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Tropical Creek Affected By Mining Using an Ecological Quality Index Based on Periphytic Algae

Lady Vargas Porras[1], Esnedy Hernández Atilano[2], Diana María Agudelo Echavarría[3], and Giovanny Ramírez Moreno[1]

1. Institute of Environmental Research of the Pacific, Chocó 270001, Colombia

2. Research Group GeoLimna, Faculty of Engineering, University of Antioquia, Medellín 050001, Colombia

3. Research Group GAIA, Faculty of Engineering, University of Antioquia, Medellín 050001, Colombia

Abstract: In order to analyze lotic water bodies with different temporality of mining abandonment (without mining S0, 5 to 10 years S1, 30 years S2 and current mining S3), the physicochemical variables of the water and the assembly of periphytic algae were correlated to evaluate the impact of the mining disturbance in Jigualito (Choco-Colombia) through the ecological quality index (EQI). One sampling point was established upstream and one downstream in each station. It was found that the frequency and abundance of the species is conditioned by the physicochemical state of the environment and that the EQI values increased in the sites without mining exploitation such as S0 (EQI: 6.9), while the most disturbed point in terms of ecological was located downstream of S2 and S3 (EQI: 5.2), where the current mining is located and in intermediate conditions were stations S1, S2 (upstream) and S3 (upstream). The relationships between the EQI and physicochemical variables suggest that the ecological quality of the habitat for algae decreases when there is over saturation of nutrients and suspended material in the water. The taxa that presented high optimal and low tolerance could be used as bioindicators of the environmental gradient in systems disturbed by mining.

Key words: periphytic algae, mining, ecological quality index

1. Introduction

Mining is an activity carried out in many countries, including underground, surface extraction, drilling, dredging and open-pit mining. The latter obtains minerals by means of surface excavations, which includes stages such as the removal of vegetation layer, contributing considerably to deforestation and the increase in the concentration of heavy metals in the environment, generating economic, social and environmental impacts [1]. Gold mining poses a significant risk to public health due to the acute and chronic toxicity associated with pollutants such as lead, mercury, cadmium, chromium and its derivatives [2].

However, one of the worst consequences of mining is related to the impact of ecosystem functions due to the fragmentation of habitats, the acidification and compaction of the soil, which reduced photosynthesis, oxygen production, transfer and cycling of nutrients, among others [3]. Latin America is one of the main suppliers of mineral resources, the environmental impacts do not stop increasing in countries like Chile, Argentina, Peru, Brazil and Colombia, which is considered an emerging power when it comes to mining and oil. In just the last 10 years, authorization to develop mineral and oil extraction projects has been sought in 40% of Colombian territories [4]. Geology, physiographic history, and land use are among the most important factors influencing distribution in surface waters, especially lotic systems [5, 6] and in megadiverse countries such as Colombia, in which

Corresponding author: Lady Vargas Porras, Environmental Engineer; research areas/interests: limnology, environmental management, aquatic pollution. E-mail: lvargas@iiap.org.co.

there are areas characterized by rain forest tropical, biodiversity is related to high water richness, one of these areas is located in the Chocó, recognized worldwide by the combination of geographical and climatic characteristics that generate a high degree of endemism [7], hence, the Chocó is registered today as one of the places most vulnerable to mining impacts developed in this area since the seventeenth century [8].

Open pit mining is the main form of exploitation of precious metals in the Chocó, this activity is developed using machinery to remove material from the soil, divert river beds and use them as a source of water supply and disposal site for the waste, which includes large amounts of sediment, chemical pollutants, metals, fats and oils [8-13].

In Colombia, some authors such as Martínez and Donato (2003) [14], Licursi and Gómez (2003) [15], Díaz and Rivera (2004) [16], Hernández et al. (2011) [17], Zapata and Donato (2005) [18], Ramírez and Plata (2008) [19], Rivera and Donato (2008) [20], Aguirre et al. (2008) [21] have used biological groups to assess the level of affectation and response of water ecosystems in the face of anthropogenic disturbances and between aquatic biota groups the use of periphytic algae in conjunction with the physicochemical variables used to understand, among other aspects, the state of ecosystem dynamics and the level of intervention of a water body [22-26].

The periphytic algae have been used in the design and application of water quality indexes, which has qualitatively and quantitatively allowed to establish ranges and ratings on the environmental status of a water ecosystem, in this respect some examples in the tropics are exposed by Bate et al. (2004) [27], Schneider and Lindstrom (2009) [28], Castro (2009) [29], Pinilla (2010) [30], Schneider and Lindstrom (2011) [31], Carmona et al. (2016) [32], Baylón et al. (2018) [33], among others; this type of work combines the physical, chemical and biological variables as a tool for the analysis of the response of the environment to natural conditions or anthropic affectations. Activities such as mining disturb sensitive aspects of periphytic algae habitat, such as the availability of substrates immersed in the stream for colonization, due to the removal of natural substrate; or the limitation of light due to greater turbidity caused by the resuspension of sediments conditions generated due to the mining disturbance and its affectation in the soil during the removal of the riverbed to take advantage of the gold extraction [34-36].

