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Bioindicators of water quality with different riparian cover in the Guapara micro watershed, Ecuador

Bioindicadores de calidad hídrica con diferente cobertura ribereña en la microcuenca Guapara, Ecuador

Bioindicadores da qualidade da água em riachos com diferentes coberturas ripícolas na microbacia hidrográfica de Guapara, Equador

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Rev. Fac. Agron. (LUZ). 2022, 39(4): e223952
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v39.n4.07

Received: 09-08-2022
Accepted: 27-09-2022
Published: 24-11-2022

Environment
Associate editor: Dr. Jorge Vilchez-Perozo
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

Keywords:
Aquatic macroinvertebrates
Land use
Biological indices

Abstract

Agricultural activities produce changes in the margins of the stream banks, causing disturbances in water quality, and in the assemblage of aquatic insect communities. The objective of this research is to evaluate the changes in the structure and composition of the aquatic macroinvertebrate community, and physicochemical variables in relation to the land use of the Guapara river, Cotopaxi province, Ecuador. Samplings were conducted during the rainy season (December to February 2018-2019) in three streams with different riparian cover: agricultural, native forest, and forest plantations, where samples of aquatic insects and physicochemical parameters were collected in *situ*. A total of 461 aquatic insects corresponding to 7 orders and 25 families were collected. In general, the highest abundance in order and family was presented by Ephemeroptera with 34 %, and Leptophlebiidae with 21 % respectively. According to the Ephemeroptera, Plecoptera Trichoptera (EPT) index, the highest ecological condition was found in streams with native forest cover, and forest plantations respectively, and decreased in the stream with agricultural cover; while BMWP-Cr indicated water contamination in the three streams. Hydrobiosidae (Trichoptera) were associated with high turbidity values; while Gerridae (Hemiptera) were associated with high dissolved oxygen concentrations; in addition, Ptilodactylidae (Coleoptera) preferred the Q1-CA, and Q3-CF conditions, while Leptophlebiidae (Ephemeroptera) were associated with the stream of native forest. A negative influence of agricultural activity on the physicochemical parameters of the water and on the structure of the aquatic insect community assemblage was evidenced.

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Resumen

Las actividades agrícolas producen cambios en los márgenes de las riberas de las quebradas ocasionando perturbaciones en la calidad hídrica y en el ensamble de las comunidades de insectos acuáticos. El objetivo de la investigación es evaluar los cambios en la estructura y composición de la comunidad de macroinvertebrados acuáticos y variables fisicoquímicas en relación con los usos de suelo del río Guapara, provincia Cotopaxi, Ecuador. Se realizaron muestreos en la temporada lluviosa (diciembre a febrero, 2018-2019) en tres quebradas con diferente cobertura riparia: agrícola, bosque nativo y plantaciones forestales, en las que se recolectaron muestras de insectos acuáticos y parámetros fisicoquímicos in *situ*. Se recolectaron 461 insectos acuáticos correspondientes a 7 órdenes y 25 familias. En general la mayor abundancia en orden y familia lo presentaron Ephemeroptera con 34 % y Leptophlebiidae con 21 % respectivamente. Según el índice Ephemeroptera, Plecoptera Trichoptera (EPT) la mayor condición ecológica la presentaron las quebradas con cobertura de bosque nativo y plantaciones forestales respectivamente y disminuyó en la quebrada con cobertura agrícola; mientras, BMWP-Cr indicó contaminación del agua en las tres quebradas. Hydrobiosidae (Trichoptera) se asoció con valores altos de turbidez; mientras, Gerridae (Hemiptera) con concentraciones altas de oxígeno disuelto; además, Ptilodactylidae (Coleoptera) se prefirió las condiciones de Q1-CA y Q3-CF, mientras Leptophlebiidae (Ephemeroptera) con la quebrada de bosque nativo. Se evidencio una influencia negativa de la actividad agrícola en los parámetros fisicoquímicos del agua y en la estructura del ensamble de comunidades de insectos acuáticos.

Palabras clave: macroinvertebrados acuáticos**,** usos de suelo, índices biológicos.

