

ECOLOGY AND BEHAVIOR

Composition of aquatic macroinvertebrate communities and adaptation of tolerance scores for the ABI index in the lower Quilca-Chili River basin, Arequipa, Peru

Composición de comunidades de macroinvertebrados acuáticos y adaptación de puntajes de tolerancia del índice ABI para la cuenca baja del río Quilca-Chili, Arequipa, Perú

Pastor Coayla-Peñaloza ^{1*}, André Cheneaux- Díaz ¹, Fernando Cobo ²

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ABSTRACT

Aquatic macroinvertebrates are essential as accurate bioindicators of water quality but their behavior may change according to regional characteristics. The Quilca–Chili basin, is one of the most important basins in southern Arequipa, Peru, yet lacks inventories that allow for the adaptation of family-level scores in biotic indices. This study aimed to analyze the structure of macroinvertebrate communities and to adapt the scores of bioindicator families for their application in the ABI index. Sampling was conducted in June and October 2022 at 16 stations using Surber nets, D-nets, and screen samplers (500 µm). The community structure and its relationship with physicochemical and biological variables were characterized. To adapt the scores of bioindicator families, Bray–Curtis similarity dendrograms and mean comparisons among grouped families were used. A total of 70 genera were identified, with the most abundant being *Aedokritus*, *Camelobaetidius*, *Cricotopus*, *Cryptonympha*, *Metrichia*, *Microcylloepus*, *Onconeura*, *Polypedilum*, and *Simulium*. The highest and lowest true diversity values were recorded in the Quilca and Vitor rivers, respectively. A trend of increasing percentage of EPT values and decreasing the percentage of Chironomidae was observed toward upstream stations. Score adjustments were made for 24 families, and four additional families were incorporated into the ABI index. Thirteen stations within the sub-basin corresponded to the “good” and “very good” water quality categories. The aquatic macroinvertebrate communities of the lower Quilca–Chili River basin showed no major alterations in their structure and diversity. The variation of the individual ABI scores of bioindicator families, may be applied to arid ecosystems across South America.

Keywords: Biotic indices, bioindicators, diversity, ecological quality, macrobenthos.

¹ Universidad Nacional de San Agustín de Arequipa, Av. Alcides Carrión s/n, Arequipa, Perú, pcoaylap@unsa.edu.pe, acheneaux@unsa.edu.pe

² Departamento de Zoología, Genética y Antropología Física, Facultad de Biología, Universidad de Santiago de Compostela, 15 782 Santiago de Compostela, España, fernando.cobo@usc.es

* Corresponding author



RESUMEN

Los macroinvertebrados acuáticos son fundamentales como bioindicadores fidedignos de calidad de agua; no obstante, su comportamiento puede cambiar de acuerdo con características regionales. La cuenca Quilca-Chili es una de las más importantes del sur de Arequipa, Perú y carece de inventarios que permitan la adaptación de puntajes de los índices bióticos. Se analizó la estructura de macroinvertebrados y se adaptaron los puntajes de familias para su empleo en el índice ABI. Se realizaron muestreos en junio y octubre de 2022, en 16 estaciones, empleando redes Surber, D-net y pantalla (500 μ m). Se caracterizó la estructura de la comunidad y su relación con variables fisicoquímicas y biológicas. Para adaptar los puntajes de las familias de bioindicadores, se utilizaron dendrogramas de similitud con el índice de Bray-Curtis y análisis de medias entre familias agrupadas. Se identificaron 70 géneros, siendo los más abundantes: *Aedokritus*, *Camelobaetidius*, *Cricotopus*, *Cryptonympha*, *Metrichia*, *Microcylloepus*, *Onconeura*, *Polypedilum* y *Simulium*. La mayor y menor diversidad verdadera se presentó en los ríos Quilca y Vitor, respectivamente. Hubo un incremento de los valores porcentuales de EPT y una disminución del porcentaje de Chironomidae río arriba. Se evidenciaron cambios de puntajes para 24 familias y se incorporaron cuatro familias al índice ABI. Trece estaciones de la subcuenca corresponden a las categorías de calidad buena y muy buena. Las comunidades de macroinvertebrados acuáticos de la cuenca baja del río Quilca-Chili no presentan alteraciones importantes en su estructura y diversidad. Las variaciones en los valores ABI pueden ser aplicados en ecosistemas áridos de América del Sur.

Palabras clave: Índices bióticos, bioindicadores, diversidad, calidad ecológica, macrobentos.

INTRODUCTION

Water is a fundamental resource for human health, maintenance of biodiversity, and the provision of ecosystem goods and services. However, on a global scale, water quality is being severely impacted by human activities. Factors such as landscape transformation, land-use changes, pollution, occupation of floodplains, and watercourse diversion for agricultural and livestock purposes have negatively affected aquatic ecosystems (Crettaz-Minaglia et al., 2014; Segnini, 2003; Steinfeld et al., 2009). In Peru, these issues are evident across its 159 hydrographic basins, many of which suffer from high levels of contamination due to livestock farming, agriculture, and organic waste discharges from urban areas (Corroto et al., 2016; Vilca-Carhuapoma, 2022).

Aquatic macroinvertebrates are widely recognized as biological indicators for water quality. Their sensitivity to pollutants and ability to inhabit diverse environments make them valuable tools for monitoring and conserving aquatic ecosystems (Giacometti 2019; Ortiz, 2005; Roldán, 1996). Thus, these organisms respond rapidly to environmental

disturbances, and their abundance, ease of sampling, and well-established taxonomy reinforce their reliability as bioindicators (Barba et al., 2013).

In this context, biotic indices have become essential tools for integrating biological and physicochemical data into environmental monitoring. The Biological Monitoring Working Party Index (BMWP) is one of the most widely used approaches worldwide for evaluating water quality based on the sensitivity of macroinvertebrate families to pollution. In Latin America, this index has been adapted to various regions, such as the BMWP/Col in Colombia, which has proved effective for assessing rivers impacted by organic pollution (Roldán, 2003).

