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Littoral macrobenthic communities and water quality in El Pañe Reservoir, Arequipa, Peru

Pastor Coayla-P [ID]ᵃ, André Alexander Cheneaux-D [ID]ᵃ, Claudia Viviana Moreno-S [ID]ᵃ, Cynthia Elizabeth Cruz-R [ID]ᵃ, Eusebio Walter Colque-R [ID]ᵃ and Cristina Damborenea [ID]ᵇ

ᵃLaboratorio de Hidrobiología, Departamento Académico de Biología, Universidad Nacional de San Agustín, Arequipa, Perú; ᵇDivisión Zoología Invertebrados, Museo de La Plata, FCNyM-UNLP, La Plata, Argentina, CONICET

ABSTRACT

High Andean ponds and reservoirs are among the least-studied environments. We evaluated the composition of littoral macrobenthos and how it is affected by the physicochemical conditions of the water in El Pañe reservoir (Peru), located at 4,550 m.a.s.l. Samples were taken between November 2017 and October 2018 from three zones in the reservoir: low (downstream), middle and high (upstream); two of these zones with fish farms (low and middle) and one zone without fish farms (high). The following physicochemical parameters of the water were measured: dissolved oxygen, conductivity, pH and temperature. The macrobenthic community was analysed through diversity indices such as Shannon-Wiener (H'), Simpson's dominance index (D), Pielou's evenness (J'), true diversity (D_1), and richness (S). The influence of the physicochemical variables on the macrobenthos was estimated by canonical correspondence analysis (CCA) and non-metric multidimensional scaling (NMDS). Dissolved oxygen was found to have lower values (<0.5 mg/l) than specified in the Environmental Quality Standards (EQS). Macroinvertebrate richness for the whole reservoir was 17 families, and the family with highest relative abundance was Chironomidae (42.24% in the low zone, 51% in the middle zone and 40.43% in the high zone). The indices showed greater species richness in the high zone, where there are no fish farms. Dissolved oxygen and conductivity were the main factors determining macrobenthos distribution and composition.

Introduction

High Andean rivers, wetlands and ponds are among the least-studied aquatic ecosystems. It is estimated that 5.24% of tropical South America lies at over 3,000 m above sea level, and the extensive central and northern Andes constitute 94% of the land above this elevation on Earth [1]. Aquatic environments at great altitudes may be affected by organic contamination, agrochemicals, sedimentation and mining waste, and they are particularly threatened by dams and water extraction [1] which makes them extremely susceptible to the effects of global climate change [2,3].

In Peru, many of the high-altitude aquatic ecosystems show deterioration in water quantity and quality, which affects their biological composition [4]. El Pañe Reservoir, located at approximately 4,550 m above sea level, is one of the sources providing water to Arequipa city, after purification [5]. The reservoir is also used for fish farming, which degrades the ecosystem through the addition of large quantities of waste, such as fish excreta and uneaten feed. A significant amount of these nutrients remains dissolved in the water column, fostering eutrophication, with its environmental, economic and social impacts [6].

Because benthic macroinvertebrates may be sensitive or tolerant to different environmental changes in their habitat, which would be reflected in a change in the structure of their communities, using them as bioindicators of water quality has become a useful tool for ongoing comprehensive identification of potential impacts [7–9]. The United Nations (UN), European Union (EU) and RAMSAR Convention suggest the use of benthic macroinvertebrates for assessment of water quality [10,11], and this type of bioassessment is included in legislation on water management in many countries [12,13]. For instance, Europe [14] and Latin America [9,15] have developed and adapted indices based on benthic macroinvertebrate families.

