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ARTICLE

Impact of iron ore mining on benthic macroinvertebrate community

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ABSTRACT: (Impact of iron ore mining on benthic macroinvertebrate community). Anthropogenic disturbances may negatively affect the quality of freshwater ecosystems. Among these disturbances, metal mining has increased at an alarming rate, often impacting small water bodies and thus aquatic communities. Therefore, the aim of this study was to test the hypothesis that the residuals of iron ore mining may decrease the species diversity of a benthic macroinvertebrate community in a stream. For this, three streams were evaluated in a mining area, and in each one samples of the macroinvertebrates were taken and a record of the abiotic factors made. It was found that taxa diversity in impacted streams is much lower than in preserved streams. Furthermore, the fauna composition in impacted streams was restricted to groups extremely resistant to environmental disturbances, such as *Chironomus* and *Pseudosmittia*. Changes in the physicochemical parameters of water, such as acidification and a decrease in dissolved oxygen, were also observed. This is one of the few studies in Brazil that demonstrates that the residuals of iron ore mining may decrease the diversity and modify the composition of the benthic macroinvertebrate community, contributing to future studies about the conservation of aquatic ecosystems.
Key words: bioindication, diversity, metal pollution, stream.

RESUMO: (Impacto da mineração de ferro na comunidade de invertebrados bentônicos). Perturbações antrópicas podem afetar negativamente a qualidade dos ecossistemas dulcícolas. Dentre essas perturbações, a mineração de metais tem crescido de forma alarmante, muitas vezes impactando pequenos corpos d'água e, consequentemente as comunidades aquáticas. Dessa forma, o objetivo deste trabalho foi testar a hipótese de que os resíduos de uma mineração de ferro podem diminuir a diversidade de espécies de macroinvertebrados bentônicos de um córrego. Para isso, três córregos foram avaliados em uma área de mineração, sendo que em cada um deles foi feita a coleta dos macroinvertebrados e o registro das variáveis abióticas. Foi constatado que a diversidade de taxa nos córregos afetados é muito inferior a do córrego preservado. Além disso, a composição da fauna nos córregos impactados se restringiu a grupos extremamente resistentes a perturbações ambientais, como Chironomus e Pseudosmittia. Também foi observada uma alteração nas variáveis físico-químicas da água, como sua acidificação e diminuição de oxigênio dissolvido. Este é um dos poucos estudos no Brasil que demonstra que os resíduos de uma mineração de ferro podem diminuir a diversidade e alterar a composição de macroinvertebrados bentônicos, contribuindo para futuros trabalhos de conservação de ecossistemas aquáticos.
Palavras-chave: Bioindicação, córrego, diversidade, poluição por metais.

INTRODUCTION

Anthropogenic disturbances may negatively affect the quality of freshwater ecosystems, altering the diversity, structure, distribution and functioning of aquatic communities (Grumiaux *et al*. 1998, Vásquez *et al.* 1999, Doi *et al.* 2007). Among these disturbances, metal mining has increased at an alarming rate, and its residuals are not always treated adequately, often being liberated into small water bodies (Smolders *et al.* 2003, Doi *et al.* 2007).

The effects of metal mining residuals in aquatic environments have already been documented for North America, Europe, Australia and New Zealand, with impacts reported on fishes, invertebrates and macrophytes and even alterations in trophic webs (Rasmussen & Lindegaard 1988, Farag *et al.* 1998, Winterbourn *et al.* 2000, Johnson & Ritchie 2003, Rohasliney & Jackson 2008). In Brazil, studies about the impacts of mining are concentrated in the southern region, with surveys focused on the extraction of coal, copper and zinc (Milesi *et al.* 2008, Bieger *et al.* 2010). Even though it is among the biggest exporters of iron ore in the world, there are few studies in Brazil investigating the effects of this kind of mining on aquatic organisms.

After treatment, the residuals from iron ore mining still contain many iron ions (Besser *et al.* 2007). These, at low concentrations, can cause water acidification, reduce respiratory efficiency in fishes and the processing of allochthonous organic matter by shredders, cause deformities in the larvae of insects and crustaceans, and change the composition of the benthic macroinvertebrate community (Dills & Rogers 1974, Callisto *et al.* 2000, Tkatcheva *et al.* 2004, Barnden & Harding 2005, Ravengai *et al.* 2005, Besser *et al.* 2007).

Among aquatic organisms, macroinvertebrates are the ones most affected by the contamination of metal ions (Wellnitz *et al.* 1994, Grumiaux *et al.* 1998, Hünken & Mutz 2007). Metal pollution can reduce the diversity and density of these organisms, causing the disappearance of the most sensitive groups, such as the insect orders Ephemeroptera, Plecoptera and Trichoptera (EPT) (Smolders

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et al. 2003, Fialkowsky & Rainbow 2006, Doi *et al.* 2007).

Due to their high sensitivity to modifications in water quality, fast response to disturbances, and ease sampling and taxonomic identification, benthic macroinvertebrates have a high potential bioindicator (Courtney & Clements 2000, Doi *et al.* 2007). Therefore, these animals can be used efficiently as bioindicators of environmental quality in sites contaminated by mining residuals.