Resumo

As actividades agrícolas produzem alterações nas margens dos bancos de riachos causando perturbações na qualidade da água e no conjunto das comunidades de insectos aquáticos. O objectivo da investigação é avaliar mudanças na estrutura e composição da comunidade de macroinvertebrados aquáticos e variáveis físico-químicas em relação ao uso do solo no rio Guapara, província de Cotopaxi, Equador. A amostragem foi realizada durante a estação chuvosa (Dezembro a Fevereiro de 2018-2019) em três riachos com diferentes coberturas ripícolas: agricultura, floresta nativa e plantações florestais, onde foram recolhidas in situ amostras de insectos aquáticos e parâmetros físico-químicos. Foram recolhidos um total de 461 insectos aquáticos correspondentes a 7 encomendas e 25 famílias. Em geral, a maior abundância em ordem e família foi encontrada em Efeméroptera com 34 % e Leptophlebiidae com 21 % respectivamente. De acordo com o índice Ephemeroptera, Plecoptera Trichoptera (EPT), a condição ecológica mais elevada foi encontrada nos riachos com cobertura florestal nativa e plantações florestais respectivamente e diminuiu no riacho com cobertura agrícola; enquanto que a BMWP-Cr indicou a poluição da água nos três riachos. Hydrobiosidae (Trichoptera) foram associados a altos valores de turbidez; enquanto Gerridae (Hemiptera) com altas concentrações de oxigénio dissolvido; além disso, Ptilodactylidae (Coleoptera) preferiu as condições Q1-CA e Q3-CF, enquanto Leptophlebiidae (Ephemeroptera) com o riacho da floresta nativa. Uma influência negativa da actividade agrícola sobre os parâmetros físico-químicos da água e sobre a estrutura do conjunto da comunidade de insectos aquáticos foi evidente.

Palavras-chave: macroinvertebrados aquáticos, uso da terra, índices biológicos.

Introduction

The increase in human activities represented by land use and cover affects the quality of multiple hydrographic networks around the world (Damanik-Ambarita *et al*., 2016). Agricultural activity is one of the main productive activities. It is estimated that agriculture constitutes 70 % and 90 % of the annual labor demand (Gozlan *et al*., 2019), and in South America, approximately 50 % of the population is dedicated to this activity (Pimentel and Burgess, 2013); consequently, poor agricultural practices generate contamination in surface water resources due to poor agrochemical management (Stehle and Schulz, 2015), deteriorating the quality of fish, and aquatic invertebrate communities (Malaj *et al*., 2014).

Ecuador is a country with high agricultural production, and poor agricultural practices. Multiple relatively current studies have documented the influence of human activities on surface water bodies in Ecuador (Capparelli *et al*., 2021; Deknock *et al*., 2019). Currently, in the province of Cotopaxi, the ecological quality of surface water resources has decreased considerably due to untreated industrial, agricultural, and petroleum wastewater discharges, being poor agricultural practices one of the main sources of contamination (Zapata *et al*., 2021).

To evaluate the impacts of anthropogenic activities on aquatic ecosystems, biological indicators are used to provide information on the ecological status of water bodies. In this sense, aquatic macroinvertebrate assemblages are excellent indicators of water quality because biota responds to stress factors from multiple spatial or temporal scales (He *et al*., 2020). In addition, using aquatic organisms in ecological studies has proven to be more effective than using environmental variables (Bonada *et al*., 2006). Numerous studies indicate that changes in land use and riparian vegetation in streams produce effects on the assemblages of aquatic insects, on their taxonomic composition, and consequently a decrease in diversity in relation to pasture covers for agricultural activities, and forest plantations (Guerrero *et al*., 2017).

The objective of the research is to evaluate the use of bioindicators of water quality with different riparian cover in the Guapara micro watershed, in Ecuador. The information from the study will serve as an ecological basis for future water quality studies with aquatic macroinvertebrates as biological indicators, in addition, it will provide information on the responses of the aquatic macroinvertebrate assemblage to change in land use, useful for the formulation of conservation, restoration, and management strategies for streams, and water bodies.

Materials and methods

Location and sampling points

The research was carried out in three streams of the Guapara River, province of Cotopaxi, Ecuador, with different vegetation covers, based on the following criteria: agricultural cover (Q1-CA); native forest cover (Q2-CN); forest plantation cover (Q3-CF). The altitudinal range of the sampling stations varied between 182.5 and 213.6 m.a.m.s.l., belonging to the tropical premontane forest zone

(Bh-PM), with temperatures ranging between 20 and 28 ºC, according to Holdridge Life Zones classification system (1978).