Competent authorities in the management of El Pañe Reservoir, such as AUTODEMA [16] and SEDAPAR [17], have conducted several assessments of water quality employing only physicochemical indicators [16,18]. Therefore, since there is no baseline information on the benthic invertebrate community in the region, assessment of water quality using bioindicators is limited. The purpose of this study was to describe the benthic macroinvertebrate community in El Pañe Reservoir, in areas without and with impact from fish farming and its potential implications regarding water quality. The aims were (1) to characterize the physicochemical conditions of the water in the reservoir; (2) to describe the diversity of benthic macroinvertebrate families; and (3) to determine the influence

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CONTACT Cristina Damborenea ✉ cdambor@fcnym.unlp.edu.ar

of the presence of fish farming in the reservoir. The production process of fish farming releases a large amount of residual feed and excreta into the water, which can be oxidized to soluble substances, increasing nitrate and phosphate concentration. Such water contamination affects the macroinvertebrate community, thus providing an indirect measurement of the effects of fish farming [6,19]. This study contributes to advancing the knowledge on high-altitude benthos and is the first study in this field conducted in such an important reservoir of the Arequipa region in Peru.

Materials and methods

Study area

This study was conducted in El Pañe Reservoir, located on the River Negrillo, a tributary of the River Colca, in Caylloma Province, Department of Arequipa (Figure 1), at an elevation of 4,524 to 4,580 m.a.s.l., in the Altiplano region of southern Peru. The reservoir is part of the headwaters of the River Chili basin. Its active storage capacity is 93 million m^3 and dead storage capacity 41.3 million m^3. It regulates El Pañe water resource and a wet watershed of 185 km^2 [16]. The dam has homogeneous section constituted of fine, silty-clay soil. Its upstream and downstream embankments have a protective rockfill, with a layer of gravels and sands providing a transition between the fine material and the rockfill [16]. The water in the reservoir is used for human consumption in Arequipa city, as well as for irrigation and livestock. The reservoir is used for artisanal *Oncorhynchus mykiss* (Walbaum, 1792)

farming in floating cages. The characteristics of the region are typical of a high Andean pond ecosystem, with mountains and nearby Andean wetlands ("*bofedales*"). Mean monthly temperature ranges from 6°C in the rainy months (December to March) to 1°C in dry months when cloud cover is lower. Average annual precipitation is 710 mm [20].

Sampling

The sampling sites were located in the low (downstream), middle and high (upstream) zones along the reservoir (Figure 1). There are fish farms in the low and middle zones but not in the high zone. Ten sampling stations were established: three in the low zone (E1–E3), four in the middle zone (E4–E7) and three in the high zone (E8–E10) (Table 1). Six sampling sessions were conducted in November and December 2017 and April, May, July and October 2018. A Hanna HI9829 multiparameter portable meter was used to measure dissolved oxygen (mg/L), pH, conductivity and temperature in the field. During each sampling session, three benthos samples were taken per station: one located randomly plus two repetitions located at least 5 m away (180 samples altogether).

Macroinvertebrates were collected in the benthos over 1 m^2 by semi-quantitative kick sampling, using a D-frame dip net (500 μm mesh and 30 cm opening). To take each sample, the substratum was agitated vigorously with the feet for 2 min. The organisms collected during each repetition were stored separately in labelled jars and fixed in 4–5% formalin. In the lab, the samples were preserved in 70% alcohol for
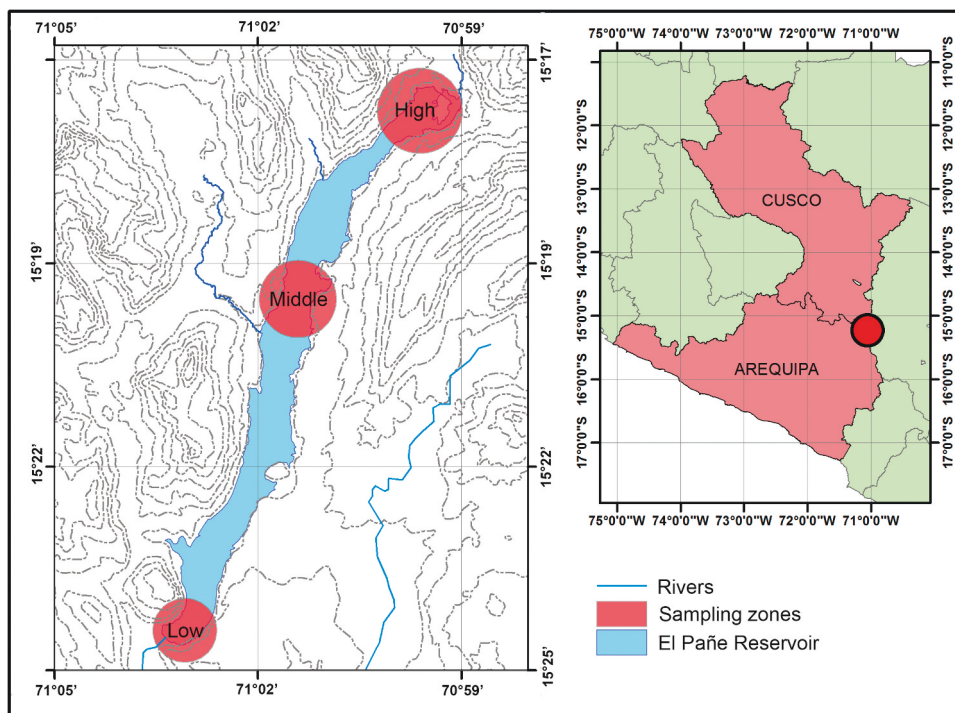

