Chapter

Benthic Macroinvertebrate Communities as Indicators of the Environmental Health of the Cunas River in the High Andes, Peru

María Custodio, Richard Peñaloza and Heidi De La Cruz

Abstract

The Cunas River is a valuable natural freshwater heritage in the central region of Peru, where diverse economic activities depend on the quantity and quality of its waters. The environmental health of the Cunas River was assessed through indicators of the diversity of benthic macroinvertebrate communities and multivariate statistical methods. Water and sediment samples were collected in sectors of three populated centers during 2017. Indicators of water quality and diversity of benthic macroinvertebrates were determined. The results reveal that most of the water quality indicators are in the range of the water quality standards of rivers in Peru. Twenty-six families of benthic macroinvertebrates were identified. The principal component analysis (PCA) of the water quality indicators through the first two components explained 79.59% of the total variance. Cluster analysis in relation to the relative abundance of benthic macroinvertebrates grouped the sampling sites into groups with similar characteristics. Principal coordinate analysis (PCO) analysis of benthic macroinvertebrate communities showed a clear separation of sites. The percentage similarity (SIMPER) analysis at the family level showed the percentage of contribution of species to the benthic fauna community. The canonical correspondence analysis (CCA) identified water quality variables that influence the distribution of benthic macroinvertebrate communities. Therefore, the information obtained will be useful for the management of similar rivers.

Keywords: benthic macroinvertebrates, diversity, water quality, river, multivariate analysis

1. Introduction

Benthic macroinvertebrates are found in all types of aquatic environments, where they are important indicators of the health of these ecosystems [1]. They inhabit the river bed (among stones, submerged aquatic plants, etc.) either during their entire biological cycle as mollusks or part of it as many insects, in which the adult phase is terrestrial and the larval aquatic phases. Benthic macroinvertebrates have a high variety of morphological and behavioral adaptations in order to take advantage of the different trophic resources offered by a fluvial ecosystem [2, 3].

The composition and structure of benthic macroinvertebrate communities are affected not only by anthropogenic stressors but also by natural factors [4]. In lotic systems, the composition and structure of these communities are controlled by biotic factors (biological interactions: predation, parasitism, competition, etc.) and abiotic factors (water velocity, temperature, discharges, among others) [5, 6]. However, the altitudinal gradient is also considered a determining factor in the distribution of these communities [7]. Although some authors point out that both temperature and oxygen partial pressure are key factors in the distribution of benthic macroinvertebrate communities in river systems [8]. Others report that the integrity of these communities depends on the structural integrity of the current and the processes associated with the physical habitat [9].

Knowledge of benthic fauna in high Andean fluvial ecosystems in the central region of Peru is still scarce considering the large number of continental aquatic ecosystems that exist. The best studied benthic macroinvertebrate communities are located in the high Andean regions of the north of the country compared to the studies carried out in the high Andean regions of central Peru. However, the studies focus on the use of benthic fauna as bioindicators of water quality in monitoring and evaluation programs, since through the analysis of the composition and structure of benthic macroinvertebrate communities, it is possible to determine the degree of disturbance that a body of water has been experiencing.

This study focuses on the Cunas River, one of the most important rivers in the Mantaro River Basin in the Central Andes of Peru. It is 101.1 km long and is located in the provinces of Chupaca, Concepción, Huancayo, and Jauja in the Junín region. In the sub-basin of Cunas River, several economic activities are developed, such as livestock, agriculture (Andean tubers, corn, and vegetables, among others), aquaculture, electricity generation, and the extraction of aggregates (sand and stone). Most of these activities take place without environmental criteria and are exerting strong pressure on the aquatic systems, affecting water quality and the composition of the biological communities. In this sense and considering the high uncertainty about the current health of this aquatic ecosystem, the objective of the study was to evaluate the environmental health of the river Cunas through indicators of water quality and diversity of benthic macroinvertebrates and multivariate statistical methods in precipitation and drought seasons.

2. Materials and methods

2.1 Description of study area

The Cunas River is located in the central highlands of Peru, in the Mantaro River watershed. It has a length of 101.1 km and is born in the Runapa-Huañunán lagoon at 4535 masl, near the watershed of the Cañete river (western chain). It is located in the provinces of Chupaca, Concepción, Huancayo, and Jauja in the Junín region. Its main channel describes the form of the letter S, with the direction of route west-east. The flow of the river varies according to the time of year. During the rainy season, the flow reaches 152.95 m^3/s, and during the dry season, it reaches 2.57 m^3/s [10]. Three sampling sectors were defined in the River Cunas, according to their representativeness of the area in terms of the influence of anthropic activity. Sector 1 was located in the town of San Blas, Concepción province, at 3440 masl (18 L 455952E 8670268S), sector 2 in Huarisca at 3315 masl (18 L 471711E 8667535S), and sector 3 in La Perla at 3229 masl (18 L 470205E 8667164S), the latter two in Chupaca

Province (**Figure 1**). In the Cunas River basin, various economic activities are developed, such as agriculture, livestock, aquaculture, tourism, and nonmetallic mining. These activities are exerting strong pressure on the aquatic environment, as there are few efforts to protect this resource.