One of the tools that can be used to evaluate this type of problems through the relationships between biological groups and environmental variables is the ecological quality index (EQI), which includes a numerical system in which the ecological quality is determined by an environmental gradient through a direct relationship analysis, the determination of tolerance ranges and optimal values by taxa based on that environmental gradient and quality weights for each evaluated station [37]. The EQI is based on the proposal of Haase and Nolte (2008) [38] and Chalar et al. (2011) [39] and its use provides information for management decision making, as well as for the design of restoration strategies and bioindication in areas with disturbances [17]. This study analyzed the response of the periphytic algae compared to the environmental gradient in the mining area adjacent to the Jigualito River in Condoto-Chocó and aims to establish the status of water bodies exposed to different times of mining activity, as well as taxa and indicator variables or sensitive to the conditions of the area, which could offer relevant information in terms of the adequate guidelines for monitoring in the area.

2. Materials and Methods

2.1 Study Area

The study area is located in the San Juan Mining District, specifically in Jigualito River municipality of Condoto (Chocó-Colombia). The area is characterized biophysically by representing a tropical rain forest, where the rainfall regime is intense with an annual rainfall ranging between 4000 and 10000 mm, average temperature is 26°C and relative humidity greater than 80% [40]. The territory is classified as "umbrofila-evergreen forest", with predominance of low altitude and alluvial forest [41]. The climate is warm, very humid and rainy. According to Holdrige's classification system (1979) [42], it corresponds to a tropical rain forest life zone (bpT). The main economic activities are mining, fishing, low-scale agriculture of corn, cassava and fruit trees. Four water sources were selected that allowed the identification of different stations according to the times of exposure to the gold mining activity. The first station corresponded to a water source without mining intervention (S0), the second presented between 5 and 10 years of cessation of activity (S1), the third had more than 30 years of activity abandonment (S2) and the last one presented current reception of mining discharges at the time of sampling (S3).

2.2 Description of Sampling Stations and Sampling Points

At each station, 2 sampling points were established located upstream (u) and downstream (d) of the source. Four samplings were made during the year 2015 between the months of May, August and October, the designation of these four samplings in the manuscript is (t1, t2, t3, and t4). The Table 1 describes the characteristics of the sampling stations.

Table 1 Location and characteristics of sampling stations and sampling points.

Station (code)	Location of sampling points (u: upstream, d: downstream)	Characteristics of the stream
Station (S0). Pichirí Creek. Stream without mining intervention	(u) N 5°1'8'' W 76°41'17'' (d) N 5°1'7,1'' W 76°41'16,8''	66 - 89 masl, running and clean waters. Area of 111.95 Ha (5.01 Km^2), length of 1.97 Km, average width of 0.057 km and is located. Riparian vegetation dominated by *.Inga sp, Miconia sp, Dialyanthera sp, Socratea exorrhiza, Gusmania sp, Matisia Castano.*
Station (S1). Sabaleta Creek. Stream with mining suspension between 5 and 10 years	(u) N 5°1'50,2'' W 76°41'20,5'' (d) N 5°1'49.6'' W 76°41'14.7''	48-63 masl, channel diverted and interrupted, lagoons connected or disconnected from the main channel. Area of 457.11 Ha (10.48 km^2), length of 2.73 km, average width of 1.26 km, vegetation interrupted in banks with predominance Gramineas and Ciperaceae
Station (S2). Marcos Díaz Creek. Stream with mining suspension for 30 years	(u) N 5°2'32.1'' W 76°41'33.6'' (d) N 5°2'35.3'' W 76°41'30.9''.	56-59 masl, channel modified and integrated by natural sectors connected with an artificial channel. The natural sectors have lotic characteristics and the channel constitutes a stretch with slow and flooded flows. area of 52.04 Ha (3.15 Km^2), length of 1.24km, average width of 0.42km. Riparian vegetation interrupted with predominance of *Spathiphyllum friedrichsthalii, Gleichenia bifida,* Gramineas and Ciperaceae.
Station (S3). Jorobibó Creek. Stream with mining activity during the study	(u) N 5°22'56.7'' W 76°36'51.3'' (d) N 5°22'51.8'' W 76°36'53.8''	90-99 masl, deviation of the channel. Area of 246.27 Ha (2.46 Km^2), length of 2.58 Km, an average width of 0.95 Km. Vegetation in interrupted banks, predominance of *Gleichenia bifid*, algunas Gramíneas (*Axonopus sp*), Ciperaceas and Aráceas.