Figure 1. Sampling zones in El Pañe Reservoir, Arequipa, Peru.

Table 1. Sampling stations at El Pañe Reservoir, Arequipa, Peru.

El Pañe zones	Stations	Latitude	Longitude
Low	E1	−15.419595°	−71.067002°
	E2	−15.415604°	−71.067321°
	E3	−15.419600°	−71.062611°
Middle	E4	−15.338155°	−71.039920°
	E5	−15.342496°	−71.032848°
	E6	−15.348957°	−71.034301°
	E7	−15.345704°	−71.041901°
High	E8	−15.299907°	−71.010848°
	E9	−15.297076°	−71.006565°
	E10	−15.306361°	−71.007921°

identification under stereomicroscope [21,22]. All macroinvertebrate individuals were identified at family level following Domínguez and Fernández [21], Merritt et al. [23], Thorp and Lovell [24] and Prat et al. [25].

Data analysis

The macrobenthos community structure was evaluated using richness (number of families) (S), relative abundance ([number of individuals in a family/total number of individuals in all families]*100), Shannon-Wiener diversity index (H′), Simpson's dominance index (D), Pielou's evenness (J′) and true diversity (D₁) [26]. A Shapiro–Wilk test was performed to determine whether the indices had a normal distribution. ANOVA was used to compare the community indices in conditions among sampling sites. A standard principal component analysis (PCA) using normalized variance-covariance matrix was performed to determine environmental variability of water quality parameters, and standard canonical correspondence analysis (CCA) was used to evaluate the relationship between the composition of macroinvertebrates and physicochemical variables. The ANOSIM permutation test (with 9,999 replicates) was used to test the hypothesis of differences in the composition of the community between sampling zones and the statistical significance of the groupings. The SIMPER similarity analysis and non-

metric multidimensional scaling (NMDS) ordination based on the Bray-Curtis index were used to explore variations in the composition of macroinvertebrate taxa among sampling zones. The analyses were performed using EXCEL® and PAST version 4.03 software [27].

Results

Physicochemical parameters

Surface water temperature, conductivity, pH and dissolved oxygen values are shown in Table 2. The conductivity was higher in December in the three sampled zones (low, middle and high). Dissolved oxygen was the only physicochemical parameter that did not meet the Water Quality Standards according to Peruvian legislation (Ministry of Environment [MINAM] Supreme Decree 004–2017), having low values in all three zones in the reservoir (<5 mg/l) (Table 2).

PCA (Figure 2) shows that the first two components explained 72.69% of the total variability between environmental variables. Component 1 had a positive correlation with pH (0.78) and dissolved oxygen (0.52) and a negative correlation with conductivity (−0.83). Component 2 had a positive correlation with temperature (0.96). Samples for December 2018 show high conductivity values.