2.2 Sample collection and analysis

Water sampling was carried out in three sectors of the San Blas, Huarisca, and La Perla population centers during 2017. In each sector, ten sampling sites were defined, and in each one of them, pH, conductivity, turbidity, dissolved oxygen (DO), temperature, and dissolved total solids (DTS) were determined in situ using the multiparameter probes Hanna Instruments (HI 991301 Microprocessor pH/temperature, HI 9835 Microprocessor Conductivity/DTS, and HI 9146 Microprocessor dissolved oxygen). Previously, the equipment was calibrated in the respective sampling site. Also, 1 L of water from a depth of 20 cm from the river surface, in the opposite direction to the current flow, was collected from each sampling site for bacteriological analysis of nitrates, phosphates, and BOD_5, in containers previously sterilized and treated with a 1:1 solution of hydrochloric acid and rinsed with distilled water. These parameters were measured according to standard methods [11].

The samples were collected using a Surber net with a square frame of 30×30 cm side (0.09 m^2 area) and a 250-μm mesh aperture. Sampling was performed by placing the mesh against the current and removing the substrate upstream of the sleeve [12]. The samples were preserved in 70% alcohol and transferred to the laboratory for identification. Taxonomic identification of benthic

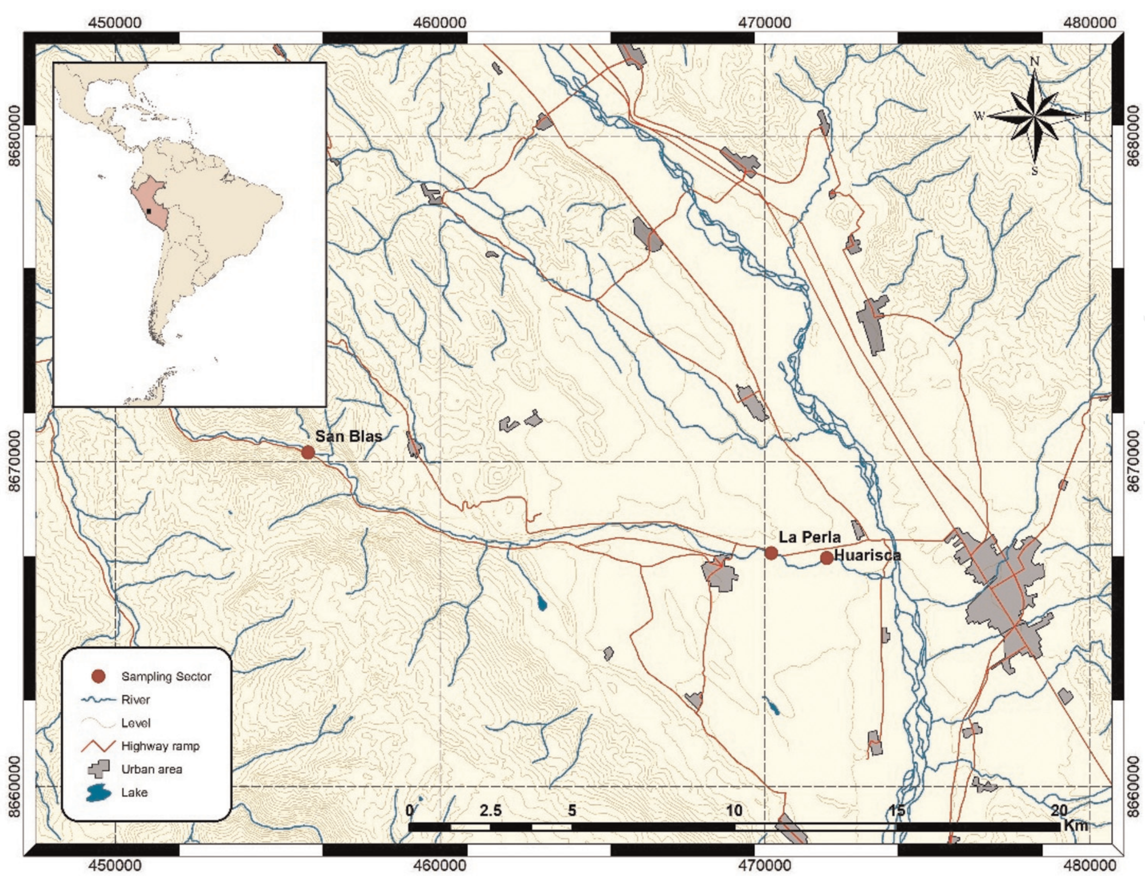

Figure 1.
Map of the location of the sampling sectors in the river Cunas.

macroinvertebrates was performed at the family level through a trinocular stereomicroscope [13].

2.3 Statistical analysis

The analysis of water quality variables was determined by normalized principal component analysis (PCA) in order to generate two-dimensional management maps [14] and search for best-fit lines according to the calculated PCs, successively maximizing the variance of the projected sampling points along each axis. Statistical significance was performed by analyzing the multivariate variance using PERMANOVA permutations [15].