2.3 Sample Taking and Analysis

The variables that were measured in situ were flow rate, velocity (m/s), temperature (°C), pH (pH units), dissolved oxygen (mg/L), conductivity (µS/cm) and dissolved solids (TDS) (mg/L), by using a YSI Professional Plus Quick 1700/1725 Multiparameter. Likewise, the nutrient concentrations of nitrates, nitrites and phosphates (mg/L) and suspended solids (SS) (mg/L) were determined using a HACH DR 900 Portable Colorimeter. To remove the phytoperiphitic samples, it was removed from the adhered material. to substrates immersed in the stream bed obtaining a total area of 240 cm^2 of scraping per station, the collected sample was fixed with a solution of lugol at 10% and transported to the laboratory in opaque plastic containers duly labeled. An inverted microscope was used to observe the algae samples, and the Sedgwick-Rafter counting chamber with a capacity of 1ml was used to mount the sample [43]. To carry out the counting of periphytic algae in the chamber, 30 observation fields were selected following a random sampling system [44]. The count was performed with a total magnification of 400X and the taxonomic determination of the periphytic algae was carried out at least up to the taxonomic gender category with the advice of a specialist.

2.4 Data Analysis

To establish the response of assemblage of periphytic algae to the changes in the physicochemical variables of the water, the ecological quality index (EQI), established by Haase and Nolte (2008) [38] and Chalar et al. (2011) [39]. This index is based on the application of a series of multivariate statistical analyzes, which included the determination of the environmental gradient through a Detrended Correspondence Analysis (DCA) [45], followed by a canonical correlation analysis (CCA) and the determination of the optimal and tolerance values for each of the taxa incorporated in the model. The calculation of the EQI was determined in accordance with equation (1) proposed by Haase and Nolte (2008) [38].

$$EQI = (\Sigma Opi*Toli*Abi)/(\Sigma Opi*Toli*Abi) \quad (1)$$

where (Opi) is the optimal value, (Toli) the tolerance value and (Abi) the abundance.

The analyzed data correspond to the abundances of the periphytic algae and the records of the physicochemical variables. All data were standardized according to Guisande-González et al. (2006) [46]. A rescheduling of station scores was performed, according to the CCA model. In the C2 program (free software) the optimal and tolerance values for each organism were obtained from a weighted averaging analysis (WA) using the abundances of the algae and the data obtained in the rescaling of the scores of the CCA mode.

Finally, a cluster was carried out between the sampling sites, using the Ward method and the Euclidean distance. All the multivariate analyzes were carried out in the statistical software R.

3. Results

Composition and structure of the periphytic algae. 52 morphotypes of periphytic algae were recorded, these belong to cyanobacteria, chlorophytes and the division with the largest number of representatives corresponds to the division Bacillariophyta or diatoms. The distribution of density and number of taxa in the stations and sampling showed trends to higher values in both parameters (410 Org/cm^2 and 13 taxa) in stations S0 and S1 (Without mining and without mining activity between 5-10 years respectively), in contrast, stations without activity for more than 30 years (S2) and especially with recent activity (S3) recorded the lowest densities and richness of organisms (303 Org/cm^2 and 8 taxa) (Fig. 1). The morphotypes with greater representation or adaptation between the seasons indifferent to the scenario (except for the station with downstream mining (S3d)) correspond to the diatom *Frustulia rhomboides* and the chlorophyte *Ulothrix* sp., In contrast, other taxa that only tend to be registered in the station without mining (S0) were *Actinella* sp., *Eunotia serra*., *Stigonema* sp., and *Surirella* sp.

3.1 Environmental Gradient

The length of the environmental gradient in the first axis registered a value of 3.87 SD, indicating that the response of the assembly of periphytic algae with respect to the physicochemical variables presented the unimodal behavior, for which the CCA model was statistically significant (p-value = 0.016). The variables used in the canonical correlation model were pH, temperature, dissolved oxygen, total dissolved solids, conductivity, flow, nitrate, nitrite, phosphate. There were no variance inflation factor (VIF) values greater than 20, which indicates the lack of collinearity between the variables used in the model. Among the physicochemical variables, flow and temperature recorded (p-value < 0.05) in the MonteCarlo test.

Fig. 2 shows the behavior of the sampling sites and the taxa as a function of the behavior of the physicochemical variables. Flow and oxygen had a positive correlation with the first axis (r = 0.45 and r = 0.40 respectively), in contrast, the temperature recorded a high inverse correlation on this same axis (r = -0.64). Due to the significance of the model, the scores of the stations in the ACC (sample scores) represent the basis for calculating the ecological quality index. In addition, it can be observed how the