The Andean Biotic Index (ABI), derived from the BMWP, was specifically developed to reflect the characteristics of high Andean ecosystems between 2000 and 4000 m above sea level (Acosta et al., 2009; Ríos-Touma et al., 2014). This index adjusts macroinvertebrate tolerance scores to environmental disturbances, considering the limited biodiversity at these altitudes. Its application has been successful in countries like Ecuador and Peru, where it has been

incorporated into multimetric systems such as the index designed for high Andean streams (Índice Multimétrico del Estado Ecológico para Ríos Altoandinos, IMEERA) to characterize the ecological quality of rivers (Ríos-Touma et al. 2014). In Ecuador, the ABI has been used to assess micro-watersheds supplying water to the city of Loja, often in conjunction with other indices such as the percentage of Ephemeroptera, Plecoptera, and Trichoptera (%EPT) (Peña et al., 2019).

In Peru, studies on macroinvertebrates have been conducted in various regions, including high Andean areas (Carrasco et al., 2020, Coayla-Peñaloza et al., 2022), coastal wetlands (Castillo-Velásquez & Huamantínco-Araujo, 2020), and the Amazon basin (Arana-Maestre et al., 2021a). However, detailed inventories are still lacking in arid basins such as the Quilca-Chili Basin in the Arequipa region, one of the country's most significant basins due to its economic and social importance.

This study aims to evaluate the variation in the structure of aquatic macroinvertebrate communities in the lower Quilca-Chili River basin and propose adjustments to the tolerance scores used in the Andean Biotic Index (ABI) to enhance its applicability in this region. These advancements will contribute to more efficient environmental monitoring and the development of effective conservation strategies for aquatic ecosystems in the area.

MATERIALS AND METHODS

Study area

The lower basin of the Quilca-Chili River, located in the Arequipa region (southern Peru), extends from the confluence of the Chili and Yura rivers to its mouth at the Pacific Ocean. The lower part of the region is characterized by an arid climate, with annual rainfall ranging between 10 and 50 mm, concentrated mainly between December and March (SENAMHI, 2011). Average temperatures vary between 15°C and 25°C, which depends on altitude and proximity to the coast.

This area encompasses the Vitor and Sihuas valleys, where the main economic activities include intensive agriculture, with crops such as rice, corn, and onions, which depend on irrigation from the Chili, Quilca, Sihuas, and Vitor rivers (ANA, 2014). Additionally, the region hosts significant mining operations, particularly for copper and gold, which contribute substantially to the local and national economy (MINEM, 2018). Sustainable management of water resources in this basin is essential to balance agricultural, mining, and urban demands, ensuring the conservation of aquatic ecosystems and the well-being of local communities.

Sampling methods

In this study, 16 sampling stations were established (Table 1, Fig. 1) along the three rivers corresponding to the lower basin: six stations in the Vitor River section (Vitor Valley), seven stations in the Sihuas River section (Sihuas Valley), and three stations in the Quilca River section. Sampling stations were defined based upon accessibility to the area and coverage of the entire lower basin.

Sampling was conducted in June and October 2022. For the collection of aquatic macroinvertebrates, three types of nets were used: Surber, D-net, and screen nets, all with a mesh size of 500 µm (Samanez Valer et al., 2014). Samples were fixed in 4 % formaldehyde and stored in 500 ml containers. In the laboratory, the samples were cleaned and preserved in 70 % alcohol, followed by taxonomic identification using a stereoscope MOTIC SMZ-171. Taxonomic keys and descriptions used are from Merritt et al. (2008), Domínguez & Fernández (2009), Huamantínco & Ortiz (2010), and Hamada et al. (2018).

Additionally, a Hanna HI9829 multiparameter equipment was used to measure *in situ* physicochemical parameters (pH, temperature, dissolved oxygen, total dissolved solids, and conductivity). Laboratory analyses were conducted for total coliforms, fecal coliforms, and organic matter in the sediment. The physicochemical parameters were compared with the Environmental Quality Standards (ECA) for water of the Peruvian government Supreme Decree N°. 002-2008-MINAM, Subcategory D1 "Vegetable irrigation" and D2 "Animal drinking water."

Table 1. Location and general characteristics of the sampling stations in the lower Quilca-Chili River basin.

RIVER	STATION	LATITUDE	LONGITUDE	ELEVATION (m)
Vitor	E01	16° 35'28.5"S	72° 0'15.20"O	986
	E02	16° 33'51.00"S	71° 58'59.30"O	1300
	E03	16° 31'16.60"S	71° 57'41.50"O	1098
	E04	16° 27'46.00"S	71° 53'46.00"O	1150
	E05	16° 25'5.90"S	71° 52'7.40"O	1274
	E06	16° 22'33.70"S	71° 48'19.70"O	1443
Sihuas	E07	16° 24'46.00"S	72° 9'50.70"O	1127
	E08	16° 23'44.00"S	72° 9'43.30"O	1152
	E09	16° 20'43.44"S	72° 7'47.61"O	1278
	E10	16° 20'6.90"S	72° 7'19.40"O	1315
	E11	16° 18'47.21"S	72° 6'2.22"O	1369
	E12	16° 16'17.10"S	72° 4'11.80"O	1514
	E13	16° 11'23.90"S	72° 2'43.50"O	1698
Quilca	E14	16° 43'25.60"S	72° 25'13.00"O	4
	E15	16° 41'26.90"S	72° 24'21.80"O	32
	E16	16° 39'6.60"S	72° 22'42.40"O	55