In the analysis of benthic macroinvertebrate communities, a hierarchical and agglomerative classification (cluster analysis) was performed, generating a similarity matrix with Bray-Curtis indices based on an abundance matrix of species transformed by square root in order to produce a dendrogram [16], while a principal coordinate analysis (PCO) was performed to produce a management graph [15]. It was characterized by species richness (S), individual density (N), Shannon diversity index (H′), and Simpson index (1-λ). The main indicator species and the associated percentage indication were determined for each significant set of species, using the percentage similarity (SIMPER) analysis [17]. Canonical correspondence analysis (CCA) was used to evaluate the relationship between water quality variables and macroinvertebrate composition.

3. Results

3.1 Water quality based on physical, chemical, and bacteriological indicators

The pH of the water presented means and standard deviation that oscillated from 6.99 ± 0.03 in the sector of the Huarisca populated center in the rainy season to 7.59 ± 0.04 in San Blas in the dry season. The highest electrical conductivity (EC) was recorded in the San Blas sector with an average of 567.70 μS/cm. The biochemical oxygen demand (BOD) registered in the La Perla sector surpassed the water quality standards of Peru, destined for human consumption and conservation of the aquatic environment (5 and 10 mg/L, respectively). The water bodies of this same sector presented the lowest concentrations of dissolved oxygen, at both times, as well as the highest temperature. The highest average of dissolved total solids was recorded in the La Perla sector with 377.40 mg/L. The average of phosphates as opposed to nitrates exceeded the water quality standards of the Peruvian Ministry of the Environment for the two types of use considered in this study in the Huarisca and La Perla sectors (**Table 1**).

Figure 2 shows the result of PCA of the water quality indicators and the sampling sectors, according to towns. The first two components explain 79.59% of the total variance. The first principal component explained 50.76% of the variance and correlated significantly with BOD, DTS, phosphates, nitrates, and thermotolerant coliforms. The second component explained 19.83% of the variance and correlated with pH and EC. Also, the distributions of the groups in the perceptual map show a clear differentiation of the sampling sectors with respect to the main variables. The sectors evaluated in the dry season present higher values of the variables with greater weight in the first two components than their peers in the rainy season, such as the La Perla sector that shows high values, mainly in the PC1 variables. The anthropogenic pressure experienced by the water bodies in the sampling sectors of the middle and lower part of the river Cunas would determine the increase of these variables. In addition, the PERMANOVA results at a significance level of 0.01 show that the observations differ significantly, according to the sampling sector and climatic season factors. That is to say, there is enough statistical evidence to affirm that the sectors have different ranges in relation to the water quality indicators.

Indicator climate season	San Blas		Huarisca		La Perla	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
pH	7.59 ± 0.04	7.06 ± 0.03	7.21 ± 0.06	6.99 ± 0.03	7.41 ± 0.05	7.12 ± 0.03
EC (μS/cm)	567.7 ± 42.23	462.6 ± 62.72	526.0 ± 36.23	482.8 ± 76.24	534.2 ± 20.48	465.7 ± 49.47
BOD_5 (mg/L)	5.47 ± 0.50	4.75 ± 0.87	9.24 ± 0.85	7.78 ± 0.73	11.92 ± 1.04	10.09 ± 1.26
Turbidity (NTU)	2.03 ± 0.40	4.85 ± 1.17	3.69 ± 1.18	14.96 ± 1.74	6.10 ± 0.75	24.21 ± 2.42
DO (mg/L)	6.95 ± 1.13	6.60 ± 0.78	7.13 ± 1.03	6.56 ± 0.84	5.94 ± 0.91	4.19 ± 0.53
Temperature (°C)	16.62 ± 0.46	15.11 ± 1.24	18.58 ± 0.92	14.62 ± 1.12	19.61 ± 0.94	15.88 ± 0.82
DTS (mg/L)	166.2 ± 4.66	120.7 ± 8.85	299.9 ± 6.42	284.1 ± 7.20	377.4 ± 8.21	352.7 ± 11.99
Phosphates (mg/L)	0.01 ± 0.00	0.021 ± 0.01	0.117 ± 0.02	0.072 ± 0.02	0.242 ± 0.01	0.118 ± 0.02
Nitrates (mg/L)	0.03 ± 0.01	0.02 ± 0.01	0.05 ± 0.01	0.04 ± 0.01	0.23 ± 0.03	0.06 ± 0.01

Table 1.
Mean and standard deviation of water quality indicators of the river Cunas, according to population center and climate season.