Sampling Station 1 (Q1-CA) (X = 693318 E and Y = 9876708 S, 213.6 m.a.m.s.l.) has agricultural plantation cover, mainly cocoa (*Theobroma* cacao L.) and banana (*Musa paradisiaca* L.) crops. Sampling Station 2 (Q2-CN) (X = 692374 E and Y = 9877600 S, 182.5 m.a.m.s.l.) corresponds to a zone with forest plantations; crops of teak (*Tectona grandis* L.f.), balsa tree (*Ochroma pyramidale* (Cav. ex Lam. Urb.) and pachaco (*Schizolobium parahyba* (Vell.) S.F. Blake) predominate here, with trees about 10 m high belonging to the timber company PLANTABAL S.A.

Sampling Station 3 (Q3-CF) (X = 693088 E and Y = 9876920 S, 207 mamsl) is a zone of native plantations with species such as laurel (*Laurus nobilis* L.), Spanish cedar (*Cedrela odorata* L.), and guarumo (*Cecropia peltata* L.).

Physicochemical and hydrological variables

The following basic physicochemical water parameters were measured *in situ*: pH, oxidation-reduction potential (POR), electrical conductivity (C.E., $\mu S.cm^{-1}$), total dissolved solids (STD, $mg.L^{-1}$), dissolved oxygen (OD, %), and turbidity (NTU) with a Hanna HI-98194 multiparameter meter. The height and depth of the water column were determined with a flexometer, and a rod graduated in units of length (cm). The flow rate (Q, $m^3.s^{-1}$) was delimited through the floating object method as described by Urdanigo *et al*., (2019b).

Collection and analysis of aquatic macroinvertebrates

The collection of aquatic macroinvertebrates was conducted in a hydrological period (rainy season) from December to February 2018-2019. Four samplings were conducted with an interval of 45 days between each sampling. The aquatic macroinvertebrates were collected using a 405 cm^2 D-net with 500 µm mesh located in the opposite direction of the water flow and were labeled and stored in containers with 70 % alcohol (Roldán, 2003). The taxonomic location of the species was done up to the family level, using a stereoscope and specialized taxonomic keys (Domínguez and Fernández, 2009), the backup specimens were analyzed and deposited in the Microbiology and Entomology laboratory of the Technical University of Quevedo, Quevedo, Ecuador.

Biological indices

The Shannon-Weaver index and Simpson's index of proportional abundance of ecological diversity were used to estimate diversity; in addition, the Ephemeroptera, Plecoptera, Trichoptera index (EPT), and the Biological Monitoring Working Party index (BMWP/Costa Rica) (MINAE, 2007) were used to determine water quality at each sampling station.

Statistical analysis

The statistical differences between the streams studied in relation to the physicochemical variables, and abundance of orders, were analyzed with a one-way ANOVA, after validating the assumptions of normality (Kolmogórov-Smirnov) and homoscedasticity (Levene's test) and Tukey's test to determine comparisons. The Shannon-Weaver, Simpson, EPT, and BMWP Costa Rica diversity indices were analyzed with the Kruskal–Wallis one-way analysis of variance, and Dunn's post-hoc test. All inferential tests were performed with a statistical significance level of $p = 0.05$.

The environmental variables and the abundance of aquatic macroinvertebrate families were correlated with a Redundancy Analysis (RDA), for this, rare species < 10% of the total frequency were eliminated (Hill and Gauch, 1980), then the Hellinger transformation was applied to the values of the families. In addition, collinear water quality variables based on the inflation variance factor (VIF) ≥ 10 were removed. Finally, RDA was applied with a step-forward selection (Blanchet *et al*., 2008). All multivariate analyses were performed using the "Vegan" package (Oksanen *et al*., 2015) of the R software platform (R Core Team, 2015).

Results and discussion

Physicochemical and hydrological variables

The physicochemical and hydrological variables measured at the three sampling stations showed significant differences in relation to water depth, height, and flow ($p < 0.05$). The greatest height and average flow were found in stream 1 (18.0 ± 1 m) and (31.88 ± 0.78 $m^3.s^{-1}$) respectively; while the greatest average depth was recorded in stream 2 (0.613 ± 0.10 m), the differences in depth and width directly influence the flow, as they are variables used to calculate the cross-sectional area of each sampled section (Urdanigo *et al*., 2019a). The rest of the variables did not show significant differences between the streams studied (table 1).

