Algae in the Acid Mine Drainage on Santa Catarina Coalfield, Brazil

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Abstract The acid mine-drainage (AMD), from the ecological point of view, affects the aquatic environments causing stress to most organisms. The low pH values, high concentration of sulfates and dissolved metal ions reduce the biological diversity. These systems can be characterized as simple ecosystems, dominated by acidophilus and acid tolerant organisms. Chlorophyta are typically dominant in these environments. The objective of this work was the identification of algae in water streams impacted by AMD in the coalfield of Santa Catarina State, Brazil. Water streams contaminated by the AMD were analyzed and the algae were collected and identified. The results showed that the aquatic environment impacted by AMD is inhabited by few algae groups. The dominant genus was filamentous green algae *Microspora*.

Key Words acid mine drainage, algae, coal mining

Introduction

The water pollution caused by acid mine drainage (AMD) is probably the most significant impact of coal in the coal region of Santa Catarina, Brazil (Alexander et al., 1995). The water derived from coal mining, coal preparation and tailing sites impacts streams from three main watersheds: Araranguá River, Tubarão River and Urussanga River.

The low pH values, the high concentration of sulfates and the dissolved metal ions reduce the biological diversity, which are dominated by acidophilic and acid-tolerant organisms (Valente and Gomes, 2007). Despite the extreme physical and chemical conditions, some algae grow in this environment. The division Clorophyta is typically dominant, including species such as *Klebsormidium* sp., *Mougeotia* sp., *Zygnema* sp., *Ulothrix* sp., *Euglena mutabilis* Schmidtz, *Pinnularia acoricola* Hust, and *Eunotia exigua* (Niyogi et al., 2002).

The identification of existing algae on acidified waters has been studied in various regions of the world, including Hocking River (Ohio, USA, Verb and Vis, 2001), Valdarcas (Portugal, Valente, 2004), Tinto River (Spain, López-Archilla et al. (2000) and New Zealand (Bray, 2007). In general, these studies highlight the interaction of factors such as pH, conductivity, concentration of dissolved metals, and the deposition of metal oxides with the biodiversity and primary production.

The objective of this study was to identify communities of algae found in water impacted by AMD in coalfield of Santa Catarina State, Brazil.

Methods

This study was conducted in the coalfield of Santa Catarina State, Brazil, including water streams of watersheds of Tubarão River, Araranguá River and Urussanga River. The area is bounded by the coordinates 28°11' to 29°03' south latitude and 49°10' to 49°37' west longitude. The climate is subtropical and the rain is well distributed throughout the year with an average annual rainfall of 1600 mm. The annual average temperature is 19°C, with the monthly average temperatures ranging from 15 °C in winter to 24°C in summer, with possible occurrence of frost.

The flow rate was measured and water samples were collected in the months of july/2009, october/2009, december/2009, and april/2010 using the water resources database carried out by the "Sindicato das Indústrias de Extração de Carvão do Estado de Santa Catarina" (SIECESC). The water analyses considered the following parameters: pH, conductivity, turbidity, Eh, color, metals (Fe, Al, Mn and Zn), sulfates, nitrogen and phosphorus. All analyses followed the procedures described in the "Standard Method for the Examination of Water and Wastewater" (APHA, 2005).

Algae sampling and identification schedule was coincident with the water sampling. The pe-

riphyton was collected in an area of 100 cm^2, packed in plastic bottles of high density polyethylene (HDPE), and preserved with Lugol for identification. Taxonomic identification was achieved by optical microscopy, based on morphological features and simple coloration tests (Bold and Wynne; 1985; Bicudo and Menezes; 2006).

Results

Table 1 lists the averages flow rates and the chemical characteristics in the six sampling places. It is possible to observe that the algae were found in water streams considering different flow rates and metaL/sulfate concentrations. However, the pH was in narrow range, varying from 2.9 to 4.1.

Table 2 summarizes the communities of acidophilic algae found in the coalfield of Santa Catarina. Periphytic community was represented by five taxa at the genus level, divided into three classes: *Chlorophyceae* (*Microspora* and *Mougeotia*), *Bacillariophyceae* (*Eunotia* and *Frustulia*) and *Euglenophyceae* (*Euglena*). Figure 1 shows the photomicrographs of the identified algae.

