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Macroinvertebrates in a high Andean wetland (Chalhuanca) of southern Peru during the dry and wet season

César R. Luque-Fernández[1], G. Anthony Pauca[1], Luis N. Villegas Paredes [1,2], Johana del Pilar Quispe Turpo[3], J. Francisco Villasante Benavides [1,2]

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1 Universidad Nacional de San Agustín de Arequipa, Instituto de Investigación de Ciencia y Gestión Ambiental (ICIGA-UNSA), Calle San Agustín 108, Arequipa, AR, Perú

2 Universidad Nacional de San Agustín de Arequipa, Departamento Académico de Biología, Av. Alcides Carrión s/n, Arequipa, AR, Perú

3 Universidad Nacional de San Agustín de Arequipa, Escuela Profesional de Biología, Av. Alcides Carrión s/n, Arequipa, AR, Perú

ORCID IDs of the author(s):

C.R.L-F. 0000-0001-8050-461X
G.A.P. 0000-0001-6367-5345
L.N.V.P. 0000-0002-7605-4326
J.d.P.Q.T. 0000-0002-6428-7229
J.F.V.B 0000-0002-6577-3122

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Correspondence:

César R. LUQUE-FERNÁNDEZ
E-mail: cluquef@unsa.edu.pe

ABSTRACT

Macroinvertebrates of the Chalhuanca high Andean wetland (bofedal) is presented, which presents two aquatic environments, river and water pools within bofedal vegetation. This wetland is located in the district of Yanque (Caylloma, Arequipa) at 4300 meters, in southern Peru. Aquatic macroinvertebrates in wetlands such as these have been sparsely studied in Peru and other localities, especially in the southern region, which is added to their taxonomic complexity for identification. For this bofedal 32 families were identified, distributed in 21 orders and 12 classes. The richest groups were Diptera, Coleoptera, Trichoptera and Anomopoda. The other groups presented only one family. By type of environment, 25 families were registered for bofedal and 26 for the river, where exclusive families were presented for found environments 05 exclusive families of bofedal (Chydoridae, Coenagrionidae, Ilyocryptidae, Lumbriculidae, Dytiscidae), and 05 exclusive families of river (Gripopterygidae, Hydrobiosidae, Hydrophilidae, Leptoceridae, Saldidae).

Keywords: Bofedal, Benthonic, Aquatic, Peatland, Surber net, Insects

Introduction

High Andean wetlands are fragile ecosystems due to their high vulnerability to climate change and anthropic disturbances (Walker *et al*., 2012). Despite this, through particular and dynamics mechanisms, try to adapt to preserve their functions, structures and interactions, and their socio-ecological attributes, such as climatic, geomorphological, hydrological, biotic and social, which determine their functionality (Walker *et al*., 2012; Andrade *et al*., 2012). The degradation and overexploitation of wetlands implies the loss of their different attributes, and with it, the sustainability of the ecosystem and the ecosystem services they provide (Vidal *et al*., 2013). The monitoring of these arises as a necessity to know their status, within these the monitoring of their waters through the use of aquatic macroinvertebrates are presented as an interesting proposal, since these have been recognized and long used as indicators of the quality of the water (Helawell, 1986; Rosenberg & Resh, 1993; Resh *et al*., 1995, Bunn & Davies, 2000; Allan, 2004) which is widespread throughout the world, however, the composition and knowledge of these may vary and be specific to each site, ecosystems and characteristics associated with them. Thus it is important to have base information on the macroinvertebrates that inhabit this environments, as well as their presence related to a seasonal change, especially in wetlands like these, that in many contribute to the main water basins of the rivers of southern Peru. Therefore, the present study aims to present a checklist of the families of aquatic macroinvertebrates present in the high Andean wetland of Chalhuanca in southern Peru, during the dry and wet season of 2018 as well as a physicochemical description that puts in context our results.