Diversity of littoral macrobenthos

Seventeen macrobenthic families were identified in El Pañe Reservoir. The highest mean relative abundance values were recorded for Chironomidae (Table 3). Corixidae followed in abundance in the high zone, Naididae in the middle zone and Lumbriculidae in the lower zone (Table 3). The values obtained for community structure indices show that in the low zone (November 2017, April and May 2018) and the middle zone

Table 2. Mean values and standard deviation of physicochemical parameters in the three sampling zones of El Pañe Reservoir, Arequipa, Peru.

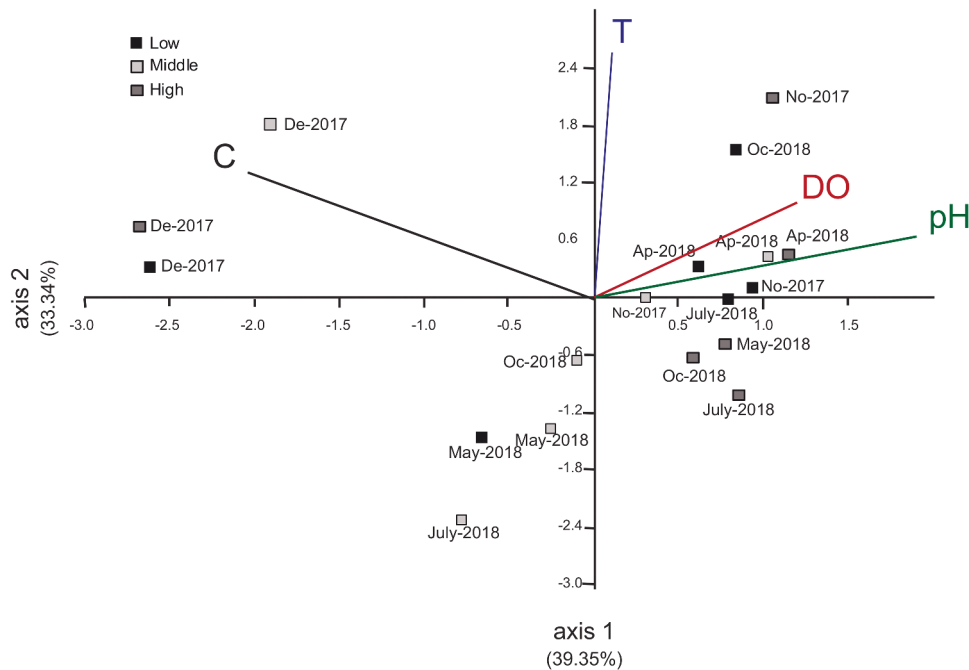| Month/Year	Zone	Temp.(°C)	pH	EC (µS/cm)	D.O.(mg/L)
NO-2017	Low	12.05 ± 0.27	8.49 ± 0.11	53 ± 2.83	3.38 ± 0.54
	Middle	12.47 ± 2.67	8.31 ± 0.18	58.33 ± 2.36	2.98 ± 0.13
	High	15.89 ± 1.64	8.38 ± 0.14	63.83 ± 11.08	3.74 ± 0.35
DE-2017	Low	12.4 ± 0.3	7.08 ± 0.56	234.17 ± 82.95	3.16 ± 0.39
	Middle	13.6 ± 1.13	7.8 ± 0.49	321.7 ± 65.25	3.5 ± 0.94
	High	13 ± 1.31	7.7 ± 0.87	290.6 ± 55.67	2.5 ± 0.14
AP-2018	Low	12.48 ± 0.57	7.87 ± 0.11	46 ± 0	3.99 ± 0.08
	Middle	12.3 ± 0.55	8.1 ± 0.2	45.3 ± 0.5	4.1 ± 0.09
	High	12.4 ± 0.25	8.3 ± 0.1	45 ± 0	3.9 ± 0.14
MA-2018	Low	10.57 ± 0.99	7.84 ± 0.22	42.83 ± 11.12	2.55 ± 0.03
	Middle	10.2 ± 0.93	8 ± 0.1	47 ± 1.58	2.8 ± 0.07
	High	11.4 ± 1.12	8.7 ± 0.21	48 ± 4.36	2.8 ± 0.09
JU-2018	Low	11.76 ± 2.81	8.59 ± 0.5	68.67 ± 34.93	3.19 ± 0.1
	Middle	7.97 ± 0.7	7.32 ± 0.18	50.13 ± 4.77	3.42 ± 0.15
	High	9.69 ± 1.43	8.35 ± 0.11	45 ± 0	3.51 ± 0.36
OC-2018	Low	14.34 ± 0.69	8.41 ± 0.6	97.89 ± 61.61	3.75 ± 0.27
	Middle	11.32 ± 0.22	7.88 ± 0.42	51 ± 1.41	3.2 ± 0.06
	High	10.4 ± 0.31	7.92 ± 0.34	46.78 ± 0.19	3.94 ± 0.02