The growing conditions in terms of pH versus iron concentration and pH versus sulfate concentration of main algae associations are presented in Figure 2. The main algae associations were just the dominance of the filamentous algae *Microspora*, the dominance of *Microspora* with substantial participation of *Frustulia*, and the dominance of *Microspora* with significant participation of *Euglena*. The amount of *Mougeotia* and *Eunotia*, in terms of biomass, was of minor importance.

Table 1 *Summary of the effluent chemistry (average) regarding some selected indicator on sampling sites studied in the coalfield of Santa Catarina*

Parameters	Ronco D'água	Santa Líbera	Barro Branco	Colonial	Afl. Sangão River	Morozini River
Flow rate (L/s)	420	181	5.6	23	386	0.45
pH	4.1	3.3	3.5	2.9	3.7	3.2
Eh (mV)	175	246	210	235	225	222
Color (Hazen)	14	98	191	1227	234	156
Turbidity (NTU)	1.4	31.6	31.6	88.8	36.0	3.3
Conductivity ($\mu S/cm^2$)	381	1720	418	1791	814	1148
Acidity (mg of $CaCO_3$/L)	64.6	2007.9	230.4	1767.7	396.7	838.4
Sulfate (mg/L)	587	3609	639	1703	811	1435
Fe (mg/L)	5.3	104.1	9.3	137.7	6.2	5.0
Al (mg/L)	12.3	66.8	11.2	94.9	14.3	25.6
Mn (mg/L)	0.74	3.85	0.35	2.34	1.63	4.87
Zn (mg/L)	0.44	4.67	0.53	2.64	1.90	1.15
Algae presence	Low	Low	Abundant	Abundant	Moderate	Moderate

Table 2 *Algae on acidic aquatic environments in the coal production region of Santa Catarina*

Place	Watershed	Division	Class	Genus
Ronco D´Água	Urussanga River	Chlorophyta	Chlorophyceae	*Microspora*
Santa Líbera	Araranguá River	Chlorophyta	Chlorophyceae	*Microspora*
		Euglenophyta	Euglenophyceae	*Euglena*
Barro Branco	Tubarão River	Chlorophyta	Chlorophyceae	*Microspora*
		Heterokontophyta	Bacillariophyceae	*Eunotia*
Colonial	Araranguá River	Chlorophyta	Chlorophyceae	*Microspora*
		Chlorophyta	Chlorophyceae	*Mougeotia*
		Heterokontophyta	Bacillariophyceae	*Frustulia*
		Heterokontophyta	Bacillariophyceae	*Eunotia*
		Euglenophyta	Euglenophyceae	*Euglena*
Afluente Rio Sangão	Araranguá River	Chlorophyta	Chlorophyceae	*Microspora*
		Heterokontophyta	Bacillariophyceae	*Eunotia*
Rio Morozini	Araranguá River	Chlorophyta	Chlorophyceae	*Microspora*
		Chlorophyta	Chlorophyceae	*Mougeotia*
		Heterokontophyta	Bacillariophyceae	*Frustulia*
		Heterokontophyta	Bacillariophyceae	*Eunotia*