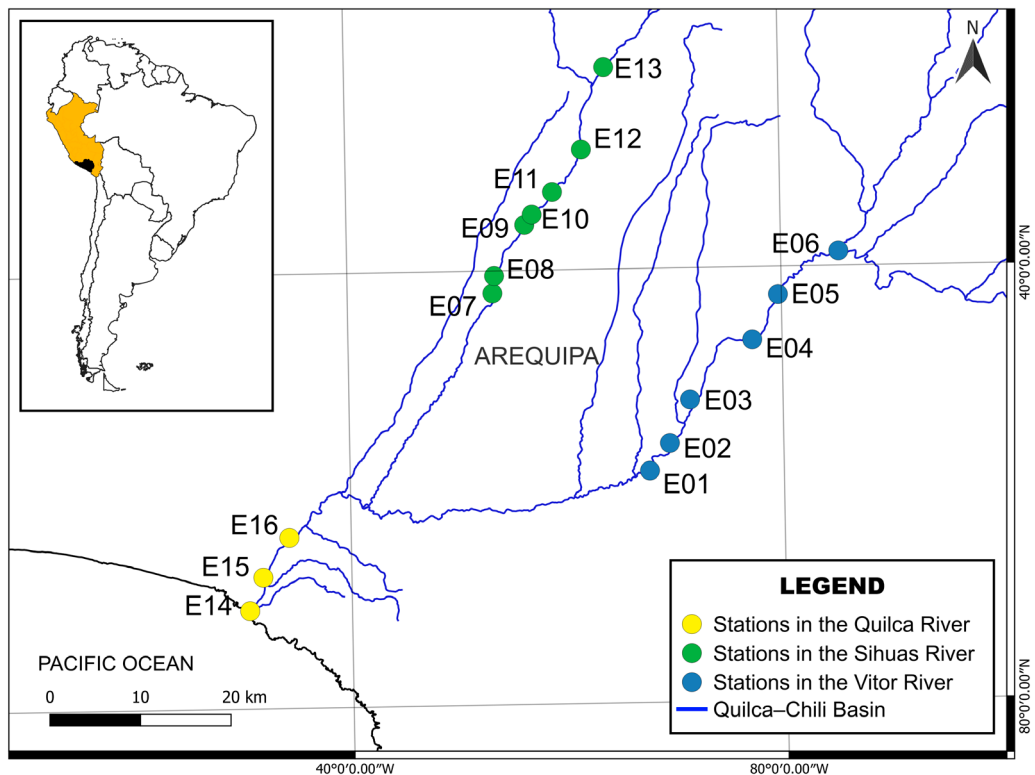


Figure 1. Location of sampling stations of the lower Quilca-Chili River basin.

Data analysis

Community structure metrics were calculated, including the Pielou evenness index (J'), true diversity (D_1), and rank-abundance curves at the basin level (Moreno, 2001). The Andean Biotic Index (ABI) was used to determine the biological quality of the water, where values greater than 106 indicate very good quality (Class I), values between 80 and 106 indicate good quality (Class II), between 53 and 79 moderate quality (Class III), between 27 and 52 poor quality (Class IV), and values below 26 correspond to very poor quality (Class V). The percentage of EPT organisms (Ephemeroptera, Plecoptera, and Trichoptera) and the percentage of Chironomidae were calculated (Ríos-Touma et al., 2014) to establish trends in the variation of the most sensitive (EPT) and tolerant (Chironomidae) groups across the sampling stations and campaigns. A canonical correspondence analysis (CCA) was performed to identify trends and associations between aquatic macroinvertebrate abundances and water physicochemical variables. Abundance and physicochemical data were square-root transformed to reduce the influence of extreme values and adjust skewed distributions (Legendre & Legendre, 2012).

To propose modifications to the tolerance scores of families included in the ABI index, the following procedure was followed: Similarity dendrograms (Bray-Curtis Index) at the family level were generated for the lower Quilca-Chili River basin, since the affinity dendrogram reflects the ecological preferences and tolerance of the taxa.

The most closely related families (up to three families) were grouped, and average scores were calculated according to the ABI index, assigning this value as the new score for each family. For families where the ABI index only considered the order or another higher taxonomic level, the score of the corresponding order was assigned, such as Oligochaeta, Hydracarina, and Hirudinea. Taxonomic families not included in the ABI index were assigned the score of the families with which they were grouped, or alternatively, the BMWP/Col (2003) score (Roldán, 2003) when they did not belong to any group. Finally, the ABI index was recalculated for each station using the newly assigned family scores, without altering the water quality category table. All analyses were carried out using EXCEL® and PAST software version 4.13 (Hammer et al., 2001).

The high similarity among several recorded species and the lack of regional background information limits a robust validation of the index and a comprehensive perfor-

mance assessment. At this stage, a variation in the tolerance scores used in the Andean ABI is proposed to adjust its applicability to the arid ecosystems of the region, where this index has been used but has not yet been calibrated under local conditions.

RESULTS

Physicochemical parameters

The pH values remained slightly alkaline during both sampling seasons (7.5–8.5). Dissolved oxygen levels were generally high across all stations, except for E1 during the first campaign. Fecal coliform counts were elevated at stations E2, E3, E4, E5, and E13, exceeding the environmental quality standards (Subcategory D1, $D_2=1000$ NMP/100 ml) during the first sampling period. The highest conductivity values were recorded at stations E8 and E14. Finally, organic matter content in the sediment was consistently low across all stations (Table S1).

Structure of the aquatic macroinvertebrate community and biotic metrics

A total of 70 genera distributed across 48 families were recorded. Chironomidae (10 spp.) and Elmidae (4 spp.) exhibited the highest species richness. The five most abundant genera, consistently present across almost all sampling stations in both campaigns were: *Polypedilum* Kieffer, 1912 (Diptera, Chironomidae), *Simulium* Latreille, 1802 (Diptera, Simuliidae), *Microcylloepus* Hinton, 1935 (Coleoptera, Elmidae), *Metrichia* Ross, 1938 (Trichoptera, Hydroptilidae), and *Camelobaetidius* Demoulin, 1966 (Ephemeroptera, Baetidae).

Some taxa were represented by a single individual across the entire lower basin, including *Nephelopsis* sp. (Hirudinea, Erpobdellidae) in the first campaign; *Trichocorixa* sp. (Hemiptera, Corixidae), *Notonecta* sp. (Hemiptera, Notonectidae), and *Crambidae* sp. (Lepidoptera) in the second campaign; and *Falklandoperla* sp. (Plecoptera, Gripopterygidae) in both sampling periods (Table S2).

In the second sampling campaign, the slope of the range-abundance curve is less steep, indicating a more equal distribution and higher species richness (64 spp.) compared to the first campaign (60 spp.). No strong dominance patterns were observed, and overall diversity remained relatively stable between both sampling periods (Fig. 2).