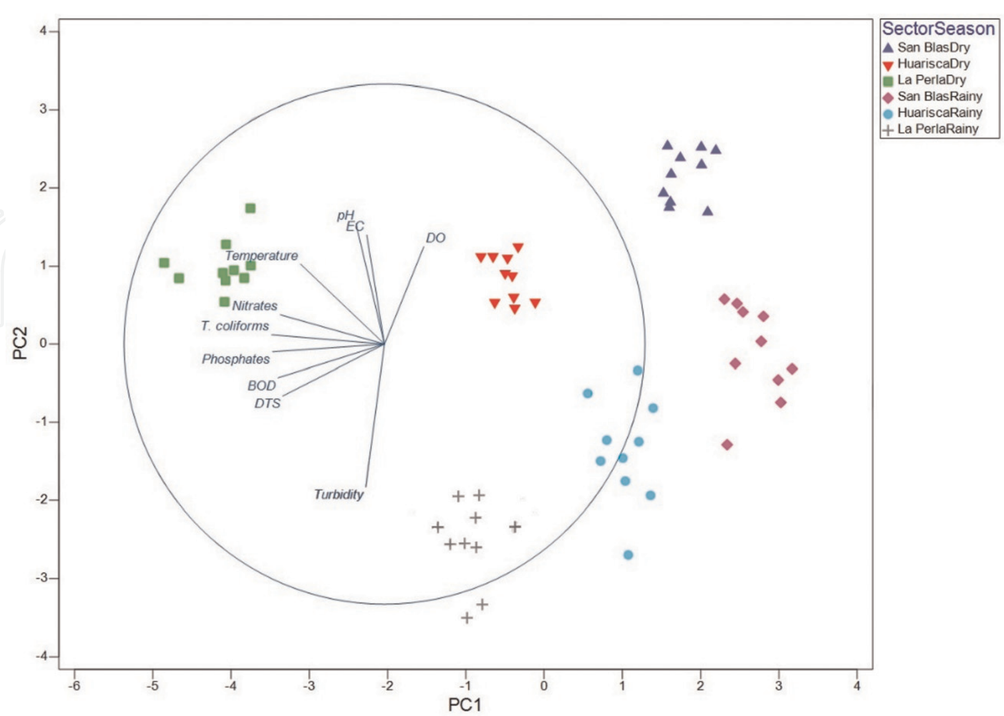

Figure 2.
Perceptual map of principal component analysis (PCA) based on the water quality indicators of the river Cunas.

3.2 Spatial and temporal variation of benthic macroinvertebrate communities

A total of 26 families of benthic macroinvertebrates were found during the two sampling seasons in San Blas, Huarisca, and La Perla sectors. The Diptera order was the most representative in abundance and richness. PCO of the composition of the benthic macroinvertebrate communities showed a clear separation of sites, mainly due to the effect of the season factor (**Figure 3**). The first management axis shows the significant separation of sectors in relation to families and number of individuals. It also shows that the groups are clearly delimited, which explains the percentage of total variation of the first two coordinates (57.02%), separating the sectors into two main groups characterized by the climatic season factor. The analysis shows that there is a high similarity in the community of benthic macroinvertebrates of the La Perla sector in the dry season for axis 1 with values ranging from 20.033 to 29.99 according to the similarity range of Bray-Curtis, making this assemblage of samples grouped by family's similarity significantly different from the others. However, this does not demerit that the other groups keep specific characteristics that make each sector keep particular characteristics that need to be studied individually. The results also reveal that the Huarisca sector in the rainy season is the most depressed in values of the number of families and individuals. The cluster analysis of benthic macroinvertebrate communities at the family level by Bray-Curtis distance range shows similar and significant associations. This is supported by the analysis of main coordinates (**Figure 3**), in which two differentiated groups are found, one with 40% similarity, explained by the climatic season factor, and the other with 60% similarity of the groups, as observed in the sector of San Blas for the rainy and low seasons, which indicates uniformity in the distribution of species (**Figure 4**).