Table 1. Physicochemical and hydrological parameters of the Guapara river sampling streams, Ecuador.

	Q1-CA	Q2-CN	Q3-CF
pH	8.82 ± 0.53	8.69 ± 0.77	8.64 ± 0.4
Oxide reduction potential (%)	153.8 ± 12.68	146.14 ± 32.01	158.45 ± 29.89
Conductivity ($\mu S.cm^{-1}$)	49.03 ± 10.74	39.93 ± 5.63	55.54 ± 17.32
Total dissolved solids ($mg.L^{-1}$)	24.39 ± 5.51	20.04 ± 2.85	27.78 ± 8.69
Dissolved oxygen (%)	50.62 ± 18.93	50.04 ± 14.38	49.93 ± 14.76
Turbidity (NTU)	30.55 ± 20.47	31.11 ± 38.76	27.99 ± 19.64
Depth (m)	0.44 ± 0.04 b	0.613 ± 0.10 a	0.38 ± 0.09 b
Height (m)	18.0 ± 1 a	10.0 ± 1.5 c	14.0 ± 1 b
Speed ($m.s^{-1}$)	3.73 ± 0.25	3.16 ± 0.64	2.86 ± 0.65
Flow ($m^3.s^{-1}$)	31.88 ± 0.78 a	20.03 ± 3.27 b	15.86 ± 2.57 b

Q1-CA: agricultural cover. Q2-CN native forest cover. Q3-CF: forest plantation cover. Different letters between sampling stations denote significant differences (Tukey, $p < 0.05$).

Taxonomic variability of aquatic macroinvertebrates between streams

A total of 461 aquatic macroinvertebrates belonging to 7 orders and 25 families were collected in the water bodies evaluated. The most abundant order was Ephemeroptera with 34 %, followed by Trichoptera with 21 %, and Coleoptera with 19 %; while Hemiptera, Odonata, Diptera, and Tricladida represented 26 % of the remaining orders. The Ephemeroptera order had a higher abundance in the streams with native forest cover, and forest plantation cover with 41 % and 38 % respectively, being lower in the stream with agricultural cover with 25 %. This is similar to that reported by Morelli and Verdi (2014), who detected the order Ephemeroptera as the most abundant in sampling areas with high forest influence. The order Coleoptera recorded the highest abundance in the stream with native forest cover with 25 %, followed by the stream with agricultural cover with 21 % respectively, having influence in both streams by the presence of organic matter, and allochthonous material due to the abundance of detritus from leaf litter (Bojsen and Jacobsen, 2003).

Although the order Coleoptera is relatively abundant in streams with forest cover (Meza *et al*., 2012), it is also detected in areas influenced by native forest. Pérez-Rodríguez *et al*. (2021) reported this order as the most abundant in a study of five streams in the protected area of native species in the Serranía de la Macuira, Colombia; similarly, Urdanigo *et al*. (2019) reported that this order was the most abundant in the stream with secondary native forest. The order Hemiptera was the most abundant in the stream with agricultural cover with 32 %; however, in coffee crop cover in Colombia, abundance levels of 2.6 % of the order Hemiptera were observed due to the low prevalence of the species *Pontoscolex corethrurus* (Annelida: Oligochaeta), which prevents further growth of the taxonomic group (Rojas-Múnera *et al*., 2021).

The order Tricladida obtained the lowest abundance among streams, in the stream with agricultural cover the order presented the lowest abundance with 1 %; while, in the streams with native forest and forest plantation cover 2 % and 4 % respectively. Likewise, the Diptera order had the lowest abundance in the stream with native forest cover (1 %), followed by 3 % in the stream with agricultural cover, and 5 % in the stream with forest plantation cover. In a study conducted by Murillo *et al*. (2018), Tricladida and Diptera were not abundant orders either, presenting higher abundances in a stream of a conserved area for the order Diptera, and in a stream with agricultural cover for Tricladida. Finally, the order Odonata presented similar abundances between streams ~ 4 %, Tampo *et al*. (2021) indicate that the tolerance of the order Odonata allows it to inhabit contaminated habitats. There were no significant statistical differences in the abundance of orders between streams ($p > 0.05$).