Material and Methods

Study Site

The town of Chalhuanca belongs to the district of Yanque (Caylloma, Arequipa, Peru) located over 4300 meters (15°43'4.12"S; 71°19'13.41"W), corresponding the Andean region, in southern Peru, and is part of the National Reserve of Salinas and Aguada Blanca (SERNANP). In this location the high Andean wetlands can be found, which are locally known as bofedales (onwards), which are a typical form of vegetation of these areas and altitudes, presenting small plants which are prostrate in the soil, mostly leathery and cushion forming, that highly depend on the water regime, the characteristic species of this bofedal are *Distichia muscoides*, *Aciachne pulvinata* and *Phylloscirpus deserticola.* These bofedales cover an approximate extension of 880 ha (Pauca *et al*. in preparation), where it is located one of the most important water dams that are part of the sub-basin of the Chili River. In this bofedal we find a river with the same name of the town, which crosses the bofedal throughout its route and has a variable width. In this ecosystem, two seasons can be distinguished, wet and dry, where the first one occurs between December to March, with long periods of precipitation reaching between 200 and 590 mm (Coaguila *et al*., 2010), and the latter occurs between April and November, presenting the lowest temperatures during the year (around -9°C) (Ramos, 2018), and there may also be rain or snowfall events, as well as the presence of frost events, generally in the months of June and July.

Data Collection

The sampling of aquatic macroinvertebrates was carried out during the dry and wet season of 2018, selecting the two aquatic environments present, bofedales formed by water pools in the middle of the vegetation, and the river. Four monitoring stations were established in each environment, distributing two in the southern region and two in the northern region of the evaluated bofedal (Figure 1). The samples at the water pools stations were obtained through the use of a D-net (MINAM, 2014), with a 500 μm mesh size, with which a sweep of the coastal area (1m^2) and center of the water body was performed. And for the river stations, a Surber net (30 x 30cm, 500 μm mesh size) was used, which was placed on the river shore, where the area covered by the net was cleaned by hand (MINAM, 2014), collecting the samples in a 500 bottle ml. For both, water pools and river, triplicate samples were taken at the sampling stations. The specimens were preserved in 5% formalin.

In the laboratory, the samples were processed by separating the large material (vegetation) and subsequently washed and processed by means of a series of sieves (2.3, 1.4, 0.7 and 0.3 mm), and finally preserved in 70% ethanol. The identification was carried out by microstereoscope or microscope according to need, the identification was carried out to the family level, for which the guidelines of: Roldan (1996), Heckman (2006, 2008), Merrit *et al*. (2008), Borkent and Spinelli (2007), Domínguez and Fernández (2009), Huamantinco and Ortiz (2010), Noreña *et al*. (2015), and the nomenclature was followed The World Register of Marine Species (WORMS, 2019). Finally, for the analysis of the composition of families between sampling stations and seasons, a cluster analysis of similarity based on presence and absence was used through the Jaccard index with PAST 3.25 software.

Additionally, at each station, physicochemical parameters of the water were measured during the evaluation season, considering temperature, pH, conductivity, dissolved oxygen, oxygen saturation and total dissolved solids (TDS). These were recorded with a portable multiparameter (Hanna HI 9829).

Figure 1. Location map of water pools within the Chalhuanca bofedal and river (Arequipa, Peru) selected for this study.

Results and Discussion

In total, 32 families were identified in the Chalhuanca River and water pools within the bofedal (supplementary material), distributed in 21 orders and 12 classes (Table 1). The most diverse orders correspond to *Diptera*, *Coleoptera*, *Trichoptera* and *Anomopoda*, where the remaining orders were represented by a single family only. In general, the diversity of aquatic macroinvertebrates in high-Andean ecosystems, such as wetlands, has been poorly studied (Molina et al., 2008; Nieto et al., 2016; Gomez, 2016; Oyague & Maldonado, 2014), the southern Peruvian wetlands being the least researched. The reason for this could be the difficulty in the taxonomic determination of macroinvertebrates (Jacobsen et al., 2008). However, it is necessary to know these inventories as it would help to understand the diversity associated with these ecosystems. On the other hand, compared against other similar researched wetlands (Oyague & Maldonado, 2014; Canchapoma et al., 2016), these results showed a low richness at the family-level assessment in the Chalhuanca bofedal. Likewise, among the theories of diversity distribution, in the case of macroinvertebrates, it is stated that diversity usually decreased at higher altitudes. (Jacobsen et al., 2008; Molina et al., 2008).