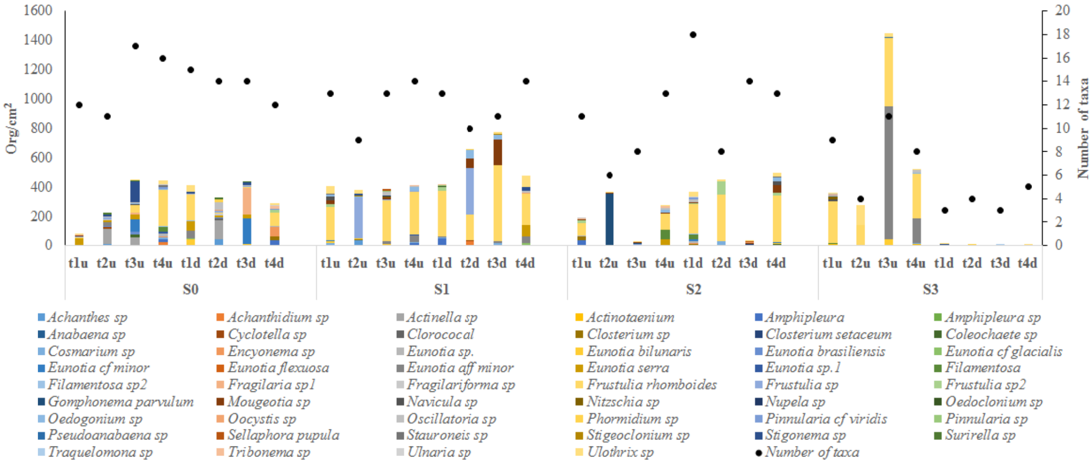

Fig. 1 Distribution of the number and total density of periphytic algal morphotypes per unit area (Org/cm²) in the stations and monitoring evaluated.

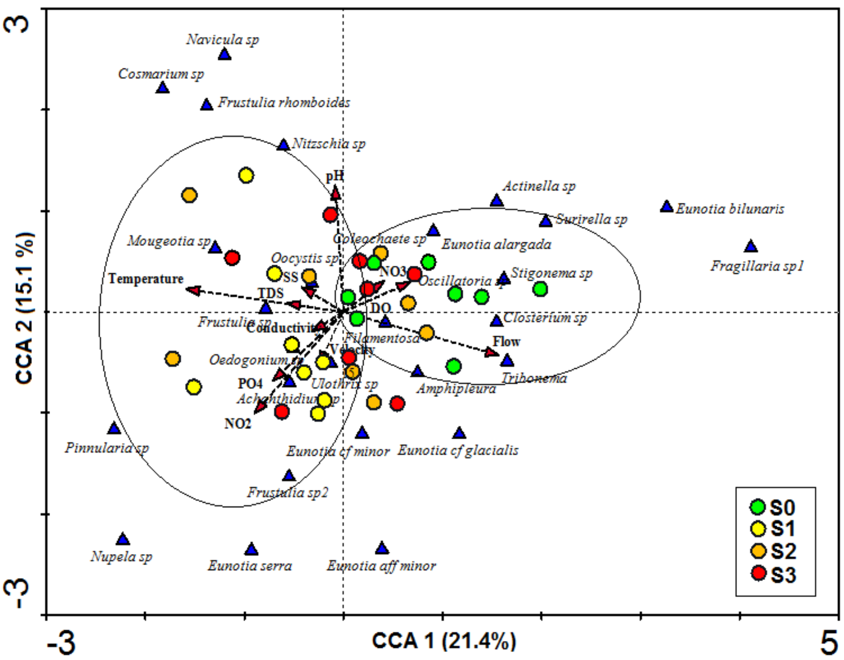

Fig. 2 Analysis of canonical correlation between taxa, sampling sites and physicochemical variables. S0: no mining activity, S1: cessation of mining activity between 5 and 10 years, S2: cessation of mining activity 30 years ago and S3 current mining activity.

sites that correspond to the station where no mining activity is currently taking place are fundamentally related to the behavior of the flow, dissolved oxygen and nitrate concentration, while the other sites where it has been carried out some kind of mining activity and where resources are currently being exploited, they are associated with nutrients such as orthophosphates and nitrites, as well as having high contents of suspended solids and high conductivity, conditions inherent to mining activity.

The staggering of the scores in the stations and samplings obtained in the CCA was done by means of the equation y = 6.2328-1.6453X, where X was replaced with the sample score value in each station. The scores were resized to a scale between one and ten according to the interpretation suggestions proposed by Chalar et al. (2011) [39], where the highest concentrations of the variables are associated with a lower physicochemical quality and therefore lower values in the samples score.

3.2 Optimal Values and Tolerance of the Taxa

The optimal and tolerance values were obtained for each of the morphotypes that were present in the different sites and samplings of the monitoring network considered (Fig. 3). 60% of the taxa obtained an optimal value above 6, however, organisms with optimal values lower than 4 and a high tolerance value were also observed. Thirty-one (31) taxa presented optimal values associated with conditions of good ecological quality (> 6.1) and thirteen (13) presented values corresponding to critical quality states (< 4.9) (Fig. 3), the numerical range of these adjudications is suggested by Haase and Nolte (2008) [38].

According to the optimal values and tolerance, among the taxa with greater amplitude of optimum range and at the same time, medium and low tolerance could be mentioned *Fragillariforma* sp., *Pinnularia* cf. *viridis*, *Eunotia* cf. *glacialis*, *Eunotia elongate*, *Tribonema* sp. and *Ulnaria* sp, all characterized by being recurrent in most of the sampling sites.

