanques and Toro rivers are similar to those observed in the Mendoza river in sections of the same Sthraler order (Medina et al. 2008). The microinvertebrate community recorded in the Rosario river and its tributaries presented a complex structure, with organisms belonging to plankton - rotifers and copepods – and benthos (amoebozoans, ostracods, tardigrades). These characteristics were also observed in shallow high Andean streams (Rodrigues Capítulo 2014), as well as in water mirrors associated with salars and low current streams (Locascio de Mitrovich et al. 2005, Nieto et al. 2016). In the present study, a low representation of ostracods and rotifers at entrance of the Salar de Olaroz (S4) and important values for decapods was recorded, the same relationship has been cited for the Archibarca stream and Cerro Overo, close to the study area, by Rodrigues Capítulo et al. (2014).

However, the assemblage that is recorded in S4 has not been found for the Rosario river in the years 2009 and 2010 by Rodrigues Capítulo et al. (2014). This could indicate that the conditions in the Rosario river draining into the Salar have changed in a period of six to seven years. From the comparison with the physicochemical data recorded by Rodrigues Capítulo et al. (2014) and those of the present study, a decrease is observed in pH (8.81/8.47-7.2), dissolved oxygen concentration (7.39/12.30-1.5 mg/L) and conductivity (11643.3/5353.3- 2820 µS/cm). From the correlation analysis obtained (Figure 4) it was determined that the abundance of ostracods was conditioned by the altitude, the dissolved oxygen and the conductivity. The decrease in the values of these parameters in S4 coincides with a decrease in the abundance of the organisms of the community. Regarding macroinvertebrates, the Insecta class was the best represented (80%) and analyzing the representativeness in the Andean axis, we found similarities in the values obtained in the study of high Andean streams in Peru (Carrasco et al. 2020) and in rivers of the Cordillera Real of Bolivia (Molina et al. 2008) to rivers of the Bolivian plateau, 53% (Jacobsen & Marín 2008. Insecta dominance was also recorded in rivers and streams of the Chilean highlands (Márquez-García et al. 2009) and rivers of Catamarca and Mendoza plateau and pre-plateau. (Hankel et al. 2018, Scheibler 2008). Similarities were observed in the diversity of orders and families of Insecta registered in S1 and the Andes of Ecuador (Baetidae, Elmidae, Simuliidae, Chironomidae, Gripopterygidae, Hyalellidae) (Jacobsen 2008, Maldonado 2014), Bolivia (Jacobsen & Marín 2008, Molina et al. 2008) and northwestern Argentina (Nieto et al. 2016, Rodrigues Capítulo 2014, Rodríguez Garay et al. 2020). In S1, the community was dominated by *Baetodes*, *A. peruvianus* and *M. tintinnabula*, with *Austrelmis*, acari, Orthocladiinae and *Podonomus* also being important. In addition, *C. tigrina* and Athericidae had a low representativeness. The assembly at the headwaters of the Rosario (Jujuy, Argentina) in May-October, was similar to that recorded by Molina et al. (2008) in the months of July and September, in streams of the Cordillera Real of Bolivia between 4400-4100 m.a.s.l. The assemblages of Trichoptera (Hydroptilidae- *Antarctoecia*) and Diptera (Simuliidae-Tabanidae –Tipulidae) were also common in other rivers in the Andean axis. The structure of the macroinvertebrate community in the Rosario river also presented similarities with those registered in pristine rivers and streams located further south (Hankel et al. 2018), evidencing the existence of an Andean axis, of which the Rosario is part. Regarding the records in the Andes of the province of Mendoza (Argentina), with lower altitudes and corresponding to a transition between the ecoregions of the High Andes and Monte (Morello et al. 2018), the structure recorded by Scheibler & Debandi (2008) in the Uspallata River at 1890-1715 m.a.s.l (UU, UD), presents similarities and differences. Among the similarities we mention the presence of *Andesiops* (Ephemeroptera), *Metrichia* (Trichoptera), Chironomidae, Simuliidae (Diptera), *Thinobius, Austrelmis* (Coleoptera). Among the differences, we mention the incorporation of other genera and families of Insecta in the aquatic community. Among them are other species of Ephemeroptera such *Massartellopsis* and *Leptohyphes eximius*, plecoptera (*Anacroneuria*), Trichoptera (*Cailloma*), Diptera (Ephydridae, Dolichopodidae). Further south, in the Patagonian Andes, the records of the macroinvertebrate communities of rhytronic rivers and streams in the provinces of Chubut and Santa Cruz (Miserendino 2001) differ even more from those recorded in the present study for the Jujuy plateau. Changes in the family-species composition and dominance of the main groups are incorporated. Among the coincidences are the representativeness of the Elmidae and the presence of Athericidae, Tipulidae, *Nais* and *Hyalella*, although they possibly belong to different species. In the present study, a decrease in species and families of macroinvertebrates was observed as the altitude decreases and approaches the Salar. An inverse behavior has been observed in the Patagonian Andes (Miserendino 2001) and in the high Andean rivers of Bolivia (Molina et al. 2008). This difference is possibly due to the existence of an association of Rosario with the salar.

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Author contributions

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