Table 1. Macroinvertebrate families present in the bofedal and Chalhuanca River (Arequipa, Peru), during the dry and wet season of 2018

Order	Family	Wet								Dry						
		Water pools				River				Water pools			River			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S4	S1	S2	S3	S4
Oribatida	Limnozetidae	x	x	x	x			x	x			x				
Trombidiformes	Limnesidae	x	x	x	x					x	x	x	x	x	x	x
Sphaeriida	Sphaeriidae	x	x	x	x	x	x	x				x				
Anomopoda	Chydoridae	x	x	x	x					x	x	x				
	Daphniidae	x	x						x							
	Ilyocryptidae	x	x	x	x							x				
Lumbriculida	Lumbriculidae	x	x	x	x											
Rhynchobdellida	Glossiphoniidae	x	x	x	x	x		x			x	x	x			
Dorylaimida	Longidoridae	x	x	x	x		x	x		x	x	x	x	x	x	x
Basommatophora	Planorbidae	x	x			x	x	x		x		x	x	x		x
Cyclopoida	Cyclopidae	x	x	x	x					x		x	x			
Anthoathecata	Hydridae						x			x						
Coleoptera	Dytiscidae									x		x				
	Elmidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Hydrophilidae							x	x							
Diptera	Ceratopogonidae											x	x	x	x	x
	Chironomidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Ephydridae											x				x
	Simuliidae							x	x			x			x	x
Ephemeroptera	Baetidae	x	x	x	x	x	x	x	x			x		x	x	x
Hemiptera	Corixidae	x	x	x	x	x	x	x	x	x		x	x		x	
	Saldidae					x										
Odonata	Coenagrionidae											x				
Plecoptera	Gripopterygidae					x	x	x	x						x	
Trichoptera	Hydrobiosidae													x		
	Hydroptilidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Leptoceridae					x		x	x							
	Limnephilidae				x				x			x				
Amphipoda	Hyalellidae	x	x	x	x	x	x	x	x	x		x	x	x		x
Podocopida	Cyprididae	x	x	x	x	x	x	x	x	x		x	x		x	
Tricladida	Dugesidae									x		x	x			x
Oligochaeta	Aelosomatidae					x	x	x	x	x		x	x	x	x	x

Water Pools VS River

Regarding the assessed environments, a total of 25 families were recorded for the water pools and 26 for the river. Out of them, five families were bofedal-exclusive (*Chydoridae*, *Coenagrionidae*, *Ilyocryptidae*, *Lumbriculidae*, *Dytiscidae*) and five were river-exclusive (*Gripopterygidae*, *Hydrobiosidae*, *Hydrophilidae*, *Leptoceridae*, *Saldidae*).

In terms of the richness of the families by seasons, similarities were found both in the dry and the wet seasons (25 families), but only five exclusive families were found during the wet season (*Daphniidae*, *Hydrophilidae*, *Leptoceridae*, *Lumbriculidae*, *Saldidae*) and five exclusive families during the dry season (*Ceratopogonidae*, *Coenagrionidae*, *Saldidae*, *Ephydridae*, *Hydrobiosidae*).

As for the similarity in the sampling stations (Figure 2), there was a greater similarity between the dry and wet seasons than between the assessed environments, where the bofedal stations assessed during the wet season were the most similar to each other (> 0,85). On the other hand, the DB2 station was different from all the others, as it presented the lowest richness among families (7) compared to the other stations, which presented an average of 14 families.