3.3 Ecological Quality Index (EQI)

Similar values were observed in the index for the sampling points upstream and downstream of the S0 station (5.6-7.8 and 6.0-7.8, respectively), S1 (5.2-6.5 upstream and 5.4-6.1 downstream), S2 (4.7-6.4 upstream and 4.5-6.1 downstream) and S3 (5.3-5.9 upstream and 5.1-5.2 downstream). These values showed strong and significant correlations with the scores of the samples in the first axis of the ACC (Spearman: r = -0.80, p < 0.05), which means that the index summarizes the relationship between the periphytic algae and environmental variables, with a minimum of loss in information. Fig. 4 shows how S0 presents the highest values of the index, while the behavior of sites S1 and S2 is homogeneous for the EQI, however the lower limit for EQI in S2 upstream

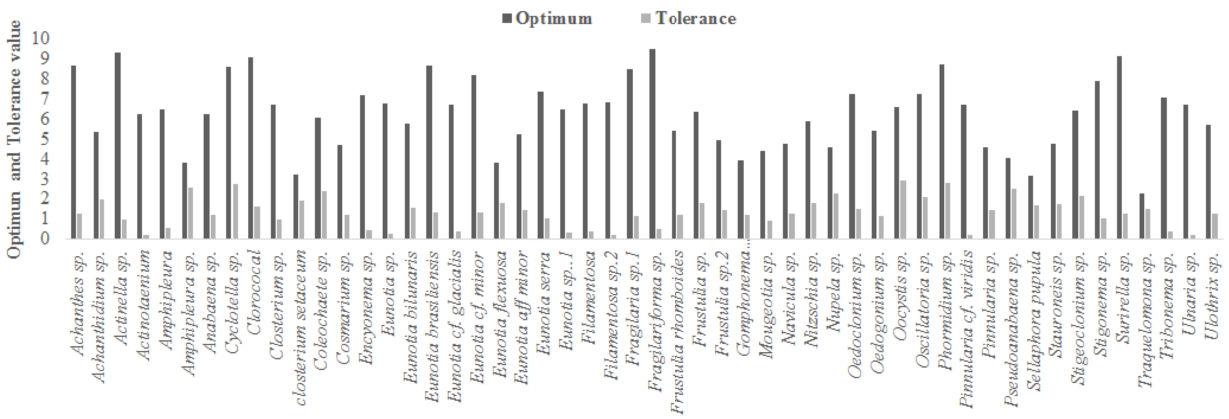

Fig. 3 Profile of the optimal and tolerance values of the registered algal morphotypes after the re-escalation analysis in association with the canonical correlation analysis.

represents the lowest index, which it is conditioned by the temporality in the samplings. The analysis of variance of Kruskal-Wallis determined for the index with respect to each of the analyzed sites, showed statistically significant differences (p-value = 0.04) between these sites.

In the grouping of the different stations by means of the index, the following distribution was generated (Fig. 5), Group 1 associated with the highest values of the index, in which the S0 station is located both upstream

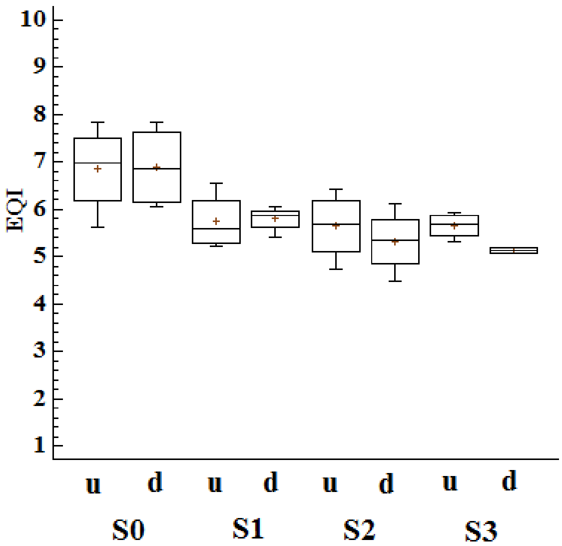

Fig. 4 Distribution of the Ecological Quality Index in the four stations, upstream (u) and downstream (d).