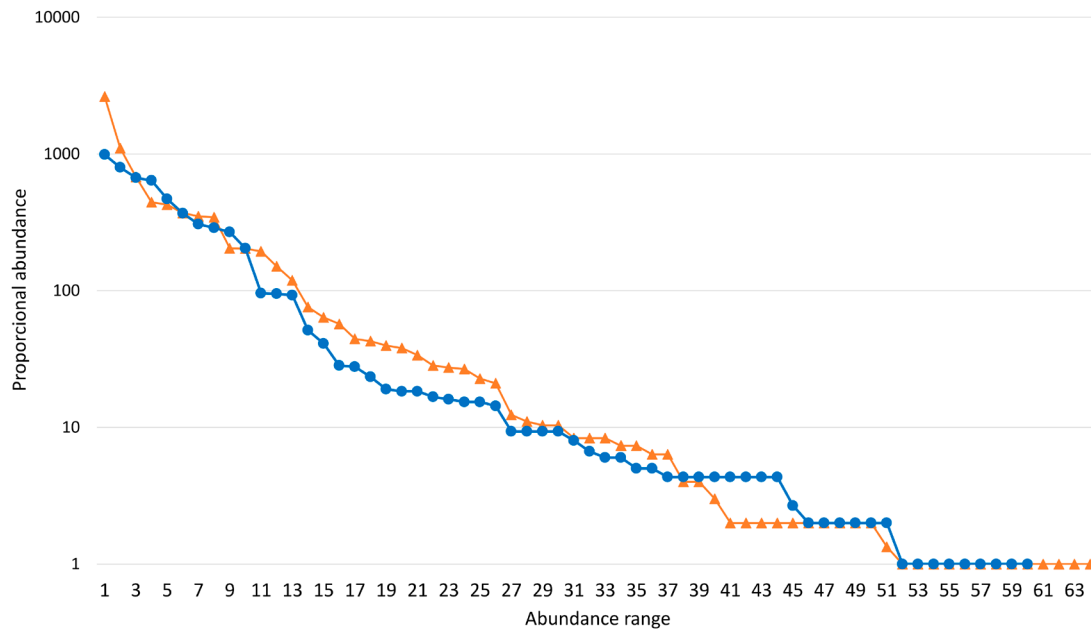


Figure 2. Rank-abundance curve for the entire lower Quilca-Chili River basin. (Blue: corresponding to the first sampling campaign; orange: corresponding to the second campaign).

The true diversity of order-1 exhibited an increasing trend from the lower to the upper zones of the three rivers. In the first campaign, the highest diversity values were recorded at stations E14 and E16 in the Quilca River. However, in the second campaign, this river showed the lowest diversity values. The Vitor and Sihuas rivers displayed little variation between campaigns, with the highest diversity recorded at E6 and E11 in the first campaign and at E6 and E12 in the second (Fig. 3a).

Pielou's evenness index values were generally high (>0.5) across most stations, indicating a relatively uniform distribution of species abundances. Exceptions were observed at stations E3 and E12 in the first campaign and at E1, E2, E8, and E14 in the second campaign, where evenness values were below 0.5 (Fig. 3b).

The percentage of Ephemeroptera, Plecoptera, and Trichoptera (%EPT), representing the most sensitive macroinvertebrate groups, showed a general increase from the lower to the upper zones of the three rivers forming the basin. Except for stations E9 and E10 in the first campaign, %EPT values remained below 50 %, indicating a low representation of these three orders in the lower Quilca-Chili River basin (Fig. 4a). Conversely, Chironomidae percentages, representing one of the most pollution-tolerant mac-

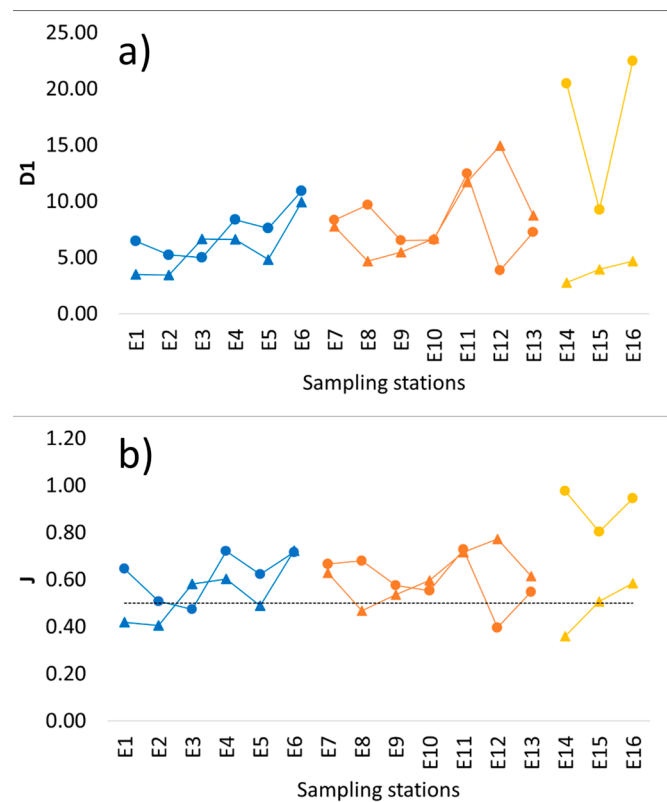


Figure 3. Community structure metrics of aquatic macroinvertebrates in the lower Quilca-Chili River basin: **a.** True diversity index; **b.** Pielou's evenness index. (Circle: first sampling campaign; triangle: second sampling campaign. Blue: Vitor River; orange: Sihuas River; yellow: Quilca River).

roinvertebrate families, showed a decreasing trend from the lower to the upper zones of all three rivers. Except for stations E1, E2, E3, E7, and E15 in the first campaign, and E2, E14, and E15 in the second, Chironomidae proportions remained below 50 % (Fig. 4b).

