2011 International Nuclear Atlantic Conference - INAC 2011
Belo Horizonte,MG, Brazil, October 24-28, 2011
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-04-5**

ZOOPLANKTON COMMUNITY OCCURRENCE IN AN AREA INFLUENCED BY URANIUM MINE, CALDAS, MG, BRAZIL

Carla R. Ferrari [1-2*], Heliana de Azevedo[1], Maria José dos S. Wisniewski[3], Cláudio V. Roque[1], Leilane B. Ronqui[1], Michelle B. de Campos, Armando L. Bruschi[1], Marcos Roberto L. Nascimento[1] and Suzelei Rodgher[4]

[1] Poços de Caldas Laboratory, Brazilian Nuclear Energy Comission.
Rodovia Poços de Caldas-Andradas, Km 13,
37701-970 Poços de Caldas, MG-Brazil.
carlarolimferrari@yahoo.com.br
hazevedo@cnen.gov.br
cvroque@cnen.gov.br
leilanebio@yahoo.com.br
michelle_borato@hotmail.com
abruschi@cnen.gov.br
pmarcos@cnen.gov.br

[2] Master in Biotechnology- University of São Paulo USP-SP.
Av. Professor Lineu Prestes - ICB IV,
05508-900 São Paulo, SP-Brazil
carlarolimferrari@yahoo.com.br

[3] Laboratory of Limnology -Federal University of Alfenas-UNIFAL-MG.
Rua Gabriel Monteiro da Silva, 714,
37130-000 Alfenas, MG-Brazil.
czw@uol.com.br

[4] Department of Ecology and Biology Evolutionary- Federal University of São Carlos-UFSCar-SP
Rodovia Washington Luis Km 13
São Carlos, SP-Brazil
surodgher@uol.com.br

ABSTRACT

The Ore Treatment Unit (UTM), situated on the Poços de Caldas -MG Plateau, is Brazil's first venture in uranium ore mining and chemical treatment and it belongs to Brazilian Nuclear Industries today. At UTM, radioactive effluents are generated due to the mine's acid drainage processes (MAD). Thus, due to the lack of scientific information with emphasis on Zooplankton Communities in areas impacted by uranium mine and MAD, the current study aimed to evaluate parameters such as electrical conductivity, pH, total phosphorus, total nitrogen, sulfate, fluoride, uranium, thorium, manganese, zinc and aluminum, as well as richness and density of the zooplankton organism's, all in samples from the Pit Mine. The electrical conductivity values observed were elevated (1976 to 2760 µS cm^{-1}), while the pH values remained acidic (3.6 to 4.1). In respect to the SO_4^{-2}, elevated concentrations were observed (366.6 - 1832.0 mg L^{-1}), as well as for F^- (33.4 to 75.1 mg L^{-1}). The U presented highest and lowest concentrations in Oct/08 and July/09, that is, 4.25 mg L^{-1} and 0.12 mg L^{-1}, respectively. The Th concentrations remained constant (0.10 - 0.30 mg L^{-1}). In respect to the Zooplankton

Community low species richness and density were observed throughout the whole period. The low richness and density values of the zooplankton species can be related to the adverse environmental conditions, which are unfavorable to the development of this community: elevated values of electrical conductivity and acidic pH, both associated to the chemical composition of the effluent *in natura*.

Keywords: uranium mine, radioactive effluents, pit mine and zooplankton community.

1. INTRODUCTION

Mining activities involve big modifications on the explored environment, resulting in chemical, biological and landscape contour alterations [1]. Such activities are related to the formation of mining lakes (pit mines), which are considered the only habitats on the landscape, being usually associated to alterations on water quality [2].

One of the main problems originated from the formation of these mining lakes is the occurrence of acid mine drainage (AMD), which results on the formation of an affluent chemically characterized by elevated acidity associated to elevated concentrations of sulfates and some common metal types (Al, Cu, Zn, Fe among others) depending on the type of mining exploration in question [3].

Uranium mines, in special, produce great quantity of waste with elevated quantities of radioactive material disposed in mine tailing piles, including the occurrence of highly toxic heavy metals, which generate negative impacts on the explored environment [4]. According to [5] the chemical element uranium is one of the greatest concerns for fresh water biota, due to its highly ecotoxicological potential. Regarding the microorganisms belonging to the zooplanktonic community, it is verified that there is a lack of information about the composition and ecology of this community in lakes impacted by uranium mine and acid mine drainage.

In this context, the aim of current study was to evaluate the chemical and physical characteristics, as well as the composition of zooplankton species in water samples collected in the Osamu Utsumi Uranium Mine Pit. It is noteworthy that the study of zooplanktonic organisms in extreme environments (elevated electrical conductivity, elevated concentrations of radioactive and stable chemical elements, acidic pH, as well as exposure to elevated ionizing radiation rates) is of great importance in order to evaluate the effect of radioactive effluents on this community, aiming to subsidize future actions related to the decommissioning of this mining area.