Redundancy analysis (RA) between families of aquatic macroinvertebrates, and environmental variables

The most abundant families in the studied streams were Leptophlebiidae (21 %), followed by Gerridae (16 %), Hydrobiosidae (13 %), and Ptilodactylidae (12 %); while the families Megapodagrionidae, Helicopsychidae, and Glossosomatidae recorded less than 1% abundance each respectively. In the study, the environmental predictor variables of the AR model associated with aquatic macroinvertebrate communities were: Dissolved Oxygen and Turbidity ($p < 0.01$), with two canonical axes explaining 23 % of the total variance by Monte Carlo permutation test, this is similar to that reported by Mosquera-Restrepo and Peña-Salamanca (2019), who determined that Dissolved Oxygen and Turbidity contribute significantly as predictor variables of the aquatic insect assemblage in the Jordan River subwatershed, Colombia. The results showed that Hydrobiosidae was positively correlated with turbidity, and was associated with the stream of native forest cover (Q2-CN) due to the high ecological conditions of the habitat since it is usually found in good water quality conditions (Mena-Rivera *et al*., 2018; Stark, 1998); however, Gerridae was influenced by low values of Dissolved Oxygen due to its tolerance with moderately polluted environments low in dissolved Oxygen (Nuñez and Fragoso-Castilla, 2019).

In addition, Ptilodactylidae presented affinity with the stream of forest plantation cover (Q3-CF), this relationship agrees with that described by Galeano-Rendón and Mancera-Rodríguez (2018) who found that this family of Coleoptera is associated with streams of forest and native cover, due to the abundance of detritus from the litter (Bojsen and Jacobsen, 2003), in contrast to streams with deforestation processes due to agricultural activities. Leptophlebiidae was associated with the stream of native forest cover because this family is not found in waters of low ecological quality influenced by the use of agricultural chemicals, industrial discharges, and domestic waters (Forio *et al*., 2016; Jandry *et al*., 2014) (figure 1).

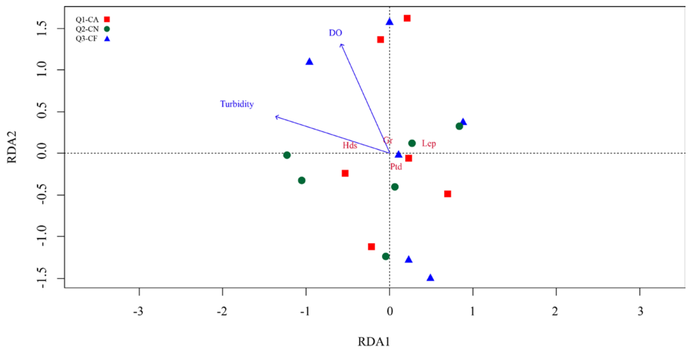

Figure 1. Redundancy analysis based on the abundance of macroinvertebrate families, and environmental variables in three streams with different riparian cover in the Guapara River, Ecuador. Q1-CA ■, agricultural cover; Q2-CN●, native forest cover; Q3-CF▲, forest plantation cover; S.D.T., Total Dissolved Solids; OD, Dissolved oxygen; Hds, Hydrobiosidae; Gr, Gerridae; Ptd, Ptilodactylidae; Lep, Leptophlebiidae.

Biological indices

The Ephemeroptera, Plecoptera, Trichoptera (EPT) index did not present significant differences ($p > 0.05$); however, regular water quality was recorded for the stream with agricultural cover (41.75 ± 11.79), and good quality for the streams with native forest 62.05 ± 18.67), and forest plantation cover (62.43 ± 19.65), similar to that described by Alomía *et al*. (2017) who noted that the EPT index presented regular water quality in both seasons, especially in station two, which is characterized as a stream with agricultural plantations. Finally, the number of EPT taxa was higher in the stream with native forest cover (9), in relation to the streams with agricultural cover and forest plantations with 8 taxa each respectively; no significant differences were found between streams. These results are related to those described by Galeano-Rendón and Mancera-Rodríguez (2018b), who pointed out that EPT taxa are sensitive to anthropic disturbances, thus proving the good ecological quality of riparian vegetation cover.

On the other hand, in the three study streams, values between 29 - 62 (px > 0.05) of the BMWP-Cr index were recorded, demonstrating water contamination in the three sampling stations. Gutiérrez-Fonseca and Lorion (2014) indicated that the BMWP-Cr index showed a low correspondence in water quality between the three types of sites (forested, grasslands with a buffer zone, and grasslands without a buffer zone).