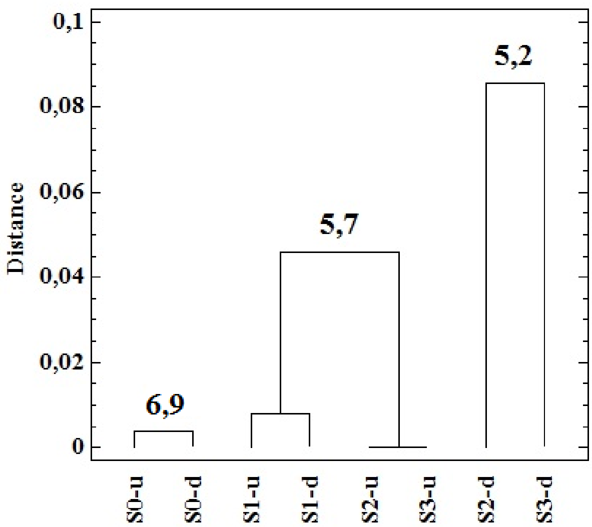

Fig. 5 Grouping analysis of the Ecological Quality Index based on the periphytic algae. The values assigned to each set indicate the average value of the EQI in each grouping.

and downstream. Group 2 intermediate values composed of most of the sites upstream and downstream in stations S1 and S2; finally, the lowest values of the index are in a last group where the sites downstream of stations S2 and S3 are associated.

3.4 Association of the EQI with the Physicochemical Variables

The correlation of the ecological quality index with the physicochemical variables submitted to the model (Table 2), established an inverse and significant relationship (p-value < 0.005) between the index and the concentration of nitrites, suspended solids and temperature (r = -0.41, r = -0.5 and r = -0.58, respectively). These results correspond to the record in the ACC, therefore, it is confirmed that the stations are grouped following a gradient that goes from waters with lower concentrations of solids and nitrites (group 1) to waters with preference to higher concentrations (group 3). Therefore, the ecological quality ranges were obtained for three variables, given the higher correlation coefficients, nitrites, solids and temperature (indicator variables). The variation of these variables was given in the following way for the studied system: suspended solids fluctuated between 1 and 1067 mg/L, nitrites between 0.0004 and 0.37 mg/L and temperature between 24.9 and 32.0°C. The ecological quality can be established based on the measurement of solids, nitrite and temperature concentrations in conjunction with the calculation of the EQI.

4. Discussion

The effects of the mining intervention with different time of exposure in the study area were first exposed by a differential distribution of the taxa's densities and riches, in this way aspects such as the specific presence of taxa associated only to the station were detected. without intervention, such was the case of *Atinella* sp., *Eunotia serra*., *Stigonema* sp., *Surirella* sp.; In contrast, other taxa were ubiquitous in all seasons, that is, when

Table 2 Spearman relationship coefficients between the ecological quality index and the environmental variables included in the canonical correspondence analysis model.

Enviromental Variable	Flow	Conductivity	NO_2-	NO_3-	Disolved Oxygen	pH	PO4-3	Suspended solids	Temperature	Velocity
Correlation (r)	0.34	-0.23	-0.41	-0.48	0.11	0.25	0.05	-0.5	-0.58	-0.32
p value	0.06	0.201	0.025	0.058	0.559	0.16	0.807	0.014	0.001	0.071

they adapted to scenarios exposed to different levels of temporary exposure to mining, such cooperation was demonstrated by *Frustulia rhomboides* and the chlorophyll *Ulothrix*, however, when the mining intervention was active, the density and richness of periphytic algae decreased drastically, evidence of the abrasive effects that the activity has on the aquatic biota and consequently of the ecosystemic functions in the hydric system. In this respect, the loss of aquatic biodiversity is one of the greatest problems currently caused by human activity, however, the consequences of this process for the functioning of freshwater ecosystems are still unknown. In this context, knowledge of biodiversity is of extreme importance, considering that several organisms can be used as bioindicators of water quality, such as fish, benthic macroinvertebrates and periphyton [47-49].

As in other studies [50-52], the structure of the periphytic algae of the water sources studied in the Jigualito del Chocó Colombian River evidenced the impact of human activities. In context to its potential as a bioindicator, the aim of this study was to determine the effect that environmental variables, as well as physical and chemical variables of the water, have on the taxonomic composition and abundance of periphytic algae adhered to natural substrates. This is how the relationships between the variables and the organisms generated, through the use of the ecological quality index, an environmental gradient that allowed the identification and categorization of the response of the periphytic algae in each season with different exposure time to mining.

Among the fundamental variables that defined the environmental gradient of the section studied were velocity, dissolved solids, conductivity, flow, nitrites, nitrates, orthophosphates, temperature, dissolved oxygen and pH, for which the most important chemical components that influence this system are they are associated with the amount of ions in the water, the hydrology and the concentration of nutrients. Most of these variables are influenced by the concentration of total suspended solids and the flow, which represents the dynamics of the natural sources and the anthropic activity that takes place in the area. This gradient of environmental variation obtained from the CCA expresses delineations in the water quality that significantly influenced the distribution of the periphytic algae. It can be established that the activities that condition this behavior are mainly due to the progressive fragmentation and the dynamics of the areas, due to the changes that have occurred in the development of mining activities in the zones, which determines a loss in connectivity which is evident in the differences that they presented in the sampling stations.