Multivariate Analysis

The CCA (Canonical Correspondence Analysis) performed using data from the first campaign (Fig. 5a) showed that the first two axes explained 86.62 % of the cumulative variance in the association between physicochemical variables and community composition. The family Baetidae was positively associated with pH and dissolved oxygen, while Chironomidae, Physidae, Hydroptilidae, and Elmidae were associated with higher levels of organic matter, and Cyprididae with higher levels of total and fecal coliforms. Using data from the second campaign (Fig. 5b), the cumulative variance reached 74.88 %. The families Simuliidae, Ceratopogonidae, and Baetidae were associated with higher pH values, while the family Naididae was associated with higher levels of organic matter, dissolved oxygen, and fecal coliforms.

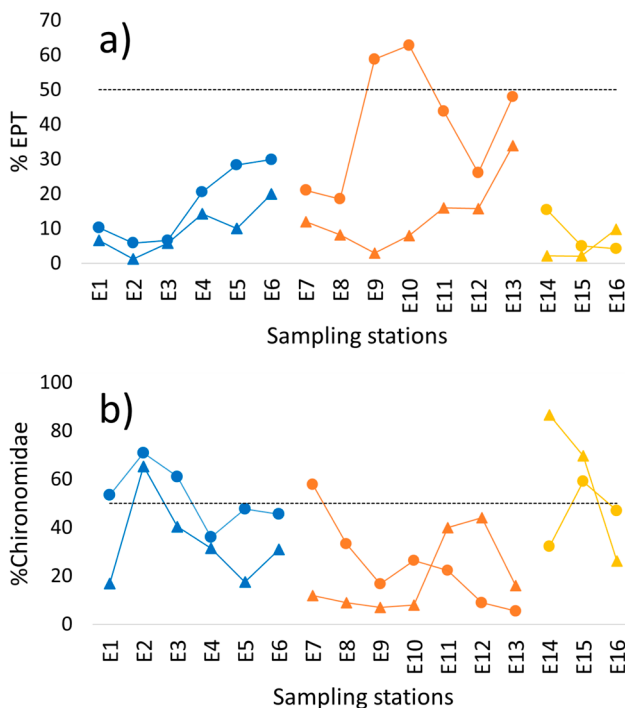


Figure 4. Biotic quality metrics of the lower Quilca-Chili River basin: **a**., EPT percentage; **b**., Chironomidae percentage. (Circle: first sampling campaign; triangle: second sampling campaign. Blue: Vitor River; orange: Sihuas River; yellow: Quilca River).

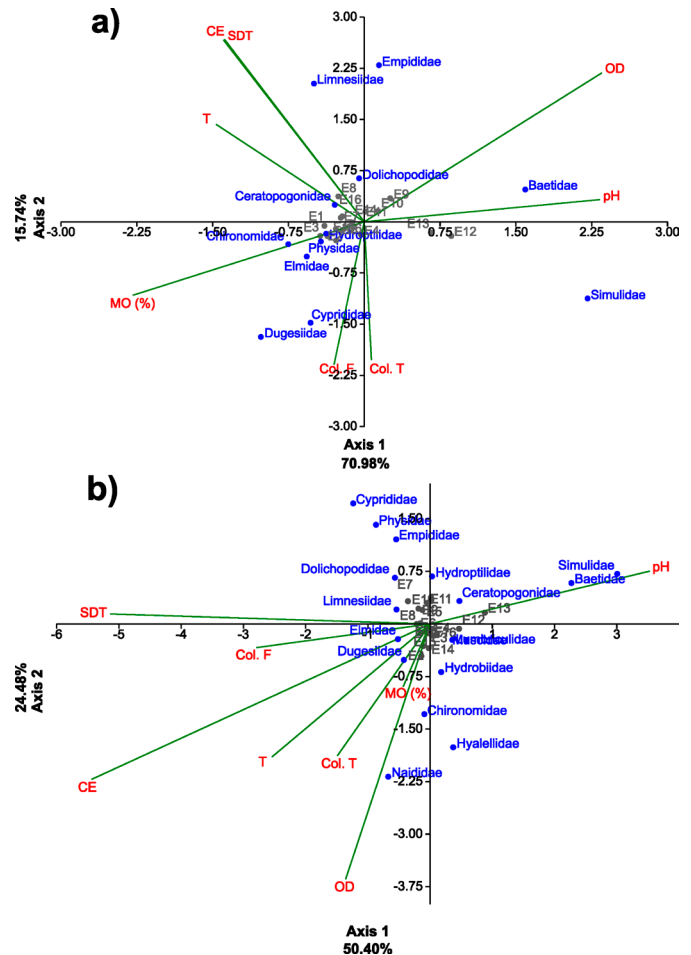


Figure 5. Canonical Correspondence Analysis (CCA) between the families present in the lower Quilca-Chili River basin and the environmental variables considered (vectors) during a) first sampling campaign and b) second campaign. (C: conductivity ($\mu\text{S}/\text{cm}$); DO: dissolved oxygen (mg/l); pH: pH; T: temperature ($^{\circ}\text{C}$); MO: organic matter in sediment (%); Col T: Total coliforms (MPN/100 ml); Col F: Fecal coliforms (MPN/100 ml)).

Modification of tolerance scores for the ABI index in the lower Quilca-Chili River basin

The cluster analysis with a cophenetic correlation coefficient of 0.82, distributed into 24 groups the 45 families of aquatic macroinvertebrates found in the lower Quilca-Chili River basin. The strongest correlations were observed in group 3 (Corixidae and Mesoveliidae), group 8 (Aeshnidae, Hydrophilidae, and Libellulidae), group 9 (Dytiscidae and Ephydriidae), group 10 (Coenagrionidae, Cochliopidae, and Veliidae), group 17 (Chrysomelidae, Limnozeteidae, and Leptohyphidae), and group 20 (Glossosomatidae, Gripopterygidae, and Tipulidae), with more than 50 % similarity (Fig. 6).