In relation to the biodiversity analyses, the Shannon index was higher (2.5) for the stream with native forest cover, although, without significant differences compared to the values presented in the streams with forest plantation cover (2.432), and agricultural cover (2.162), respectively, similar to the study conducted by Morelli and Verdi (2014), whose streams with forest plantation cover, obtained values of the Shannon index between 1.06 and 2.55. Simpson's index did not show significant differences between streams either; however, this index showed lower dominance in streams with native forest cover (0.115), and forest plantation cover (0.116), compared to a slight increase in the stream with agricultural plantations cover with 0.168. These results differ from what was recorded by Rosado *et al*. (2017) where Simpson's dominance index was higher in streams with an anthropic disturbance with 0.78, while the streams with agricultural cover showed the lowest dominance of 0.58.

Conclusions

These results reveal that in the Guapara micro watershed there is an alteration in water quality, and in the structure of aquatic insect assemblages due to poor agricultural practices, and changes in land use on the banks of the streams. The streams with native forest cover and forest plantation presented the highest ecological quality according to the EPT index, which recorded the highest response on water quality at the sampling stations.

Literature cited

Alomía, J., Iannacone, J. A., Alvariño, L., & Ventura, K. (2017). Macroinvertebrados Bentónicos Para Evaluar La Calidad De Las Aguas De La Cuenca Alta Del Río Huallaga, Perú. *The Biologist*, *1*(2), 65–84. https://doi.org/10.24039/rtb2017151144

Blanchet, F. G., Legendre, P., & Borcard, D. (2008). Forward selection of explanatory variables. *Ecology*, *89*(9), 2623–2632. https://doi.org/10.1890/07-0986.1

Bojsen, B. H., and Jacobsen, D. (2003). Effects of deforestation on macroinvertebrate diversity and assemblage structure in Ecuadorian Amazon streams. *Archiv Fur Hydrobiologie*, *158*(3), 317–342.

Bonada, N., Prat, N., Resh, V. H., & Statzner, B. (2006). Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. *Annu. Rev. Entomol.*, *51*, 495–523.

Capparelli, M. V., Molinero, J., Moulatlet, G. M., Barrado, M., Prado-Alcívar, S., Cabrera, M., Gimiliani, G., Ñacato, C., Pinos-Velez, V., & Cipriani-Avila, I. (2021). Microplastics in rivers and coastal waters of the province of Esmeraldas, Ecuador. *Marine Pollution Bulletin*, *173*. https://doi.org/10.1016/j.marpolbul.2021.113067

Damanik-Ambarita, M. N., Lock, K., Boets, P., Everaert, G., Nguyen, T. H. T., Forio, M. A. E., Musonge, P. L. S., Suhareva, N., Bennetsen, E., Landuyt, D., Dominguez-Granda, L., & Goethals, P. L. M. (2016). Ecological water quality analysis of the Guayas river basin (Ecuador) based on macroinvertebrates indices. *Limnologica*, *57*, 27–59. https://doi.org/10.1016/j.limno.2016.01.001

Deknock, A., De Troyer, N., Houbraken, M., Dominguez-Granda, L., Nolivos, I., Van Echelpoel, W., Forio, M. A. E., Spanoghe, P., & Goethals, P. (2019). Distribution of agricultural pesticides in the freshwater environment of the Guayas river basin (Ecuador). *Science of The Total Environment*, *646*, 996–1008. https://doi.org/10.1016/j.scitotenv.2018.07.185

Domínguez, E., and Fernández, H. R. (2009). *Macroinvertebrados bentónicos sudamericanos Sistemática y biología*. Fundación Miguel Lillo.

Forio, M. A. E., Van Echelpoel, W., Dominguez-Granda, L., Mereta, S. T., Ambelu, A., Hoang, T. H., Boets, P., & Goethals, P. L. M. (2016). Analysing the effects of water quality on the occurrence of freshwater macroinvertebrate taxa among tropical river basins from different continents. *Ai Communications*, *29*(6), 665–685.

Galeano-Rendón, E., and Mancera-Rodríguez, N. J. (2018). Efectos de la deforestación sobre la diversidad y la estructura del ensamblaje de macroinvertebrados en cuatro quebradas Andinas en Colombia. *Revista de Biología Tropical*, *66*(4), 1721–1740.