Thus, the aim of this study is to verify whether the residuals originating from iron ore mining can negatively affect the benthic macroinvertebrate community and abiotic and physical factors, testing the hypothesis that these residuals reduce species diversity.

MATERIALS AND METHODS

The study was conducted at the Estação de Pesquisa e Desenvolvimento Ambiental de Peti (EPDA) in the state of Minas Gerais, southeastern Brazil (10°52′23″ and 19°54′27″S, 43°20′51″ and 43°23′28″W). The climate is humid subtropical, with a dry season from April to September and a rainy season between October and March (Costa *et al.* 2006). Moreover, there are large reserves of iron ore in the region, as well as mining areas within the limits of the EPDA.

In this work, we studied the Brucutu and Frederico streams, and a third one formed by the union of both, here called Junction. The streams are part of the River Doce watershed, and although they cross the EPDA, their springs are not located within the research station.

The headwaters of the Brucutu stream are located within an area of exploration of iron ore beside the EPDA. All rejects produced by this mining are discharged into its waters, increasing the flow speed and producing a red color. Due to increased water speed, the soil erosion in the margins is continuous along its course and there is no arboreal riparian vegetation. The bottom substrate is homogeneous and very particulate.

The Frederico stream, on the other hand, is not influenced by the mining residuals. The water is transparent and has riparian vegetation composed of arboreal species throughout the studied section. The bottom substrate is heterogeneous, consisting of leaves, pebble, sand and clay.

The Junction of the two streams already described has the same physical characteristics as the Brucutu, including the absence of riparian vegetation, bottom substrate and water features.

The sampling of the benthic macroinvertebrates was conducted at the beginning of the rainy season (October) in 2010. Ten samples were collected from each of the three streams, resulting in 30 sampling sites. In the Brucutu and Junction streams, the studied stretch was 150 meters, with samples taken every 15 meters. However, in the Frederico stream, due to the physical limits of the EPDA, the samples were taken every 12 meters, totaling 120 meters studied.

The samplings of benthic macroinvertebrates were taken using a Surber net with an area of 900 cm^2 and a 225 µm mesh. The collection of the bottom substrate was carried out for about two minutes and at each site the same amount of material was sampled. In the field, the sediment sampled was placed in 600 ml plastic containers and preserved in ethanol, 70%.

In the laboratory, the sediment was washed in a system of 0.2, 1 and 2 mm sieves , and only the macroinvertebrates were retained. The animals were preserved in ethanol, 70% and identified with the aid of dichotomous keys, down to the lowest taxonomic level, based on the studies of Salles *et al.* (2004), Calor (2007), Pinho (2008) and Mariano & Polegatto (2011).

In order to verify whether there were differences between the physical and abiotic factors of the three streams, the following variables were measured: water speed, temperature, pH, conductivity and dissolved oxygen. Water flow speed was measured at the center of the channel and on the sides, where a floating object in the water was released and the time spent to complete three meters was recorded. Then, the mean of these three measurements was calculated, which represented the water flow velocity in each stream (Bueno *et al.* 2003). The other variables were measured with electronic instruments.

The structure of the benthic macroinvertebrate communities in the three streams was evaluated by the values of total richness, by the Shannon-Wiener diversity index (H') and by the Margalef Richness and Equitability index, and expressed by the Pielou index.

RESULTS

We found 14 macroinvertebrate taxa, and the insects were the most abundant and diverse in the three streams (Table 1).

The Brucutu and Junction streams presented low total richness (four and five taxa, respectively). All the taxonomic groups were shared between these two streams, except for Oligochaeta, which was found only in the Junction. In Brucutu there was a predominance of the genus *Chironomus* (42%), and in the Junction, the genera *Culicoides* and *Chironomus* were the most abundant (34% each). The few genera found in these two streams are typical of environments with large amounts of organic matter and low levels of dissolved oxygen, as well as being considered bioindicators of bad water quality (Smolders *et al.* 2003, Doi *et al.* 2007).

The Frederico stream had the highest total richness (14 taxa), almost three times higher than the other streams in the study. In addition, nine of these taxa were only found in this stream. The presence of genera from the Ephemeroptera and Trichoptera orders, typical bioindicators of good water quality (Doi *et al.* 2007), demonstrated that the degree of preservation of the Frederico stream is possibly higher than that of the others.

The Shannon-Wiener diversity index varied among the streams. Brucutu showed the lowest values of diversity (1.1), followed by Junction (1.2) and the Frederico stream

Table 1. Number of benthic macroinvertebrate individuals in three streams at the Estação de Pesquisa e Desenvolvimento Ambiental de Peti, Minas Gerais state, Brazil.