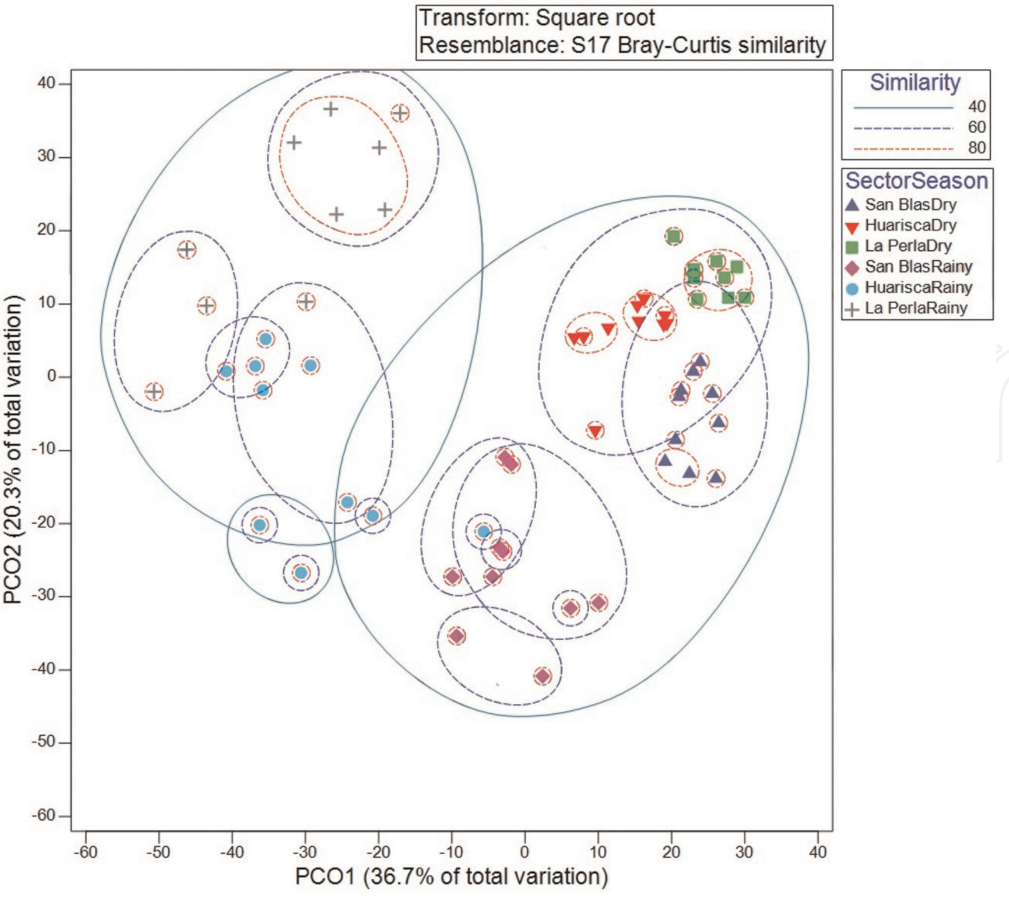

Figure 3.
Principal coordinates analysis (PCO) based on the number of families and abundances of benthic macroinvertebrates of the three sampling sectors, according to sampling season.

The nonmetric multidimensional scaling analysis shows an average stress level value of 0.16, which according to the range given by Kruskal indicates an acceptable interpretation in the perceptual map. In addition, the high values in nitrates, phosphates, temperature, and thermotolerant coliforms would be conditioning the presence of a greater number of individuals, as can be observed in the La Perla sector during the dry season (**Figure 5**).

The results of the composition of the benthic macroinvertebrate community in the sampling sectors obtained by SIMPER analysis at family level showed that the

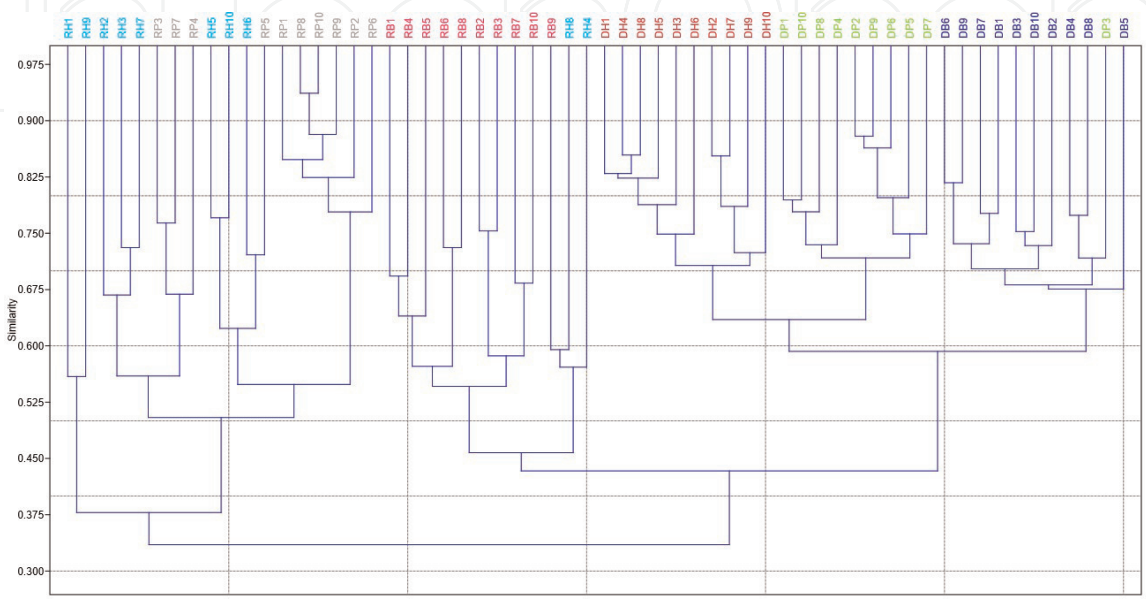

Figure 4.
Dendrogram based on the distances of Bray-Curtis from the benthic macroinvertebrate community of the Cunas River, according to sector and sampling season.