Gozlan, R. E., Karimov, B. K., Zadereev, E., Kuznetsova, D., & Brucet, S. (2019). Status, trends, and future dynamics of freshwater ecosystems in Europe and Central Asia. *Inland Waters*, *9*(1), 78–94. https://doi.org/10.1080/20442041.2018.1510271

Guerrero, N., Díaz, M., Urdánigo, J., Tayhing, C., Guerrero, V., & Yepez, Á. (2017). Uso de suelo y su influencia en la calidad del agua de la microcuenca El Sapanal, Ecuador. *Revista Cubana de Ciencias Biológicas*, *5*(2), 1–11. http://www.rccb.uh.cu/index.php/RCCB/article/view/156/265

Gutiérrez-Fonseca, P. E., and Lorion, C. M. (2014). Application of the BMWP-Costa Rica biotic index in aquatic biomonitoring: Sensitivity to collection method and sampling intensity. *Revista de Biologia Tropical*, *62*(April), 275–289. https://doi.org/10.15517/rbt.v62i0.15792

He, S., Soininen, J., Chen, K., & Wang, B. (2020). Environmental factors override dispersal-related factors in shaping diatom and macroinvertebrate communities within stream networks in China. *Frontiers in Ecology and Evolution*, *8*, 141.

Hill, M. O., and Gauch, H. G. (1980). Detrended correspondence analysis: An improved ordination technique. *Vegetatio*, *42*(1), 47–58. https://doi.org/10.1007/BF00048870

Holdridge, L. (1978). *Ecología basada en zonas de vida*. Instituto Interamericano de Ciencias Agrícolas (IICA). http://repositorio.iica.int/handle/11324/7936

Jandry, J., Brulin, M., Parinet, B., & Grandjean, F. (2014). Ephemeroptera communities as bioindicators of the suitability of headwater streams for restocking with white-clawed crayfish, Austropotamobius pallipes. *Ecological Indicators*, *46*, 560–565.

Malaj, E., Von Der Ohe, P. C., Grote, M., Kühne, R., Mondy, C. P., Usseglio-Polatera, P., Brack, W., & Schäfer, R. B. (2014). Organic chemicals jeopardize the health of freshwater ecosystems on the continental scale. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(26), 9549–9554. https://doi.org/10.1073/pnas.1321082111

Mena-Rivera, L., Vásquez-Bolaños, O., Gómez-Castro, C., Fonseca-Sánchez, A., Rodríguez-Rodríguez, A., & Sánchez-Gutiérrez, R. (2018). Ecosystemic assessment of surface water quality in the Virilla river: towards sanitation processes in Costa Rica. *Water*, *10*(7), 845.

Meza, M., Rubio, J., Días, A., & Walteros, L. (2012). Calidad de agua y composición de macroinvertebrados acuáticos en la subcuenca alta del río Chinchiná. Water quality and composition of aquatic macroinvertebrates in the subwatershed of river Chinchiná. Caldasia. *Caldasia*, *34*(2), 443–456. http://www.icn.unal.edu.co/

MINAE. (2007). *Reglamento para la Evaluación y Clasificación de la Calidad de los Cuerpos de Aguas Superficiales*. *178*. www.cimar.ucr.ac.cr/PDFS/Reglamento Evaluacion y Clasifica-cion_Calidad_Agua_Superficial.pdf

Morelli, E., and Verdi, A. (2014). Diversidad de macroinvertebrados acuáticos en cursos de agua dulce con vegetación ribereña nativa de Uruguay. *Revista Mexicana de Biodiversidad*, *85*(4), 1160–1170. https://doi.org/10.7550/rmb.45419

Mosquera-Restrepo, D., and Peña-Salamanca, E. J. (2019). “Ensamblaje” de macroinvertebrados acuáticos y su relación con variables fisicoquímicas en un río de montaña en Colombia. *Revista de Biología Tropical*, *67*(6), 1235–1246.

Murillo, S. A., Mendoza, A., Restrepo, E. S., & Rodríguez, M. Á. (2018). Utilización de macroinvertebrados acuáticos como herramienta para determinar la calidad del agua en la quebrada Santo Tomás, municipio de Pensilvania, Colombia. *Revista de La Academia Colombiana de Ciencias Exactas, Físicas y Naturales*, *42*(164), 212–220. https://doi.org/10.18257/raccefyn.655

Nuñez, J. C., and Fragoso-Castilla, P. J. (2019). Uso de macroinvertebrados acuáticos como bioindicadores de contaminación del agua de la Ciénaga Mata de Palma (Colombia). *Información Tecnológica*, *30*(5), 319–330.