Figure 2. Plot of zones with sampling months in El Pañe high Andean reservoir in Arequipa, Peru, according to principal component analysis (PCA) for environmental variables: C, conductivity (µS/cm); DO, dissolved oxygen (mg/L); pH; T, temperature (°C). Component 1 explains 39.35% and component 2 explains 33.34% of the total variability.

Table 3. Mean relative abundances (%) of aquatic macroinvertebrate families in El Pañe Reservoir, Arequipa, Peru, in each sample zone.

Family	Low	Middle	High
Chironomidae	42.24	51.00	40.43
Glossiphoniidae	7.58	4.85	1.92
Dugesiidae	13.15	5.24	0.89
Naididae	15.17	25.02	13.54
Lumbriculidae	18.03	2.79	2.44
Corixidae	1.67	0.91	32.91
Cyprididae	0.13	7.30	0.84
Limnesiidae	0.37	2.46	0.48
Longidoridae	0.48	0.14	0.23
Hydroptilidae	0.02	0.03	1.39
Elmidae	0.01	0.00	0.42
Tabanidae	0.00	0.16	0.05
Muscidae	0.06	0.06	0.01
Baetidae	0.00	0.01	0.64
Ceratopoginidae	0.00	0.00	0.02
Limnephilidae	1.08	0.01	0.13
Tipulidae	0.00	0.01	0.00

(December 2017, April, May and July 2018), dominance (D) is greater than evenness (J); in contrast to the high zone where there is greater evenness, except in April 2018. Shannon-Wiener diversity index (H) and true diversity (D_1) were greater in the high zone than in the low and middle zones, except in April and October 2018 (Figure 3). The Shapiro–Wilk test showed the normal distribution of the community structure indices (S: W = 0.92, p = 0.319; D: W = 0.91, p = 0.194; H: W = 0.95, p = 0.637; J': W = 0.97, p = 0.866; D_1: W = 0.96; p = 0.802). ANOVA showed that there is no significant difference in D, J', H and D_1 among different zones, while S differed significantly among zones (Table 4).

The ANOSIM similarity analysis showed that macrobenthos composition in the high zone differed significantly (R = 0.172 and p < 0.05) from that in the low and middle zones. The SIMPER analysis showed that the three zones had a mean dissimilarity of 58.59%. The main families contributing to this dissimilarity were Chironomidae (28.23%), Naididae (20.48%), Corixidae (18.74%) and Lumbriculidae (11.4%).

CCA (Figure 4) showed that the accumulated variance of the association between physicochemical variables and community composition was explained by the first two axes in 93.97%. Chironomidae was associated to dissolved oxygen, while Corixidae and Lumbriculidae were associated with pH.

The NMDS analysis provides a graphic representation of the similarity among the zones in the reservoir. The high zone is distinct from the middle and low zones (stress = 0.17; R of axis 1 = 0.47 and R of axis 2 = 0.37) (Figure 5).