2. MATERIALS AND METHODS

2.1. Study Area

2.1.1. Pit Mine

The Osamu Utsumi Uranium Mine of the Brazilian Nuclear Industries (INB), located in the city of Poços de Caldas, Minas Gerais, constitutes the first mining-industrial venture of concentrated uranium ore production to operate in Brazil. In the mining area's Pit Mine,

radioactive effluents are generated by AMD processes. In the Pit Mine, the AMD occurs basically by the natural oxidation of the metallic sulfide pyrite (FeS_2), which in contact with water and oxygen leads to the formation of sulfuric acid, which when dissolved in water, promotes the solubilization of minerals present in the rock.

2.2. Experimental Design

On the Pit Mine point (PM= 21º 56' 46,0''S e 46º 30' 06,7'' W) trimestrial collections of water samples were carried out in the surface region close to the margin from the month of October 2008 to July 2009.

2.3. Physical and Chemical Variables

2.3.1. Electrical Conductivity, hydrogenic potential (pH), total phosphorus (TP), total nitrogen (TN,) sulfate (SO_4^{-2}), fluoride (F^-), uranium (U), thorium (Th), manganese (Mn), zinc (Zn) and aluminum (Al)

The electrical conductivity measurements of the water were performed with the aid of a conductimeter (brand Digimed) with the use of a selective electrode, the pH was measured using a pH selective electrode combined with a temperature sensor (WTW-320). For the determination of nutrient concentrations, water samples were collected using a vertical bottle, of five liters, Van Dorn type, for sampling on the surface, through and on the bottom of the water column, based on the following methodologies: for total nitrogen, the methodology described by [6]; for total phosphorus, the technique described by [7].

The uranium and thorium radionuclides analyses were performed according to the methodology described by [8], while the total metals (Mn, Zn and Al) analyzed only on the months of January and July 2009, the analysis followed the methodology described in [9].

2.4. Zooplanktonic Community

For the qualitative analysis of zooplanktonic organisms, horizontal hauls were performed with the aid of a plankton net of 60µm mesh pore size. Then, the organisms were fixed in 4% formaldehyde (final concentration) and the samples were stored in glass bottles for subsequent screening of the material. The identification of the zooplanktonic organisms was conducted under an optical microscope (Zeiss-Axioplan-2) with magnification up to 1000x, based on specialized bibliography [10] [11] [12] [13] [14] and [15]. For the quantitative analysis, vertical hauls were performed while knowing the site depth and the filtered volume. For the determination of the collected volume, the cylinder volume formula was used ($\pi.r^2 \times h$) $\times$ number of hauls where: π=3.14 r =0.15 m (net radius) h=depth. The cladocerans and copepods countings were carried out in checkered acrylic plates under a Zeiss-Stemi SV11 stereoscopic microscope, with magnification up to 66x, counting sub-samples or even the whole samples for the rare organisms. For the rotifers, sub-samples of 1mL were counted in a Sedgewick-Rafter chamber under optical microscope with magnification up to 1000x.

3. RESULTS AND DISCUSSION

The results of the physical and chemical variables are presented on Table 1.
In the current study, the low pH values recorded at the PM (3.6 - 4.1) can be explained by the occurrence of acid mine drainage, that constitutes the main environmental liabilities of the

UTM, being the result of natural oxidation of the metallic sulfide pyrite (FeS_2), which in presence of water and oxygen leads to the formation of sulfuric acid, that contributes to the reduction of pH values in this site. According to [16] the processes of surface water acidification caused by oxidation of the metallic sulfide pyrite are well known and documented, in areas impacted by mining activities.

The electrical conductivity values recorded at the PM ranged from 1976 to 2760 µS cm^{-1} (average = 2391.5 µS cm^{-1}) (Table 1). In Lake Plessa, located in Lusatia, Germany, an average value of electrical conductivity was found to be superior (4450 µS cm^{-1}) to the one recorded at the PM [17]. According to [18] in a study conducted in the acid Lake ML111, formed in a coal mining area, also located in Lusatia, Germany, values of maximum and minimum electrical conductivity were (2800 a 2000 µS cm^{-1}), values considered closer when compared to the ones detected at the PM.

Concerning the recorded results for the total form nutrients, the values of phosphorus and nitrogen ranged respectively, from 5.6 to 17.95 µg L^{-1} and 700 to 840 µg L^{-1} (Table 1). In a study conducted in a uranium mining lake in Canada, the total phosphorus values recorded (ranging from 90 to 200 µg L^{-1}), are higher when compared to those recorded at the PM [2]. In a study conducted by [16] at Lake Cospuden, located in Lusatia, Germany, impacted by mining activity, the author registered total nitrogen concentration values ranging from 500 to 1100 µg L^{-1}, similar to recorded values at the PM.