The correlation between the physicochemical variables and the periphytic algae, through the ecological quality index, showed that the most ecologically disturbed season corresponds to the areas with current mining operation, however this is conditioned to the sampling period, so stations where there was development of mining activities may show low ecological quality index. This result may be related to the changes that this activity causes in the aquatic ecosystems and associated vegetation, since the process developed for the extraction of metals includes the deforestation of banks and the surrounding forest matrix, which consequently displays other effects such as the contribution of high concentrations of solids, the modification of the substrates and the deviation of the channel, generating the degradation of the environmental conditions of the bodies of lotic water. According to Hauer and Lamberti (1996) [53] the fluvial processes are governed mainly by the current flow, the morphology, the energy transfer rates, the cycles of matter and nutrients and the disturbance regimes, which are determining in the distribution of organisms in space and time [54].

Martínez and Donato (2003) [14] have indicated that hydrological, physical and chemical characteristics, as well as disturbances, spatial and temporal heterogeneity in rivers, define distribution, dispersion, colonization, the response of organisms to the environment and their ecological status. This explains the difference of the EQI between the stations, for the case of those sampling sites with temporalities of mining cessation between 5 to 10 years and 30 years (S1 and S2) intermediate values were presented, evidencing that they are still in the process of recovery, where the restoration of the disturbance is complex, given the break in the stability of physical, chemical and biological processes.

The highest values of the ecological quality index coincided with the season without mining, showing that bodies of water without this disturbance have a high numerical range in the quality status as habitat for the biological study group, which is why they constitute areas of priority attention for conservation within the basin and that can also serve as comparative control stations when projecting induced restoration activities. In an intermediate group were the sites with cessation of mining activity and the upstream site where mining activities are currently taking place, this could indicate that the areas upstream of the mining discharges retain environmental characteristics and ecological conditions similar to the natural ecosystems in process of recovery.

The results of the index and its relation with environmental variables indicated that the ecological quality of the stations is directly influenced by specific physicochemical variables such as the concentration of inorganic forms of nitrogen, suspended solids and temperature, that is, these variables account for the status or the ecological quality of the habitat for the periphytic algae, showed in an increase in nutrients and suspended material in the water, such as occurs during the mining disturbance, decreases the ecological quality according to the index. The above, together with the statistical significance of an inversely proportional relationship on the part of the temperature, makes it possible to infer from the results of the index, that the degradation of the habitat due to deforestation, erosion and the consequent increase in the temperature in the water caused by the mining, could generate greater stress for the development of the periphytic algae community, which coincides with what was expressed by Allan (1995) [55], Hynes (1970) [56] and Roldán and Ramírez (2008) [57], who affirm that the main factors that control the dynamics of the periphytic algae and limit their production are light, nutrients, temperature, velocity of current and substrate, the first three being the main factors.

They determined the optimal ranges and tolerance for taxa, allowed to identify the ranges in which organisms respond to the environmental gradient. The optimal value corresponds to the score of each taxon in the gradient of environmental variation, in other words, it is the expression of the coupling of abundance to environmental conditions; however, the optimum value must be analyzed in conjunction with the tolerance value, which describes the ecological amplitude along the environmental gradient [39], that is, the persistence of the abundance of the independent taxa of the variation of environmental conditions.

In general, the frequency and abundance of several species with optimum levels greater than 6 suggests adaptation to the environmental conditions of the studied stations [17]. Additionally, it is proposed that the periphytic algae that presented high optimal values and in turn medium to low tolerance levels, indicate sensitivity to the amplitude of the environmental range and for this reason could be used as bioindicators for the evaluation and monitoring of water ecosystems disturbed by mining, not only in the town of Jigualito, also in the mining district of the San Juan River, which shows the same patterns of mining exploitation in Jigualito, water regimes and environmental conditions; some of the periphytic algae with these characteristics were *Achanthes* sp., *Actinella* sp., *Encyonema* sp., *Eunotia brasiliensis*, *Eunotia* cf. *minor*, *Fragilaria* sp., *Oedoclonium* cf., *Oscillatoria* sp., *Phormidium* sp., *Stigonema* sp. and *Surirella* sp. To confirm the use of these organisms as bioindicators, it is recommended to gather results from alternative systems and to define comparisons between average values of tolerance, so that the response to environmental variability can be corroborated. These morphotypes will be of considerable attention in terms of their degree of occurrence and abundance in future samplings, since they will allow to identify changes in the physicochemical quality.

The results of the optimal values and tolerance can also help to identify the taxa adapted to the mining disturbance in the Jigualito area, such as *Fragillariforma* sp., *Pinnularia* cf. *viridis*, *Eunotia* cf. *glacialis*, *Eunotia elongate*, *Tribonema* sp. and *Ulnaria* sp, indicated adaptation or high level of tolerance to the adverse conditions of the periphytic algae growth, that is, low availability of light and environmental stress by nutrients and solids, these morphotypes correspond to elongated unicellular forms with silica exoskeleton and filaments, specifically diatoms and chlorophytes with conspicuous and projected shapes with an important axial linear dimension, these forms indicate adaptation to low availability of light as they project their surface volume ratio to make their physiology more efficient.