Discussion

The Altiplano region of the Andes is a topographically complex region located at a high elevation, with low atmospheric pressure, high insolation and wide seasonal and daily variations in temperature [28]. Although the aquatic environments in this region are an important resource for the human population, they are among the least studied [28]. Studies on macroinvertebrate richness in rivers in this region have increased in recent years [28–30], but there is limited information for ponds and reservoirs in the Andean Altiplano [1].
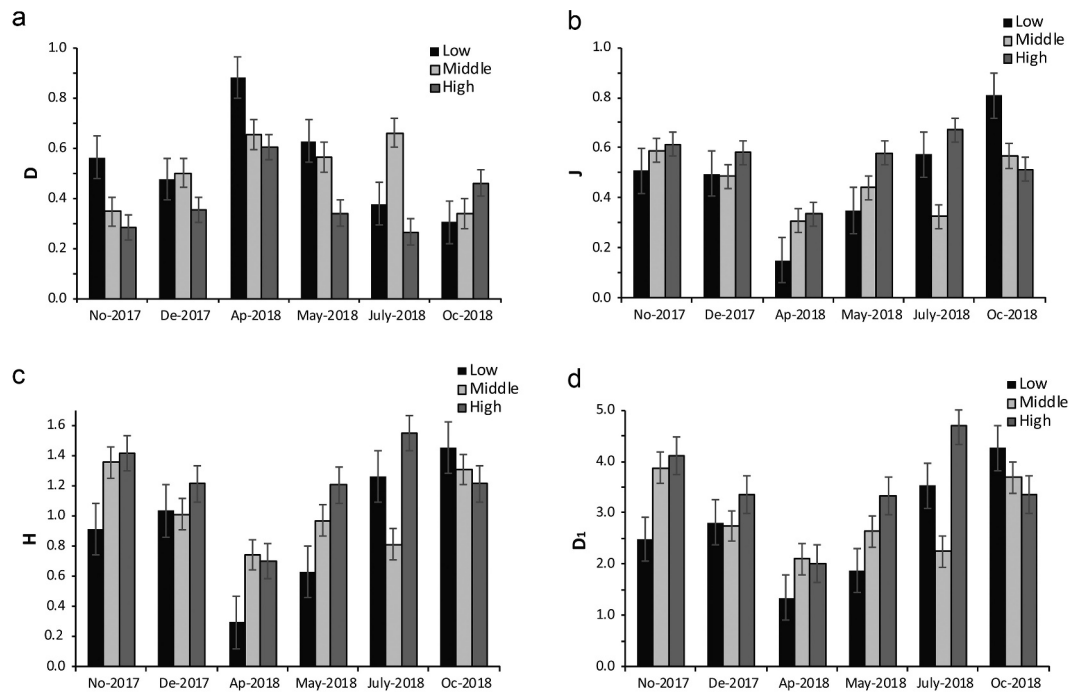
Figure 3. Community structure indices for El Pañe Reservoir, Arequipa, Peru, in each sampling session. A, Simpson's dominance index (D); B, Shannon-Wiener diversity (H); C, Pielou's evenness (J'); D, true diversity (D_1).

Table 4. ANOVA test for community indices among sampling zones. Significant values in bold.

	DF	F	p
Species Diversity Index (H)	2	1.16	0.3402
Simpson´s dominance index (D)	2	1.54	0.2474
Pielou's evenness index (J')	2	0.55	0.5889
True diversity (D_1)	2	1.16	0.3406
Richness (S)	2	9.01	**0.0027**

This highlights the importance of the findings of the current study, which was conducted in a reservoir at 4,500 m.a.s.l.