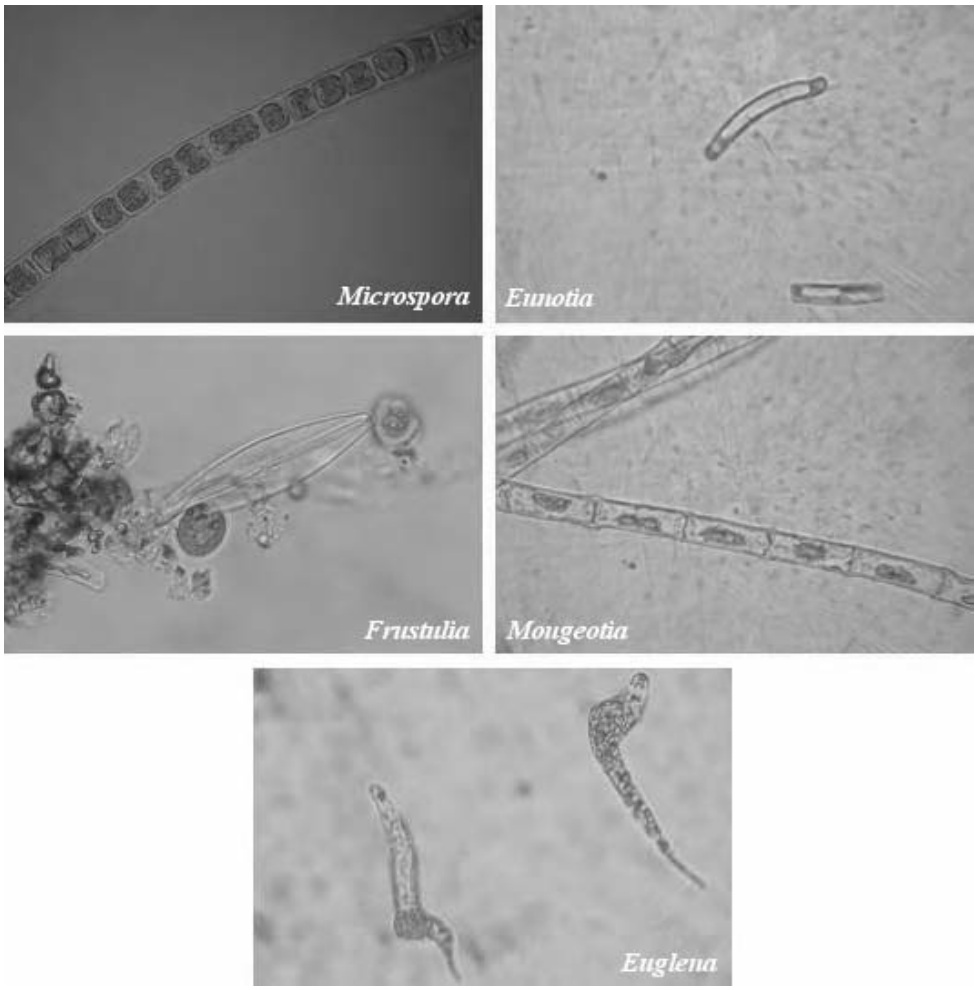

Figure 1 *Photomicrographs showing the algae identified in the coalfield of Santa Catarina Scale: increase of 1000×*

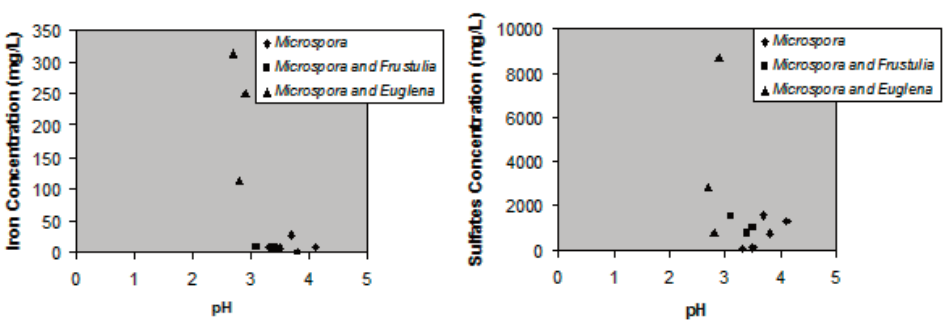

Figure 2 *Relation between sulfate and pH and sulfate and iron in the main associations of algae in the periphyton in the coal region of Santa Catarina, Brazil*

The filamentous algae *Microspora* demonstrated the best adaptation, being present in a wide range of pH (between 2.9 and 4.1) and with different levels of concentration of iron and sulfate. The genus *Frustulia* has developed well at pH between 2.7 and 3.5 and in water streams with low levels of iron and sulfate. The genus *Euglena* grew successfully in the sampling places more affected by the AMD, with pH between 2.7 and 3.0 and higher levels of sulfates and iron.

The most significant productivity, expressed as accumulated biomass, was in the winter where the biomass of periphyton can reach up to 14 g/m^2. The amount of biomass reduces in the spring with, in some places, a complete absence in the summer. The algae mats were found on unconsolidated sediments (like clay and sand), rocks and even in concrete, playing an important role in natural attenuation of stream waters degraded by AMD (Lawrence et al., 1998). These organisms ensure primary production interfering with the mobility of chemical species dissolved in the aquatic medium, like metals and sulfates (Valente and Gomes, 2007) being the pioneer species in the natural recovery of water courses impacted by AMD.

Conclusion

The watersheds in the carboniferous region of Santa Catarina, Brazil, are extensively impacted by the AMD. The results showed that the aquatic environment impacted by AMD can be inhabited by few algae groups. The genuses identified were: *Microspora*, *Eunotia*, *Euglena*, *Mougeotia*, and *Frustulia*. The dominant genus was the filamentous green algae *Microspora*. These organisms play an important role in natural attenuation of stream waters degraded by AMD.

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