Specifically, Díaz and Rivera (2004) [16] have indicated that *Pinnularia* cf. *viridis* is considered a facultative heterotrophic diatom, which allows its reproduction in extreme ecosystems and with morphological variability. Also, authors such as Hustedt (1959) [58] and Bourelly (1968) [59] have reported for the genus *Eunotia* sp. its ability to withstand slightly acidic waters and intervened environments. Reports that coincide with the trends obtained in this study. In general, the frequency and abundance of several species with high optima corroborated that there is adaptation to the conditions and environmental stress of the selected stations and in the first instance, they are the organisms that can provide help in the monitoring of the behavior of the basins.

The open-pit mining activity developed in the town of Jigualito-Chocó, degrades the environmental and ecological conditions of the water sources exposed to the exploitation process, the riparian vegetation and the associated forests are deforested to access the soil layers that contain the metals, in addition the hydric bodies are diverted to capture the water, used in the washing of the lithological substrates, which in turn increases the discharge of sediments, generating a modification in the physicochemical and hydrological conditions, affecting the community of parasite algae that colonize the substrata immersed in the current, that is to say, one of the components of the primary productivity of the fluvial ecosystem, since the base in the trophic structure is altered, diminishing the supply of the environmental services.

In this study, the water sources disturbed by mining registered high concentrations of suspended solids and nutrients, authors such as Luttenton and Baisden (2006) [60], Cushing and Allan (2001) [61] support the idea that in rivers where activities are carried out that provide sediments, the amount of solids in suspension and the availability of nutrients increases, which hinders the penetration of light into the body of water, inducing changes in the periphytic community, such as the reduction of primary productivity and diversity. The results obtained, show that although these affectations are reduced with time, their effects are persistent in the long term, since when comparing the environmental and ecological state of the different stations, it was found that during the first 5 to 10 years of cessation of mining activity occurs a reduction in the amount of suspended solid material favored by sedimentation, but temperatures increase as a result of greater exposure to the sun due to the lack of associated vegetation and low flow rates. The trend of the physicochemical variables, the ecological analyzes of the periphytic algal structure and the calculation of the ecological quality index, showed that the downstream point of the station with current intervention presented the lowest values of ecological quality, as well as indicated that the seasons of 5 to 10 years and 30 years of mining cessation have intermediate conditions, that is, in the process of stabilization, finally the environments that have not had this type of intervention showed the best ecological quality.

It can be inferred that the mining disturbance has a complex process of temporary restoration in the affected water ecosystems and that it is not enough to stop the activity for 10 or 30 years to return to the initial state of a source without intervention. The ecology of continuous processes in river ecosystems [62], as a spiral of nutrients [63] or as a series of discontinuities [64], state that environmental and biological conditions they distribute along the channel and their interaction determines the operation and in this case, the mining modifies them drastically, interrupting the continuity of the quality of the habitat, which will generate a long process to enable the possibility of restoring the offer of environmental services.

The information obtained was useful to analyze the impacts and behavior of the disturbance and showed that with the apparent improvement of turbidity in stations affected by mining between 10 to 30 years, the systems do not present similar conditions to a place without intervention. Finally, this work invites us to think that the monitoring, monitoring and restoration requirements demanded by the areas affected by mining vary according to the exposure time, the ecological impact generated by the extension of this type of extraction in mega-diverse geographic areas such as Chocó and other areas of Colombia has not been studied and represents an important challenge in the adequate approach to the problem and its mitigation.

According to Pineda et al. (2014) [65], Canonical Correspondence Analysis (ACC) and weighted averages (AW) have been objective and effective methods for the development of biological indices that assess environmental quality. The estimation of the ecological quality index in the Jigualito town combined the potential of the direct gradient analysis (ACC) together with a weighted average model (WA). In the case of Colombia, some publications were found that combine both tools to establish optimal and tolerance scores with periphytic algae and other bioindicator groups [17, 37], on this occasion it is concluded that the EQI was a tool that made it possible to environmentally diagnose areas with different anthropic interventions of a mining nature, by means of categories that refer to an ecological state and that were constructed from correlations between physicochemical variables with the abundance of the periphytic algae, a condition that does not meet the conventional indexes. The index provided an objective and rigorous response to evaluate in numerical form the position of each of the sampling stations in a gradient associated with the concentration of solids, nutrients and temperature, variables that affect the distribution of the optimal values and tolerance of the algae periphytic to the physicochemical conditions of the zones, which suggest deterioration of the stations where some type of mining activity has been carried out, and where, in addition, the slow recovery of the aquatic ecosystems is evidenced despite the cessation of the mining activities. In accordance with the elaboration of any aquatic ecological index requires the physicochemical data of an adequate design in the monitoring network, which contemplates the influence of clean waters until contaminated; quantify the taxonomic resolution quantitatively and determine the abundance of each taxon.

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