The physicochemical characteristics of high Andean rivers are variable and fluctuate over space and time [1]. Comparison of the variables recorded in this study to values published for similar environments shows that the temperature, pH and conductivity ranges are typical of the Andes, due to the geological conditions [29,31,32]. Conductivity found for El Pañe Reservoir in this study was lower than the average reported by Villamarin et al. [29] for the River Colca basin in Perú during the dry season. According to these authors, the high conductivity values in the River Colca, compared to rivers at other latitudes, are due to the basin's geological characteristics. The current study recorded temporal variation in conductivity. At all sampling sites, conductivity was highest in December, which is the dry season when there is no rainfall and the reservoir is at its lowest level. Dissolved oxygen values were lower than expected for a lentic water body at high altitude [33]. For Lake Titicaca, at 3,810 m.a.s.l., normal
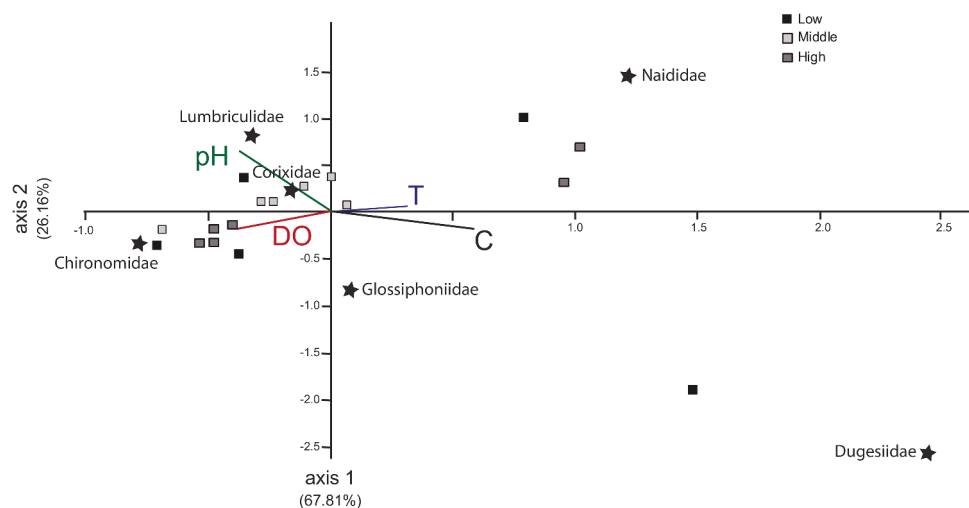

Figure 4. Canonical correspondence analysis (CCA) showing the association among the families present in El Pañe high Andean reservoir in Arequipa, Peru, and the environmental variables considered (vectors). C, conductivity (µS/cm); DO, dissolved oxygen (mg/L); pH; T, temperature (°C).
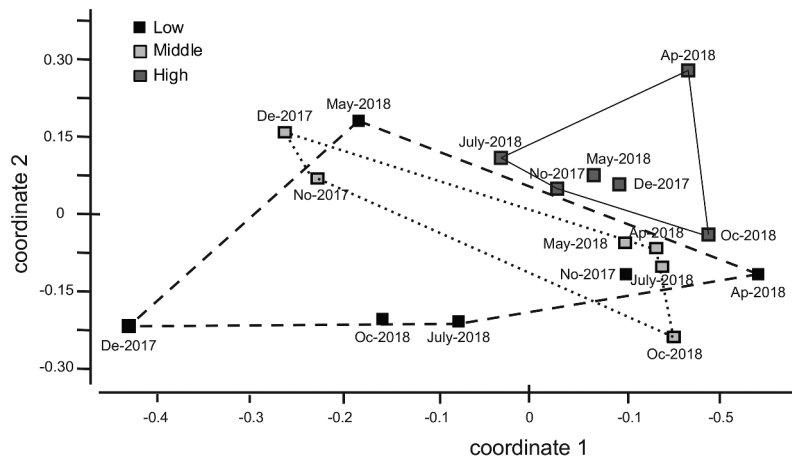
Figure 5. Non-metric multidimensional scaling (NMDS). Samples are distinguished according to zones and months (No, November; De: December; Ap: April; May; July; Oc, October) in the high Andean reservoir El Pañe, Arequipa, Peru. Solid line, samples from high zone; dashed line, from middle zone; doted line, from low zone.

dissolved oxygen range is 4.5–7.5 mg/L [33]. This may be explained by the low atmospheric pressure as a result of the elevation of El Pañe Reservoir (4,550 m. a.s.l.) [1]. Also, high altitude streams are close to a critical oxygen level because their natural oxygen saturation at atmosphere equilibrium may be about 60% (e.g. Bolivian Altiplano streams at 3,000 m.a.s.l.). They are thus more sensitive to dissolved oxygen lowering due to organic pollution [28]. The waste from the fish farming load increases the proliferation of microorganisms that break it down, leading to a reduction in dissolved oxygen concentration and an increase in inorganic nutrients such as ammonium and phosphate [34].