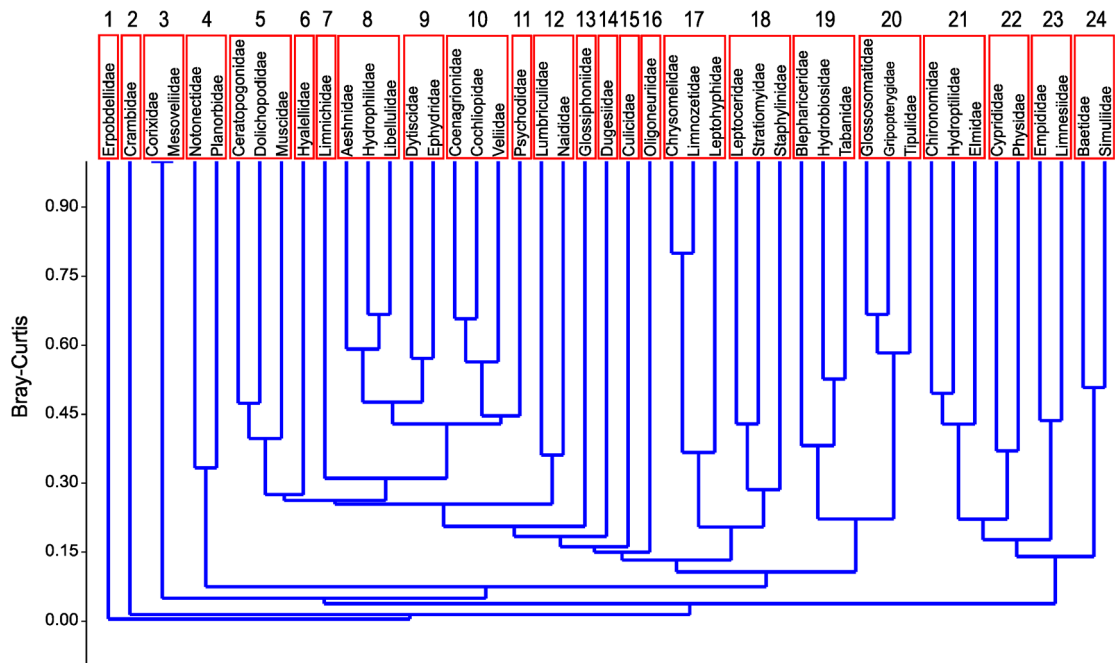


Figure 6. Bray-Curtis similarity dendrogram among macroinvertebrate families in the lower Quilca-Chili River basin. The squares at the top indicate the numbered groups formed.

Considering the obtained groupings, the tolerance scores of the ABI index were modified for 29 families. In many cases, the variation in the score was one or two points; however, in some cases, such as Gripopterygidae, Blephariceridae, and Leptoceridae, the value decreased by three points compared to the original ABI index values, while for Tabanidae, the value increased by three points. New families such as Limnidae, Chrysomelidae, Mesoleptidae, and Crambidae were also recorded in the lower Quilca-Chili River basin (Table 2) but are not included in the original index.

Stations E1, E14, and E15 (Fig. 7a and 7b) showed values between 35 and 59 points in both seasons, indicating moderate water quality. Stations E4 and E16 only exhibited these values in the first and second campaigns, respectively. The remaining stations had values above 59 points, indicating that the biological quality of their waters was good (59-96) or very good (>96), as observed in stations E11, E12, and E13 of the Sihuas River. Regarding the total values obtained after modifying the tolerance scores, no significant differences were observed, as there were no changes in the categories for all stations and both campaigns (Fig. 7a and 7b).

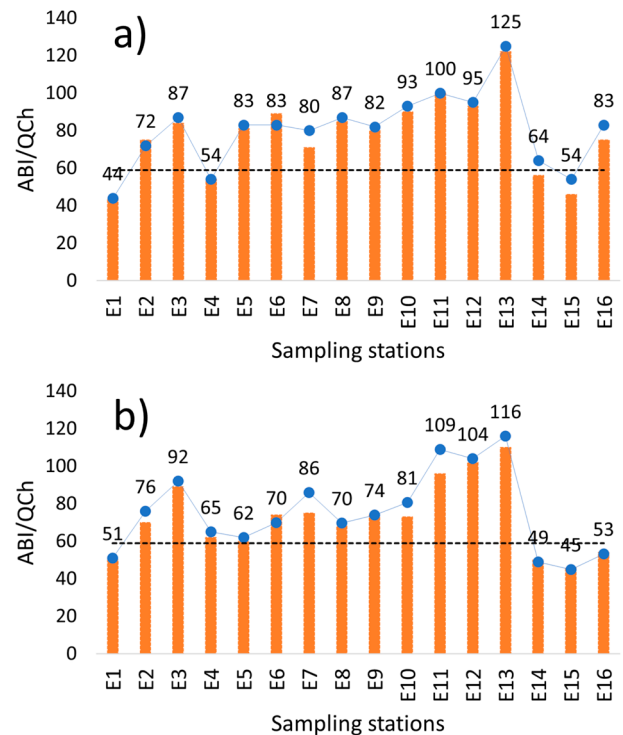


Figure 7. Biotic quality metrics of the lower Quilca-Chili River basin: **a.**, First sampling campaign; **b.**, second sampling campaign. (Orange columns: biotic quality according to the tolerance scores for the IBI; blue dots: biotic quality according to the modified tolerance scores for the IBI)

Table 2. Scores of the Andean Biotic Index (ABI) for aquatic macroinvertebrates of the Tropical Andes and modified scores for the case of the lower Quilca-Chili River basin (ABI Q/Ch). (Blue: modified scores; green: added scores).