Concerning the ion sulfate, the recorded concentrations presented a wide variation throughout the study period, since values ranged from 366.6 to 1832.0 mg L^{-1}, while the fluoride values recorded ranged only from 33.4 to 75.1 mg L^{-1}. It was also verified that, for the heavy metals manganese, zinc and aluminum, there were records of elevated concentrations, with the highest values detected in samples from jan/09 for the three elements, which are: 142.8 mg L^{-1}, 19.9 mg L^{-1} and 70.85 mg L^{-1}, respectively. Concerning the element uranium, the concentrations ranged from 0.12 to 4.25 mg L^{-1}. For thorium, the highest recorded value was 0.30 mg L^{-1} on april/09 (Table 1).
At the PM, the elevated values of sulfate, fluoride, manganese, zinc and aluminum recorded at this site are related to AMD. According to [19] the UTM effluents, chemically characterized before treatment for subsequent discharge on the environment, presented elevated concentrations of fluoride, sulfate, manganese, zinc, uranium, thorium, among other elements, which are in accordance with the results of the current study.

Table 1. Variable values (pH, electrical conductivity, total phosphorus, total nitrogen, sulfate, fluoride, uranium, thorium, manganese, zinc and aluminum) at the Pit Mine point (PM), on the months of October/2008 (Oct/08), January/2009 (Jan/09), April/2009 (April/09) and July/2009 (Jul/09), average and standard deviation.

Variables	Oct/08	Jan/09	Apr/09	Jul/09	Average	Standard Deviation
pH	4.1	3.6	3.7	3.9	3.8	0.2
Eletrical Conductivity ($\mu S.cm^{-1}$)	2600.0	2230.0	2760.0	1976.0	2391.5	355.0
Total phosphorus ($\mu g\ L^{-1}$)	5.60	10.35	17.95	13.10	11.8	5.2
Total nitrogen ($\mu g\ L^{-1}$)	700.0	770.0	840.0	700.0	752.5	67.0
Sulfate ($mg\ L^{-1}$)	1832.0	1653.0	1800.0	366.6	1412.9	701.9
Fluoride ($mg\ L^{-1}$)	75.1	65.7	47.1	33.4	55.3	18.7
Manganese ($mg\ L^{-1}$)	-	142.8	-	94.1	118.5	34.4
Zinc ($mg\ L^{-1}$)	-	19.9	-	15.9	17.9	2.8
Aluminum ($mg\ L^{-1}$)	-	70.85	-	68.25	69.6	1.8
Thorium ($mg\ L^{-1}$)	0.10	0.11	0.30	0.10	0.2	0.1
Uranium ($mg\ L^{-1}$)	4.25	3.17	4.23	0.12	2.9	1.9

- Analysis not conducted

Regarding the zooplanktonic community there were records of low species richness and density throughout the whole period of study. In samples from the PM only 3 species were detected, being one of the Phylum Rotifera (*Keratella americana*) and two of the Cladocera group (*Bosmina* sp. and *Bosminopsis deitersi*), in addition to another representative of the Rotifer group, belonging to the Bdelloidea order. The highest density value recorded at the PM was only 5.65 ind. m^{-3} on april/09 (Figure 1).

According to [16] acid lakes influenced by mining activities present peculiar characteristics such as: low species diversity and zooplanktonic crustacean (Cladocera, Copepoda) and rotifers abundance, as well as the absence of sensitive groups such as the Daphnids. In the current study, this same tendency was observed, once this environment was characterized by low diversity, abundance and density of zooplanktonic organisms, in addition to the absence of sensitive groups, in accordance to information from [16].
In an acid lake formed after the closing of a uranium mine, the occurrence of the *Kerattela* sp. genus was recorded, with values ranging from 0.008 to 0.016 ind.m^{-3} (lower density) [2].
In samples from the PM, the species *Keratella americana* belonging to the *Keratella* genus was detected, although, it presented a higher density value of 1.41 ind.m^{-3}, when compared to the values recorded by [2] (Figure 1). According to [11] *Keratella americana* is a species associated to acidic waters. In the current study, the occurrence of this species at the PM was related to acidic pH values, which corroborates with information from [11].

The presence of the Cladocera (*Bosmina* sp. and *Bosminopsis deitersi*) at the PM together with the Rotifer (*Keratella americana* and Bdelloidea), even in low densities, can indicate this species capacity to endure the chemical stress of this environment, according the results cited above.