Taxa	Frederico	Brucutu	Junção
Arthropoda			
Insecta			
Diptera			
Chironomidae			
Chironomus	17	42	33
Pseudosmittia	10	27	25
Ceratopogonidae			
Culicoides	13	28	33
Trichoptera			
Leptoceridae			
Nectopsyche	5		
Hydroptilidae			
Oxyethira	4		
Hydropsychidae			
Leptonema	1		
Calamoceratidae			
Phylloicus	2		
Ephemeroptera			
Leptophlebiidae			
Massartella	2		
Odonata			
Libelullidae	1	3	1
Coleoptera			
Elmidae	6		
Annelida			
Oligochaeta	6		5
Mollusca			
Gastropoda	7		
Crustacea			
Cladocera	25		
Platyhelminthes			
Turbellaria	17		
Total	**116**	**100**	**97**

(2.3), which was the most diverse. The same pattern also occurred for the Margalef Richness index, which was highest for Frederico (2.7), intermediate in Junction (0.9) and lowest in the Brucutu stream (0.7). For Equitability values, the Frederico stream had the highest value (0.87), followed by Brucutu (0.85), and Junction had the lowest value (0.8).

The physical and abiotic factors also varied among streams (Table 2). The lowest values of pH and dissolved oxygen were recorded in Brucutu and the highest in Frederico. The electrical conductivity, water speed and temperature were highest in the Brucutu and Junction streams and lowest in Frederico.

DISCUSSION

Iron ore mining residuals negatively affect the benthic macroinvertebrate community, reducing the diversity and altering the taxa composition, both in the streams where the release occurs and in the junction. The control stream, unaffected by residuals, supports three times more macroinvertebrate diversity than those affected, presenting a diverse and typical fauna from preserved environments.

Table 2. Physicochemical variables recorded in three streams at the Estação de Pesquisa e Desenvolvimento Ambiental de Peti, Minas Gerais state, Brazil. Units: EC (electrical conductivity), $\mu S/cm^{-1}$; DO (dissolved oxygen), mg/L; T (temperature), °C; WS (water speed), m/s.

Stream	pH	EC	DO	T	WS
Frederico	7.5	9	7.4	22.8	0.3
Brucutu	5.3	42	5.2	25.4	0.75
Junção	6.0	29	6.3	24.8	0.9

Mining can cause many negative effects on aquatic systems, such as destabilization of the bottom substrate by iron precipitates and reduction of the feeding potential of several organisms, by causing decreased periphyton deposited on the surfaces, such as rocks and leaf litter (Rasmussen & Lindegaard 1988).

However, perhaps one of the worst consequences of iron ore mining is the change in water chemical characteristics, such as acidification (Ravengai *et al.* 2005). This kind of mining leads to acid drainage, releasing sulfuric acid and iron sulfate in the environment, consuming large amounts of oxygen from the water and reducing its availability to aquatic organisms (Ravengai *et al.* 2005). A decrease of the pH in the water caused by mining residuals was also observed in this study, so acidification of the water can become toxic to most macroinvertebrate communities (Guerold *et al.* 2000), which may lead to a change in ecosystem structure and affect the richness and equitability of species (Doi *et al.* 2007).

The EPT families are the most affected by the toxicity resulting from the very acidic conditions, and are rarely found in areas with pH below four (García-Criado *et al.* 1999, Doi *et al.* 2007, Hünken & Mutz 2007). Apparently, in the Brucutu and Junction streams, the genera of Ephemeroptera and Trichoptera may also be affected by water acidification; however, other factors could have influenced their absence in these environments, such as low dissolved oxygen, a fact already observed in other studies about mining residuals (Dills & Rogers 1974, Johnson & Ritchie 2003, Ravengai *et al.* 2005).

On the other hand, some families of insects, such as Chironomidae, can benefit from the changes to natural conditions of aquatic environments resulting from mining (Ravengai *et al.* 2005). In disturbed habitats, these organisms become the most abundant and dominant within communities (Doi *et al.* 2007), as was also observed in this study. This is due to the fact that these animals can adapt to many different environmental conditions (Callisto *et al.* 2000), presenting a low mortality rate and high recolonization capacity when submitted to metal pollution, besides presenting genes that enable them to survive under conditions of high concentrations of these substances (Groenendijk *et al.* 2002). Moreover, the larvae of these insects are capable of present behavioral and physiological adaptations that enable them to support anaerobic conditions and large temperature variations (Walshe 1948) in habitats with differences in environmental quality (Frouz *et al.* 2003).

Apparently the negative effects of iron ore mining are not restricted to the affected stream (Rasmussen & Lindegaard 1988, Johnson & Ritchie 2003, Doi *et al.* 2007), so the decrease in species richness and the physicochemical water changes may extend to other water bodies, as was the case with the Brucutu and Junction streams. Iron residuals can spread in a large part of the watershed, affecting sites up to ten miles away from mining, besides penetrating aquifers, affecting distant environments and many other organisms (Ravengai *et al.* 2005).

This is one of the first studies in Brazil to demonstrate that residuals from iron ore mining may reduce the diversity and change the composition of a benthic macroinvertebrate community in a stream. By changing the physical environment and the chemical conditions of the water, the residuals can deeply modify the functioning of ecosystems and their negative effects are not yet completely understood. Therefore, future studies should investigate how the aquatic communities respond to environmental changes caused by iron ore mining residuals and what the long-term effect of this metal is in the ecosystem, since the negative effects are not restricted to the affected site.

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