ORDER	FAMILIES	ABI Score	ABI Q/Ch Score	ORDER	FAMILIES	ABI Score	ABI Q/Ch Score
Turbellaria	DugesIIDae	5	5	Trichoptera	Leptoceridae	8	5
Hirudinea	Glossiphoniidae	3	3		Hydroptilidae	6	4
	Erpobdellidae	3	3		Hydrobiosidae	8	7
Oligochaeta	Naididae	1	1	Lepidoptera	Glossosomatidae	7	7
	Lumbriculidae	1	1		Crambidae	-	4
Gasteropoda	Physidae	3	3	Coleoptera	Staphylinidae	3	5
	Planorbidae	3	4		Elmidae	5	4
	Cochliopidae	3	5		Dytiscidae	3	3
Amphipoda	Hyaellidae	6	6		Hydrophilidae	3	5
Ostracoda	Cypridae	3	3		Limnichidae	-	6
Hydracarina	Limnesiidae	4	5		Chrysomelidae	-	6
	Limnozetidae	4	5		Blephariceridae	10	7
Ephemeroptera	Baetidae	4	5		Simuliidae	5	5
	Leptohyphidae	7	6		Tabanidae	4	7
	Oligoneuriidae	10	10		Tipulidae	5	7
Odonata	Aeshnidae	6	5	Diptera	Ceratopogonidae	4	3
	Libellulidae	6	5		Psychodidae	3	3
	Coenagrionidae	6	5		Dolichopodidae	4	3
Plecoptera	Gripopterygidae	10	7		Stratiomyidae	4	5
Heteroptera	Veliidae	5	5		Empididae	4	4
	Corixidae	5	5		Chironomidae	2	4
	Notonectidae	5	4		Culicidae	2	2
	Mesoveliidae	-	5		Muscidae	2	3
					Ephydriidae	2	3

DISCUSSION

Physicochemical parameters

During the first campaign, dissolved oxygen levels in stations E4, E5, and E6 of the Vitor River were below the ECA (Estándares de Calidad Ambiental, or Environmental Quality Standards). Similarly, electrical conductivity in stations E7 and E8 of the Sihuas River remained below the standards in both campaigns. This could be attributed to the proximity of these stations to agricultural and

livestock areas, which directly influence these parameters (García-Pérez et al., 2018; Solís-Castro et al., 2018).

During the second campaign, dissolved oxygen levels were higher and met the ECA standards in stations E14, E15, and E16 of the Quilca River, near its mouth at the Pacific Ocean. According to Posada et al. (2013), this increase could be related to the influence of the sea, which causes turbulence, aeration, and even an increase in primary productivity in river waters close to the coast.

Structure of the aquatic macroinvertebrate community and biotic metrics

Stations E14 and E16 showed higher true diversity values compared to other stations in the basin, due to a more equitable distribution between the number of species and their abundances. In contrast, some stations with higher richness exhibited differences in species abundance, with certain dominant species. Despite these variations, many stations maintained equitable distributions, suggesting that these aquatic macroinvertebrate communities are not showing evident impacts and that their habitats retain environmental stability. This aligns with previous studies, which indicate that less disturbed ecosystems with low human intervention tend to exhibit greater macroinvertebrate diversity, making these factors key to biodiversity conservation in arid and semi-arid regions (Castillo-Velásquez & Huamantínco-Araujo, 2020; Hankel et al., 2018; Moya et al., 2009; Sandoval et al., 2021).

Research conducted by Ferru & Fierro (2015) and Coayla et al. (2024) in arid basins of South America, reported 66 and 32 taxa of aquatic macroinvertebrates, respectively. In comparison, the present study which recorded 70 taxa, indicating higher specific richness. However, a similar dominance pattern was observed. In all cases the family Chironomidae constituted the dominant group within the evaluated communities, highlighting its broad environmental tolerance and adaptability to this type of ecosystems.

The low representation of species from the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) in the studied basin coincides with patterns observed in other aquatic ecosystems in Peru with arid and semi-arid conditions (Arana-Maestre et al., 2021b; Coayla-Peñaloza et al., 2023; Coayla-Peñaloza et al., 2024). The arid climate, characteristic of the rivers in southern coastal Peru, results in scarce riparian vegetation, reduced organic matter input, and the formation of essential aquatic microhabitats for the development of these groups. The limited presence of leaves and other detritus decreases the availability of food for species that depend on decomposing plant matter, affecting their survival and reproduction (Allan & Castillo, 2007). Additionally, hydrological variability, influenced by both irrigation systems like the Majes Irrigation Project and natural droughts, disrupts the life cycles of these insects (Vinson & Hawkins, 2003), collectively influencing their distribution and abundance. Studies conducted

in arid zones have recorded a scarce presence of these groups, while their greatest diversity is found in regions with more humid and temperate climates (Palma, 2013), suggesting that their low representation is not necessarily related to water quality but rather to prevailing environmental conditions.

The increase in EPT percentages at upper-basin stations suggests an improvement in water quality, reflecting the presence of sensitive taxa in areas less impacted by human activities. On the other hand, the high proportion of Chironomidae recorded in some stations aligns with previous studies that have associated their dominance with rivers affected by organic pollution and hydromorphological alterations. The decrease in this family in upstream stations suggests better ecological conditions. Seasonal variation in the abundance of *Camelobaetidius* sp. suggests that this species responds dynamically to environmental changes. In our study, we observed a decrease in its abundance from the first to the second campaign, which could be related to factors such as reduced flow, changes in current velocity, and food availability. Hydrological stability is key for substrate colonization by the Baetidae family, and alterations in these conditions can affect their presence in aquatic ecosystems. Overall, these patterns reflect a longitudinal gradient of ecological quality, in concordance with previous studies in high Andean rivers (Acosta et al., 2009; Baptista et al., 2001; Barba et al., 2013; Forero-Céspedes et al., 2013a; Giacometti 2019; Nieto et al., 2020; Peña et al., 2019; Ríos-Touma et al., 2014; Roldán, 2003).

Throughout the basin, the families Chironomidae, Elmidae, and Hydroptilidae are among the most representative. The Hydroptilidae family is considered an indicator of good water quality and shows a relationship with the Elmidae family, which is also associated with well-oxygenated and clean water environments. Meanwhile, members of the Chironomidae family, although highly tolerant to different habitats, tend to group with these families due to their adaptability to various environmental conditions (Sierpe & Sunico, 2019). Although dipterans, in general, show higher abundance due to their adaptability, their presence is not restricted to low-quality water environments, as some species can inhabit well-oxygenated rivers (Gutiérrez Garaviz et al., 2014). Within this family, genera such as *Corynoneura* and *Cricotopus* have been reported in environments with good oxygenation, suggesting a wid-

er ecological range and potential use in future analyses of distribution patterns (Villamarín et al., 2021).