In some acid lakes impacted by coal mining, in Lusatia, Germany, studies conducted by [18] [20] and [21] (with pH ranging from 2.6 to 3.8) indicated the presence of some rotifer species which are characteristic of these environments, such as *Brachionus sericus*, *Cephalodella hoodi*, *Elosa worallii* and *Rotaria rotatoria* (Bdelloidea order) and of the *Chydorus sphaericus* species (cladoceran).
It is notable, that in the study by[18] the coal mining lakes ML111 (pH=2.6) and ML117 (pH=3.0) with lower pH value, presented elevated values of electrical conductivity, sulfate, iron and aluminum, factors that when combined, can be associated to low richness of zooplanktonic species, that is, only 3 and 7, respectively. In the same study, Lake Felix, which presented a range of pH variation between 3.4 and 3.8, was marked by the presence of 11 zooplanktonic species. In a study conducted on Lake Plessa, a coal mining lake also located in the region of Lusatia, Germany, the presence of only two rotifer species *Cephalodella hoodi* and *Rotaria rotatoria* (Bdelloidea) was verified [17]. This lake presented record of an extremely low pH value (average pH=2.3), associated to elevated values of electrical conductivity, sulfate, iron, aluminum, manganese and zinc.

When comparing results from the different studies approaching zooplanktonic species richness in acid lakes in the region of Lusatia, Germany, it can be verified that the acidic pH associated to elevated values of electrical conductivity, sulfate, iron, aluminum, manganese and zinc influenced the zooplanktonic species richness in these environments. Thus, the pH values and the chemical condition of the water were related to the increase or decrease in zooplanktonic species richness.
Based on the results obtained in the PM samples the chemical quality of the water in relation to pH was “better” on this site, that is, the water pH values were less acidic. On the other hand, some chemical parameters such as: electrical conductivity, sulfate, zinc, manganese, aluminum and iron presented records of lower than or similar concentrations to the ones recorded by [18] and [17] however, there were records of lower zooplanktonic species richness in samples from the PM, when compared to results recorded by these authors.

Thus, the results of the current study indicate that uranium and thorium radionuclides may have interfered in the composition and richness of species found in the PM. Since uranium has recognized toxicity to aquatic life [22], it can be inferred that this variable had an important role on the reduction of zooplanktonic species richness and density on this site.

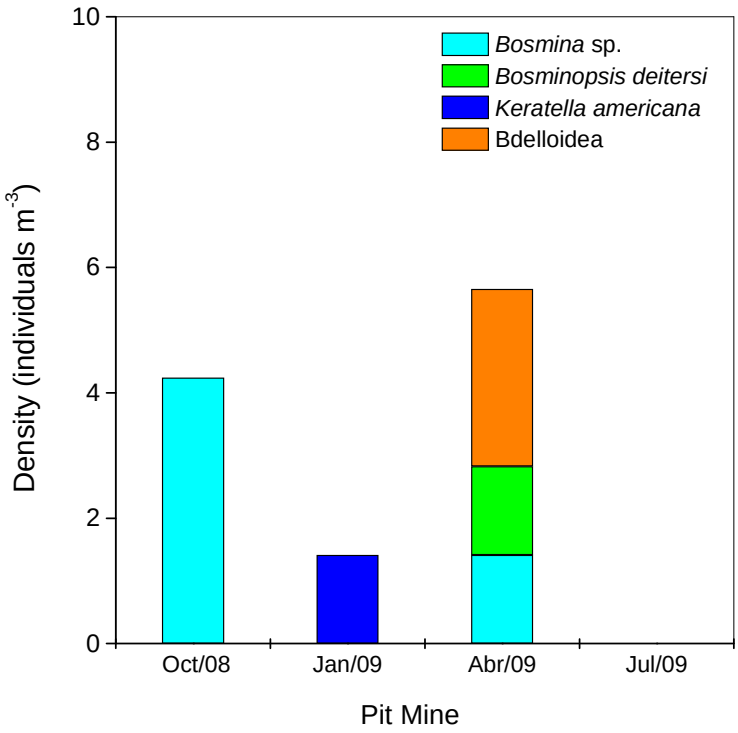

Figure 1. Density (ind.m^{-3}) of *Bosmina* sp., *Bosminopsis deitersi*, *Keratella americana* species and Bdelloidea order in samples from the Pit Mine on the months of October 2008 (Oct/08), January (Jan/09), April (April/09) and July (Jul/09) 2009.

4. CONCLUSIONS

In the current study, the low richness and density values of the zooplanktonic community species can be related to adverse environmental conditions of the site, not favorable to the development and permanence of this community such as: acidic pH, elevated electrical conductivity, low nutrient concentrations as well as presence of the radioactive metals uranium and thorium recorded in this environment. The presence of *Keratella americana*, *Bosminopsis deitersi*, *Bosmina* sp. species and the Bdelloidea order indicates resistance of these species to extreme environmental conditions on this site.

ACKNOWLEDGMENTS

FINANCIAL SUPPORT: Fundação de Amparo a Pesquisa do Estado de Minas Gerais

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