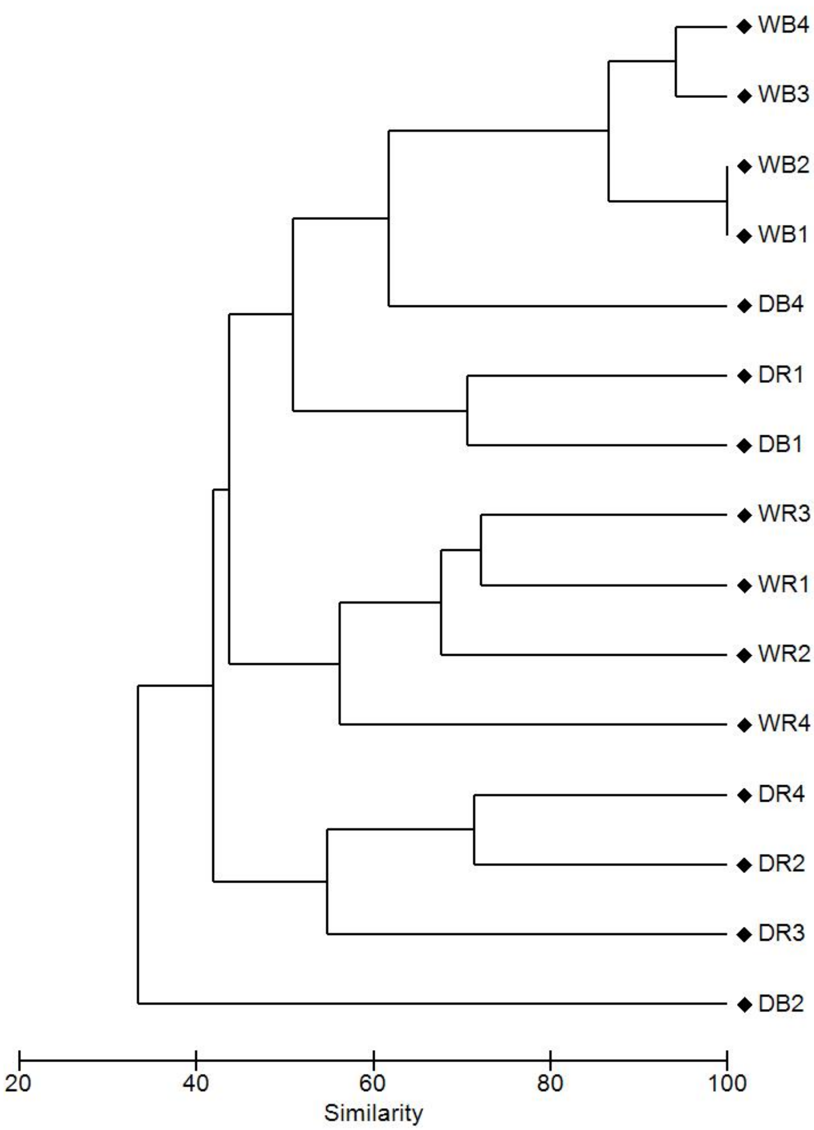


Figure 2. Similarity cluster based on the Jaccard Index for sampling stations and seasons, where the first letter corresponds to the season (W = wet, D = dry) and the second letter to the assessed habitat (B = bofedal, R = river).

On the absence of differences in the number of families found in the research stations and environments, this is due to the great capacity of these organisms to adapt to the conditions presented, which has been widely documented (Molina et al., 2008; Domínguez & Fernández 2009; Oyague & Maldonado, 2014). On the other hand, the bofedal environment would be expected to present the greatest aquatic macroinvertebrate richness because it provides greater places of refuge, both in the substrate and in the vegetation that compose it for macroinvertebrates. This could also be supported by the identification at a more specific taxonomic level, where these differences could have been shown (Moya et al., 2009; Nieto et al., 2016) compared to the Chalhuanca River environment.

On the presence of the families found in this study, many of them (*Baetidae*, *Elmidae*, *Simuliidae*, *Chironomidae*, *Gripopterygidae*, *Hyalellidae*) correspond to what was found in other high-Andean water ecosystems studied, which is mentioned by Nieto et al. (2016), who studied the patterns of aquatic macroinvertebrate communities in the Argentine *puna*.

As for the exclusivity of some families found in the water pools environment, this would be correlated with the heterogeneity of the bofedal and the physicochemical conditions of the water bodies forming within them, as well as the associated vegetation (Oyague & Maldonado, 2014). However, several of the families found exclusively in this environment can also be found in lotic environments (Roldan, 1996; Dominguez & Fernandez, 2009), except for individuals of the *Dysticidae* family that are more associated with slow environments with fallen leaves and vegetation (Dominguez & Fernandez, 2009).

In the case of the river environment, the *Plecoptera* and *Trichoptera* were exclusive groups, which, according to bibliography (Roldan, 1996), are usually more associated with areas of cold, fast and well-oxygenated waters, with special relevance in rivers with rocky bottoms located along 2000 meters above sea level. In addition, despite there are records of individuals from the *Hydrophilidae*, *Saldidae* and *Dytiscidae* families, little information is available about the species that make them up, especially for South America (Roldan, 1996), where even the *Dytiscidae* taxa have been considered of interest due to their rarity (Ansaloni et al., 2016).

Physical-Chemical Characterization

The physicochemical data are shown in Table 2, where the temperature of the water bodies varies between 6°C and 23°C, and the temperature within the bofedal is higher than that recorded in the river. The pH presented neutral values that varied between 7.3 - 8.4. During the dry season, the pH values in the bofedal were lower than in the river, while during the wet season they were higher, with the exception of the first station (S1). The conductivity varied between 40 and 70 $\mu S\ cm^{-1}$, presenting a constant between seasons (wet and dry) and the assessed sampling stations, as well as TDS values. As to dissolved oxygen, the values were between 3 ppm and 7 ppm, where the dry season showed higher values, similar to those present in oxygen saturation that occurred between 60% and 90%.