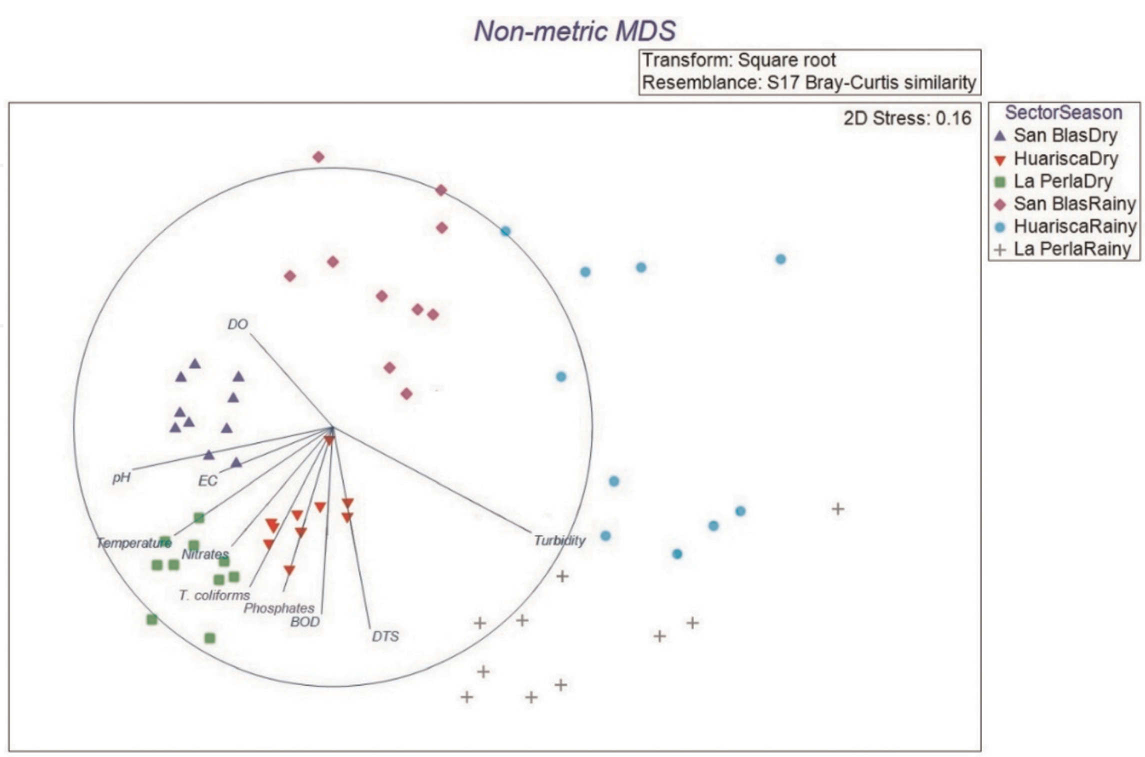

Figure 5.
Analysis of nonmetric multidimensional scaling based on the richness and abundance of benthic macroinvertebrates of the three sampling sectors, according to sampling season.

Sampling sector	Taxa	Contribution%		Diversity indicators			
		Dry	Rainy	S	N	H′	1-λ
San Blas	Baetidae	28.60	40.50	26	2741	1.83	0.26
	Chironomidae	24.81	29.08				
	Simuliidae	10.73	11.45				
	Elmidae	9.81					
Huarisca	Chironomidae	44.46	73.11	22	2218	1.31	0.48
	Simuliidae	16.45					
	Baetidae	12.60					
La Perla	Chironomidae	52.29	98.42	14	5394	0.77	0.74
	Baetidae	21.60					

S, number of families; N, number of individuals; H′, Shannon-Wiener index; 1-λ, Simpson index.

Table 2.
Percentage of the contribution of benthic macroinvertebrate families obtained through SIMPER analysis and mean of diversity indicators.

highest percentages of contribution in the San Blas sector were made by individuals from Baetidae (40.50%), followed by Chironomidae (29.08%) and Elmidae (11.45%), contributing 81.02% of the total taxa in the rainy season. With respect to diversity indicators, the San Blas sector presented the highest richness and diversity. The results also show that the most dominant family in the Huarisca and La Perla sectors was Chironomidae, with high contribution percentages in both sampling periods (**Table 2**). However, during the rainy season, the Chironomidae reached the highest percentage of contribution in the composition of the benthic macroinvertebrate communities of the Huarisca and La Perla sectors, with 73.11 and 98.42% of the total taxa.

3.3 Relationship of water quality and variation patterns of benthic macroinvertebrate communities

The CCA of the water quality and diversity variables of benthic macroinvertebrates shows the new canonical axes extracted and their relationship with the significant water quality variables. In the San Blas sector for both climatic seasons, the largest number of species fits the first axis and has a greater affinity for high EC, DO, and pH values, while the Huarisca and La Perla sectors for the rainy season tend to have less diversity (**Figure 6**).

The results of the matrix similarity test of the water quality variables and benthic macroinvertebrates showed a Spearman correlation coefficient of 66.4%. The best analysis of BIOENV, taking into account the 10 variables under study, shows that turbidity is the variable that has the highest correlation value with the distribution of biological data, with a 60% value in the Spearman range.

The result of the distance-based redundancy analysis (dbRDA) of the variables of water quality and relative abundance of benthic macroinvertebrates is presented in **Figure 7**. The first axis of the redundancy analysis explains 33.0% of the total variance and the second axis 15.7%. The first axis of the dbRDA coordinate shows a higher load for turbidity and pH. It also shows that the values of nitrates, thermotolerant coliforms, and pH are higher in the La Perla and San Blas sectors in the dry season.