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O’Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., & Wagner, H. (2015). *Vegan: Community Ecology Package* (R package version 2. 3-0). https://cran.r-project.org/package=vegan

Pérez-Rodríguez, C., Manjarres-Pinzón, G., & Tamaris-Turizo, C. . (2021). Insectos acuáticos asociados a arroyos de la Serranía de La Macuira - La Guajira, Colombia. *Revista U.D.C.A Actualidad & Divulgación Científica*, *24*(1). https://doi.org/10.31910/rudca.v24.n1.2021.1941

Pimentel, D., and Burgess, M. (2013). Soil erosion threatens food production. *Agriculture (Switzerland)*, *3*(3), 443–463. https://doi.org/10.3390/agriculture3030443

R Core Team. (2015). *A language and environment for statistical computing. R Foundation for Statistical Computing*.

Rojas-Múnera, D. M., Feijoo-Martínez, A., Molina-Rico, L. J., Zúñiga, M. C., & Quintero, H. (2021). Differential impact of altitude and a plantain cultivation system on soil macroinvertebrates in the Colombian Coffee Region. *Applied Soil Ecology*, *164*, 103931. https://doi.org/https://doi.org/10.1016/j.apsoil.2021.103931

Roldán, G. (2003). *Bioindicación de la calidad del agua en Colombia: propuesta para el uso del método BMWP Col* (Universidad de Antioquia (ed.)). Editorial Universidad de Antioquia. https://books.google.com.ec/books?id=ZEjgIKZTF2UC

Rosado Yépez, Á., Bolívar Yépez, Á., Urdánigo Zambrano, J., Morales Cabezas, D. C., Guerrero Chuez, N. M., and Tayhing Cajas, C. C. (2017). Macroinvertebrados acuáticos como indicadores de calidad hídrica en áreas de descargas residuales al río Quevedo, Ecuador. *Ciencias Tecn UTEQ*, *10*(1), 27–34.

Stark, J. D. (1998). SQMCI: A biotic index for freshwater macroinvertebrate coded-abundance data. *New Zealand Journal of Marine and Freshwater Research*, *32*(1), 55–66.

Stehle, S., and Schulz, R. (2015). Agricultural insecticides threaten surface waters at the global scale. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(18), 5750–5755. https://doi.org/10.1073/pnas.1500232112

Tampo, L., Kaboré, I., Alhassan, E. H., Ouéda, A., Bawa, L. M., & Djaneye-Boundjou, G. (2021). Benthic macroinvertebrates as ecological indicators: their sensitivity to the water quality and human disturbances in a tropical river. *Frontiers in Water*, *3*, 662765.

Urdanigo, J. P., Díaz Ponce, M., Tay-Hing Cajas, C., Sánchez Fonseca, C., Yong Benitez, R., Armijo Albán, K., Guerrero Chúez, N., & Mancera-Rodríguez, N. J. (2019a). Diversidad de macroinvertebrados acuáticos en quebradas con diferente cobertura ribereña en del bosque Protector Murocomba, cantón Valencia, Ecuador. *Revista de Biología Tropical*, *67*(4), 861–878. https://doi.org/10.15517/rbt.v67i4.35190

Urdanigo, J. P., Díaz Ponce, M., Tay-Hing Cajas, C., Sánchez Fonseca, C., Yong Benitez, R., Armijo Albán, K., Guerrero Chúez, N., & Mancera-Rodríguez, N. J. (2019b). Diversidad de macroinvertebrados acuáticos en quebradas con diferente cobertura ribereña en del bosque Protector Murocomba, cantón Valencia, Ecuador. *Revista de Biología Tropical*, *67*(4), 861–878. https://doi.org/10.15517/rbt.v67i4.35190

Zapata, D., Oleas, N. H., Páez-Vacas, M., & Tobes, I. (2021). Water Quality Assessment of the Cutuchi River Basin (Ecuador): A Review of Technical Documents. *IOP Conference Series: Earth and Environmental Science*, *690*(1), 12058. https://doi.org/10.1088/1755-1315/690/1/012058