Table 2. Physicochemical parameters in the bofedal and Chalhuanca River (Arequipa, Peru), during the dry and wet season of 2018

Parameter	wet								dry						
	bofedal				river				bofedal			river			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S4	S1	S2	S3	S4
Temperature (°C)	14.07	18.32	18.25	22.81	9.95	14.39	14.47	16.52	9.97	13.04	11.74	5.68	12.29	13.58	13.08
pH	7.65	8.45	7.79	7.89	7.98	7.55	7.33	7.35	7.57	7.50	7.58	7.38	7.90	7.87	7.48
Conductivity(μS/cm)	65.27	44.44	48.89	64.25	51.67	48.86	49.00	44.14	55.50	47.00	19.50	62.50	46.50	50.00	50.00
Dissolved oxygen (ppm)	3.60	4.07	4.15	2.92	3.70	3.83	3.29	3.24	6.63	5.08	4.14	5.43	5.10	4.67	4.46
Dissolved oxygen saturation (%)	67.73	80.54	83.92	66.23	63.18	67.33	62.50	64.43	72.05	79.05	62.25	73.60	80.00	70.80	68.50
TDS (ppm)	32.55	22.22	24.67	32.00	25.83	24.43	24.60	22.14	28.00	23.50	10.50	31.50	21.00	25.00	25.00

Based on the values of the obtained physicochemical parameters, these exhibit acceptable ranges for water, according to with the Water Quality Standards of the Peruvian Law (ECA, as per its initials in Spanish). Likewise, the obtained values are similar to the values of other assessed wetlands in Peru (Oyague & Maldonado, 2014; Sulca et al., 2017) and Bolivia (Coronel et al., 2009; Molina et al., 2008; Loza et al., 2015), except for the dissolved oxygen values that were lower for the Chalhuanca wetlands, especially during the wet season.

Furthermore, as already known, macroinvertebrates have been used as water-quality bioindicators (Hellawell, 1986; Metcalfe-Smith, 1994; Bonada et al., 2006; Roldán-Perez, 2016), where some of the families found in this study (*Gripopterygidae*, *Hidrobiosidae*, *Limnephilidae*, *Leptoceridae*) would characterize the waters of the studied environments, from acceptable to regular conditions, compared to the scales of the Biological Monitoring Working Group (BMWP) and the Andean Biotic Index (ABI) (Armitage et al., 1983; Acosta et al., 2009; Ríos-Touma et al., 2014), for this study, the highest accumulated scores of macroinvertebrates were present in the river, this occurred for both seasons (47.88 ±13.16) in comparison to the wetland pools (36.71 ±13.03), As for the average score per taxon, there were no differences for the environments and seasons where the values were around 4.62 ±0.55.

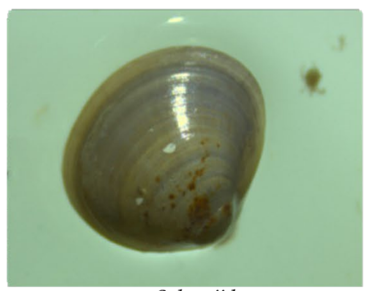
Conclusion

In conclusion, this study found 32 families of macroinvertebrates, which evaluated together with the physicochemical and biological parameters would qualify this bofedal as in acceptable conditions. It is noted that even assessing at the family level, the knowledge about biodiversity in the aquatic macroinvertebrate community in high-Andean systems is quite significant, regarding their fragility, even more so when they are part of a protected natural area like National Reserve of Salinas and Aguada Blanca in Peru. Moreover, since they serve as indicators of water condition or the impacts that water bodies would be suffering, whether they are natural changes or disturbances caused by human intervention, the data presented here could serve as a baseline for future monitoring of water quality changes across time.