The Baetidae family is closely associated with high levels of pH and dissolved oxygen. This relationship aligns with previous studies that report their preference for fast-flowing habitats with high oxygen levels, positioning them as indicators of good water quality (Baptista et al., 2001; Domínguez & Fernández, 2009; Domínguez et al., 2006; Forero-Céspedes & Reinoso-Flórez, 2013b; Gutiérrez & Reinoso, 2010; Roldán 2003; Zuñiga et al., 2004).

On the other hand, the families Chironomidae, Physidae, Hydroptilidae, and Elmidae show a strong association with high levels of organic matter, which aligns with studies that highlight the affinity of these four families for organic matter and their capacity to tolerate diverse levels of pollution (Damborenea et al., 2020; González-Córdoba et al., 2020; Mosquera-Murillo, 2019; Oviedo-Machado & Reinoso-Flórez, 2018).

This makes them key organisms for water quality biomonitoring (Domínguez & Fernández, 2009; Navarrete-Salgado et al., 2004; Rojas-Céspedes et al., 2023; Tapia et al., 2018). Similarly, Hydroptilidae is characterized by its high adaptability to variations in organic matter availability, allowing it to colonize different aquatic environments (De Moor and Ivanov, 2008; Gómez-Aguirre et al., 2009; Mosquera-Murillo, 2019; Oliveira et al., 2005; Springer, 2010; Vásquez et al., 2008).

Finally, ostracods of the Cyprididae family show a marked positive relationship with total and fecal coliform parameters, which can be explained by their high resistance to physicochemical changes of the water (Chaparro-Herrera et al., 2020) and their bacterial feeding capacity, enabling them to thrive in environments with high organic loads (Góngora-Aguilar, 2021).

Modification of Tolerance Scores for the ABI Index in the Lower Quilca-Chili River Basin

The results in the lower Quilca-Chili River basin suggest the need to adapt the tolerance scores of the Andean Biotic Index (ABI). The values for 29 families of aquatic macroinvertebrates were modified, with variations generally of one or two points. However, in cases such as Gripopterygidae, Blephariceridae, and Leptoceridae, the reduction was more pronounced, indicating greater tolerance to local environmental factors. In contrast, Tabanidae showed an

increase of three points, suggesting greater susceptibility to the conditions of the lower basin. These findings align with studies conducted in high Andean rivers in Ecuador and Peru, which indicate that biotic indices require specific adjustments based on the hydroclimatic characteristics of each region (Peña et al., 2019; Ríos-Touma et al., 2014). Additionally, in basins in Colombia and Bolivia, the variable sensitivity of certain taxa in affected environments has been documented, highlighting the importance of calibrating tolerance scores according to local conditions (Roldán, 2003; Acosta et al., 2009), particularly for this basin, which is part of an arid ecosystem.

The absence of families with high scores (10, 9, 8) in the lower Quilca-Chili River basin could be due to the presence of more stressful ecological and environmental factors compared to less altered high Andean ecosystems. In aquatic systems located at higher altitudes and with less human intervention, highly sensitive organisms such as Blephariceridae and Perlidae are commonly found, with high scores in biotic indices (Ríos-Touma et al., 2014 & Roldán, 2003). However, in rivers located in arid zones, the availability of suitable habitats for these groups is limited due to factors such as lower flow, higher water temperatures, and potential human-induced alterations, which reduce the presence of species less tolerant to pollution (Giacometti, 2019 & Vilca-Carhuapoma, 2022). Furthermore, the inclusion of new families such as Limnichidae, Chrysomelidae, Mesoveliidae, and Crambidae suggests that the macroinvertebrate community in the lower Quilca-Chili basin is dominated by organisms with medium to high tolerance. This trend aligns with studies that associate lower flow velocity, increased sedimentation, and anthropogenic alterations with a reduction in the diversity and abundance of sensitive macroinvertebrates (Helson & Williams, 2013). Thus, the adaptation of the ABI scores in the lower Quilca-Chili basin will allow for a more accurate assessment of water quality and contribute to more appropriate conservation strategies for these aquatic ecosystems.

The families Coenagrionidae, Libellulidae, and Aeshnidae showed a reduction in their scores after adaptation to the ABI index. This result coincides with Ruiz-Picos et al. (2017a, 2017b), who, while calibrating the BMWP index in two rivers in Mexico, also recorded a significant decrease in the scores of this group. These results suggest that odonates have a higher tolerance to pollution than initially

considered. However, the increase in the scores of Tabanidae and Chironomidae indicates greater sensitivity to pollution. In the study by Magallón Ortega et al. (2021), a similar variation was recorded, noting that some Chironomidae species can reflect specific conditions of environmental stress, while Tabanidae larvae tend to inhabit areas with greater ecological stability in tropical ecosystems.

The downstream stations, specifically E1 and E4 in the Vitor River, as well as E14, E15, and E16 in the Quilca River, where the Vitor and Sihuas rivers converge, are the only ones with moderate water quality. This can be attributed to the river water quality as it naturally tends to decrease from higher to lower zones due to the accumulation of materials transported along its course, which can affect local diversity (Rincón-Bello et al., 2021). Additionally, these stations have little emergent vegetation, which influences the reduction in the richness of macroinvertebrate families and affects the final ABI index score (Roldán, 2003; Meneses-Campo et al., 2019).

Research on biotic indices based on macroinvertebrates in Andean fluvial systems is essential for understanding the ecological status of these unique and vulnerable ecosystems. This study contributes to the adaptation of the ABI index for arid ecosystems in southern Peru, making it applicable for assessing ecological quality in water-scarce environments and providing valuable methodological information for biomonitoring programs in arid regions worldwide. Therefore, advancing specific studies in the Andes not only enhances regional environmental management but also contributes to the development of more accurate and representative monitoring tools (Roldán-Pérez, 2016).

AUTHOR CONTRIBUTIONS

PCP conceptualization, investigation, writing original draft preparation, supervision, funding acquisition; ACD conceptualization, investigation, data analysis, curation, specimen identification; FC writing, final manuscript review.

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