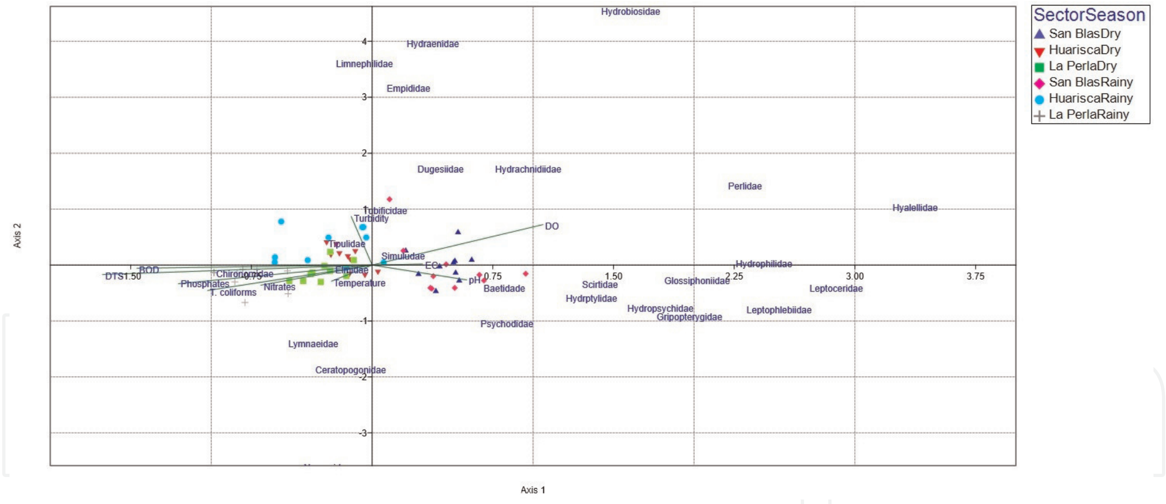

Figure 6.
Analysis of the canonical correspondence of the variables of water quality and diversity of benthic macroinvertebrates of the river Cunas.

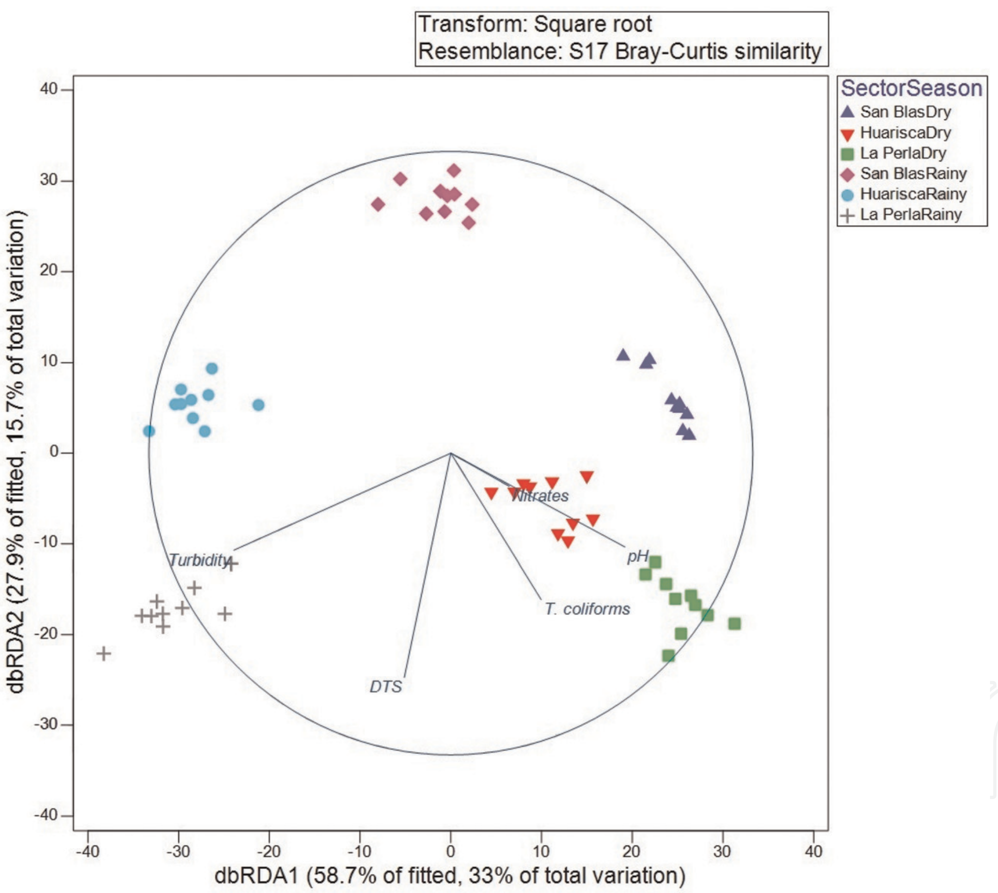

Figure 7.
Perceptual map of the distance-based redundancy analysis (dbRDA) of better physicochemical predictors on the composition of benthic macroinvertebrate communities in the river Cunas.

4. Discussion

4.1 Water quality based on physical, chemical, and bacteriological indicators

The results obtained from the evaluation of water quality in the sampling sectors of the river Cunas reveal a progressive deterioration downstream from the headwaters of the basin. This behavior is due to the increase of anthropogenic activities due to the accelerated population growth and migration to urban areas in the region. The higher values of conductivity, BOD recorded in the La Perla sector, are due to the high loads of organic matter in untreated wastewater from different sources [18]. In this sector, BOD values exceeded ~~by far~~ the quality standards of water destined for the conservation of aquatic life, the production of drinking water, and other uses of Peruvian norms [19], as well as the ranks established by the World Health Organization [20] and the Canadian Council of Ministers of the Environment [21].