Supplementary material: Showing the individuals belonging to the macroinvertebrates families present in the high Andean wetland of Chalhuanca (Arequipa, Peru)

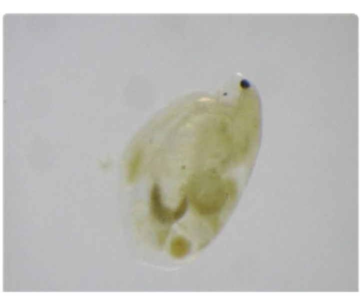
01 *Limnozetidae* ORIBATIDA ARACHNIDA

02 *Limnesiidae* TROMBIDIFORMES AR ACHNIDA

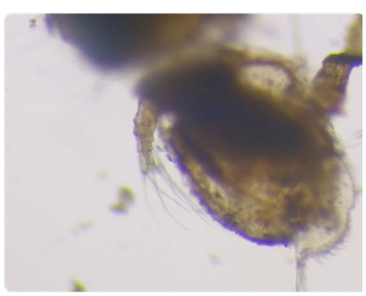


03 *Sphaeriidae* SPHAERIIDA BIVALVIA

04 *Chydoridae* ANOMOPODA BRANCHIOPODA



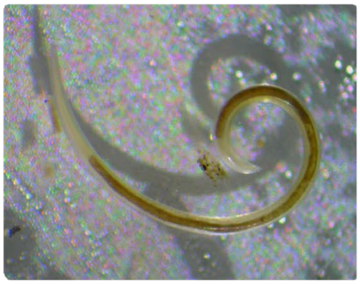
04 *Daphniidae* ANOMOPODA BRANCHIOPODA



06 *Ilyocryptidae* ANOMOPODA BRANCHIOPODA

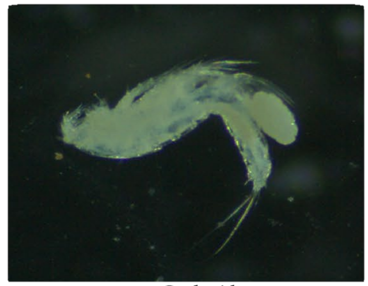
07 *Lumbriculidae* LUMBRICULIDA CLITELLATA

08 *Glossiphoniidae* RHYNCHOBDELLIDA CLITELLATA



08 *Longidoridae*
DORYLAIMIDA
ENOPLEA

10 *Planorbidae*
BASOMMATOPHORA
GASTROPODA

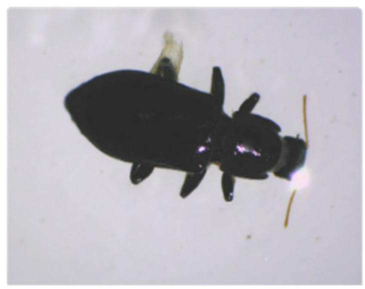


11 *Cyclopidae*
CYCLOPOIDA
HEXANAUPLIA

12 *Hydridae*
ANTHOATHECATA
HYDROZOA

12 *Dytiscidae*
COLEOPTERA
INSECTA

14 *Elmidae*
COLEOPTERA
INSECTA



15 *Elmidae*
COLEOPTERA
INSECTA

16 *Hydrophilidae*
COLEOPTERA
INSECTA

17 *Ceratopogonidae*
DIPTERA
INSECTA

18 *Chironomidae*
DIPTERA
INSECTA

19 *Ephydridae*
DIPTERA
INSECTA

20 *Simuliidae*
DIPTERA
INSECTA


21 *Baetidae* **EPHEMEROPTERA**


22 *Corixidae* **HEMIPTERA**


23 *Saldidae* **HEMIPTERA**


24 *Coenagrionidae* **ODONATA**


24 *Gripopterygidae* **PLECOPTERA**


25 *Hidrobiosidae* **TRICHOPTERA**


27 *Hydroptilidae* **TRICHOPTERA**


28 *Hydroptilidae* **TRICHOPTERA**


29 *Limnephilidae* **TRICHOPTERA**


30 *Hyalellidae* **AMPHIPODA** **MALACOSTRACA**


31 *Cyprididae* **PODOCOPIDA** **OSTRACODA**


32 *Dugesiidae* **TRICLADIDA** **TURBELLARIA**

Chalhuanca's Bofedal, Caylloma, Arequipa-Peru

Compliance with Ethical Standard

Conflict of interests: The authors declare that for this article they have no actual, potential or perceived conflict of interests.

Ethics committee approval: This study was conducted according to the ethics committee procedures and the evaluations were carried out under research authorization provided by the R.N. of Salinas and Aguada Blanca-SERNANP (Resolución Jefatural N°-002-2018 SERNANP-DGANP- JEF).

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