Several studies [35–39] report that in lentic systems (regardless of geographic area), the most representative littoral macrobenthos in high-altitude lakes and ponds usually consists of larvae of the family Chironomidae and Oligochaeta at high densities due to the amount of organic matter [40, 41] and low oxygen concentrations, because the heme group in their circulatory system enables them to live at low oxygen concentrations. Other studies [42–45] agree in reporting the families Glossiphoniidae, Naididae and Corixidae in ecosystems of this kind. It is important to note that in the high zone in the current study, there is high abundance of the family Corixidae. This may be due to the fact that because there is no fish farm in this zone, there are few free trout, which are the main predators of some aquatic insects [19,44]. Trichoptera and Plecoptera had no representativity, since they usually live under logs, rocks or plant material in fast-flowing, well-oxygenated, cold lotic currents, and these conditions are absent in El Pañe Reservoir.

Species diversity and true diversity were low in all reservoir zones, possibly because there is low diversity of habitats in these ecosystems at high latitudes, and

therefore a low supply of ecological niches, conditioning macrobenthos diversity [46]. According to Leiva [45], high diversity values are directly related to the variety of habitats and good balance in communities. Evenness values were low, due to the reduction in abundance of sensitive insects and increase in dominance of families tolerant of hypoxia as a result in the increase in organic matter [47,48], such as Chironomidae and Naididae. This was noted mainly in the low and middle zones, where there are fish farms. NMDS differentiated the high zone without impact from fish farming and grouped the two zones impacted by fish farming (low and middle zones), reflecting the fact that benthic macrofauna is a good indicator of this condition.

Numerous studies highlight the importance of the impact of pH, conductivity, dissolved oxygen, and total suspended solids on the distribution of benthic macrofauna in lotic systems [21,22,49–51], though there is limited available information of this kind for lentic environments and even less for high Andean lentic environments. The CCA confirmed the importance of dissolved oxygen in high Andean ecosystems, where it was found to be associated to families tolerant to low levels of dissolved oxygen such as Chironomidae. In the current study, the family Naididae was associated with conductivity. With regard to other representative families, such as Dugesiidae and Glossiphoniidae, their trophic functionality may be more relevant than the influence of the physicochemical variables studied.

The results of this study show differences in the representativity of the benthic macroinvertebrates in high Andean zones with and without fish farms. It has been shown that intensive fish farming produces ecological effects at multiple levels in high Andean environments [19], in addition to the effects of the

accumulation of organic matter at the bottom, dead organic matter and the proportion of uneaten food [6].

Authors' participation

PCP, AACHD, CVMS, CECR and EWCR conducted the fieldwork and analysis and wrote the manuscript. CD did the final review of the paper.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Pastor Coayla-P 🔘 http://orcid.org/0000-0002-2317-7154
Andréé Alexander Cheneaux-D 🔘 http://orcid.org/0000-0002-7148-0174
Claudia Viviana Moreno-S 🔘 http://orcid.org/0000-0001-5124-5663
Cynthia Elizabeth Cruz-R 🔘 http://orcid.org/0000-0001-6178-5129
Eusebio Walter Colque-R 🔘 http://orcid.org/0000-0001-9136-3306
Cristina Damborenea 🔘 http://orcid.org/0000-0002-6411-1282

Geolocation information

Samples from El Pañe Reservoir, Arequipa, Peru, between −15.297076° to −15.419600° latitude, and −71.006565° to −71.067002° longitude.

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