The results obtained through the PCA reveal that the Cunas River has been experiencing a process of worsening water quality. This is due to the strong anthropogenic activities such as aquaculture in the middle part of the river (San Blas), nonmetallic mining throughout the river course (extraction of aggregates), and discharge of wastewater from nearby urban settlements. The La Perla sector has a poor water quality with respect to BOD and DO. The low concentration of BOD is due to the consumption of this gas in the biodegradation processes, as shown by the high concentrations of BOD registered in this sector. These results are supported by Ayandiran et al. [22], who state that the low oxygen concentration is related to the strong activity of microorganisms that require large amounts of oxygen to metabolize and degrade organic matter. However, another determining factor of oxygen dissolution is temperature, since it determines the tendency of its physical properties, as well as the wealth and distribution of biological communities [23].

Nutrients such as phosphorus in aquatic environments limit the growth of algae and plants, so their determination allows detection of eutrophication problems [24]. The average total phosphorus values obtained in the Huarisca and La Perla sectors exceed the environmental quality standards for the conservation of the aquatic environment (0.035 mg/L). This increase would be related to wastewater discharges, the contribution of detergents, and the drainage of fertilized agricultural soils [25], since the marginal strip of a large part of the river is cultivated areas. In the case of the La Perla sector, the results obtained allow us to classify this body of water in a hypertrophic state with a great algal bloom. In addition, these high concentrations of phosphorus reveal the pollution events through which this sector of the river crosses due to the strong pressure exerted by anthropogenic activities, among them, livestock activities, since cattle feces are a potential source of phosphorus. The mean nitrate concentration values did not exceed the environmental quality standards. In addition, the interaction between phosphorus and iron, at low DO concentrations, results in the release of phosphorus attached to the water column, increasing its concentrations [26].

4.2 Spatial and temporal distribution of benthic macroinvertebrate communities

The most abundant benthic macroinvertebrates corresponded to individuals of the class Insecta, order Diptera. The results also reveal significant differences between the macroinvertebrate communities of the evaluated sectors, being the Chironomidae family the most representative with a wide range of distribution [27], in the three altitudinal floors where the sampling sectors were established. As for the contribution of benthic macroinvertebrate families to community composition, the Chironomidae family was consolidated as one of the most important families in the three sampling sectors. The results also reveal that benthic macroinvertebrate communities are dominated by Chironomidae, Simuliidae, and Baetidae families. The abundance of these families confirms the average level of oxygenation of the water masses in the sectors of the river Cunas studied. However, the abundance of the Baetidae family in the San Blas sector indicates that the water masses are oligotrophic, as these organisms usually live at this type of trophic level.

However, the decline of the Baetidae occurs downstream due to low oxygenation levels. These results coincide with those recorded in other studies in aquatic environments with low oxygen levels, where the dominance is of the family Chironomidae [28]. In addition, the dominance of this family in aquatic environments is related to the decrease in water quality, food quality, and interference with breathing mechanisms [29].

This study demonstrates the significant correlation between water quality and benthic macroinvertebrate diversity indicators. These results coincide with those of Verdonschot et al. [30] and Mykrä et al. [31], who report that in temperate climate zones, seasonality plays a vital role in the structure of macroinvertebrate communities. However, the results obtained through the analysis with multivariate methods reveal that the high values in nitrates, phosphates, temperature, and thermotolerant coliforms would be conditioning the presence of a greater number of individuals of the family Chironomidae, resilient to organic pollution, especially in the Huarisca and La Perla sectors. Meanwhile, in San Blas the benthic macroinvertebrate communities have a greater affinity for high EC, OD, and pH values. However, the results of BIOENV's best analysis show that turbidity is the variable that has the highest correlation value with the distribution of benthic macroinvertebrates.

5. Conclusion

The river Cunas constitutes an essential source of water for the diverse uses to the populations that settle in its basin. The quality of the water in the sampling sectors of the river reveals a progressive deterioration as anthropogenic activities increase as a result of the accelerated population growth and migration to urban areas in the region. The regular water quality in the Huarisca and La Perla sectors is due to the high loads of organic matter in the wastewater discharged into the river, the contribution of nutrients from detergents, and the drainage of fertilized agricultural soils. This condition of the river in these sectors would influence the composition of benthic macroinvertebrate communities. The presence of a higher number of individuals of the Chironomidae family, resilient to organic contamination, especially in the Huarisca and La Perla sectors, reveals the disturbance that the river has been experiencing.

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Conflict of interest

The authors declare that they have no conflict of interest.

Authors' contributions

María Custodio developed the concept and design of the field study and performed the analysis of benthic macroinvertebrate communities, determination of thermotolerant coliforms, and writing of the manuscript. Heidi De la Cruz carried out the determination of the physical-chemical parameters in situ and in the laboratory. Richard Peñaloza carried out the water and sediment sampling, elaborated the location map of the study, and carried out the statistical analysis. All authors approved the final version prior to submission.

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