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Review

The natural rehabilitation of an anthropogenically acidified tropical Lake: Two decades of monitoring

Cristiano V.M. Araújo [a,b,*], Salomão J. Cohin-de-Pinho [a], Carla B.A. Chastinet [c], Sandro L. Machado [d], Eduardo M. da Silva [a]

[a] Instituto de Biologia, Federal University of Bahia, Campus de Ondina, 40170-115 Salvador, BA, Brazil
[b] IMAR – Instituto do MAR, Department of Life Sciences, University of Coimbra, Apartado 3046, 3001-401 Coimbra, Portugal
[c] Instituto do Meio Ambiente e Recursos Hídricos, Rua São Francisco, No. 1, 40245-060 Salvador, BA, Brazil
[d] Departamento de Ciência e Tecnologia dos Materiais, Escola Politécnica, Federal University of Bahia, 40210-630 Salvador, BA, Brazil

HIGHLIGHTS

- Natural rehabilitation of an acidified Lake was monitored during two decades.
- pH, conductivity, sulphate, iron and toxicity of the water were monthly recorded.
- Toxicity levels were related to Lake pH values which ranged with rain and dry regime.
- Moving average approach using pH data showed clearly the Lake recovery process.
- Recent data highlight Lake rehabilitation and the efficiency of the containment plan.

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ABSTRACT

The rehabilitation of a pond after approximately 20 years of strong acidified conditions due to industrial and domestic waste deposition in its catchment basin is reviewed. We describe in this study the acidification process that occurred in a tropical pond in Northeast Brazil (Dunas Lake), the rehabilitation plan for the pond and the subsequent monitoring conducted over two decades. After the contamination assessment by the late 80s, a rehabilitation plan was carried out in the early 90s, in which the contaminated soil and water have been removed and reduced, respectively. No further attempt to neutralize the water or any remediation has been carried out. A toxicity monitoring plan based on toxicity assays with the fish *Poecilia reticulata* was employed to verify the natural rehabilitation of the pond. The data on toxicity, pH, conductivity, sulphate and dissolved iron recorded from 1994 to 2010 were also compiled and discussed. The collected data in 2003 and 2004 indicated changes in water quality and from them complementary management actions, namely improvement in the containment plant, were conducted in 2005. Results for toxicity assays and pH results indicated interannual changes in the water quality similar to rainy-dry periods. Moving average approach using pH data clearly showed the recovery process of Dunas Lake as well as the importance of the containment plan to reduce the contamination. Finally, a summary of the recent situation after two decades of rehabilitation is provided.

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* Corresponding author at: Instituto de Biologia, Federal University of Bahia, Campus de Ondina, 40170-115 Salvador, BA, Brazil. Tel.: +55 71 3263 6525; fax: +55 71 3263 6511.
E-mail address: cristiano.araujo@icman.csic.es (C.V.M. Araújo).

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1. Introduction

Acidification from anthropogenic sources has attracted much attention during the past 50 years because it is one of the principal drivers of environmental disruption in many parts of the world (Gorham, 1998; Driscoll et al., 2003). Such acidification arises primarily from the consequences of acid rain and acid mine drainage, although other types of anthropogenic activities, such as vegetation burning (Geller et al., 1998; Ribeiro et al., 2002; Mello et al., 2006), and natural causes of regional importance, such as volcanic activity, may also play a role. Unfortunately, studies of acidification are primarily focused on highly developed and temperate-zone countries. In Brazil, studies of acidification are most frequently performed in the subtropical south-eastern, most industrialized region, where mining, industries, biogenic emissions and sugar-cane burning could be related to the acidification of soils and waters (Moreira-Nordemann et al., 1988; Rodhe et al., 1988; de Mello, 2001; Lara et al., 2001; Krusche et al., 2003; Martinelli et al., 2006; Mello et al., 2006).

According to da Silva et al. (2000, 1999a, 1999b), by the end of 80's, some industrial and domestic solid residues, whose principal source was a titanium dioxide plant, were deposited on the dunes adjacent to the Dunas Lake (Camaçari, Bahia, Brazil), a pond located between coastal secondary dunes. The residues were subsequently leached by rainwater percolating through the dunes sandy soil, contaminating the ground- and the surface water. Ground- and surface water pH decreased to values as low as 1.8 (Gomes, 1994). Chemical intervention to neutralize the deleterious effects of acidification should be the most reasonable alternative because under extremely acid conditions, the natural rehabilitation of Dunas Lake would not be considered feasible in practice. Nevertheless, these conditions could offer an excellent opportunity to monitor the capacity and time necessary for the natural rehabilitation of that ecosystem. Thus, a rehabilitation plan with no chemical intervention and, subsequently, a monitoring plan based on the measurements of a number of parameters (pH, conductivity, sulphate and dissolved iron concentration, and toxicity assay) were designed. The basic focus of the current review is the ecotoxicological studies that were conducted over eighteen years to monitor the reduction in toxicity and the role played by pH in producing the toxicity. Because the pH was determined to be the factor primarily responsible for the toxicity (Araújo et al., 2008a), we also decided to verify the existence of seasonal fluctuations and interannual trends of the pH data using moving average analysis.

2. Material and methods

2.1. Dunas Lake: general description and origin of contamination

Dunas Lake is located in Camaçari (Bahia, Brazil), along the South Atlantic coast (12.803003 S, 38.219324 W). It consists of a narrow, shallow body of freshwater located in a depression surrounded by secondary dunes, adjacent to a wetland system that runs parallel to the coast and presents no surface connection between them. Groundwater inflow is the primary source of water input to the wetland system. A more detailed description of Dunas Lake is given in da Silva et al. (2000, 1999a, 1999b).

At the end of the 80's, large quantities of solid residues (sulphur, iron, titanium dioxide, ilmenite and domestic wastes, mostly paper, cardboard, plastic bags and wood) from the industrial activity from a titanium dioxide plant have been dumped on the dunes adjacent to the pond. The groundwater and surface waters were heavily contaminated, and the pH decreased to an extremely acid value (1.8). Additionally, the concentrations of dissolved iron and sulphate and the subsequent precipitation of humic acids increased. These changes affected the transparency of the water and disrupted the biological communities in the pond (da Silva et al., 2000, 1999a, 1999b). The contamination plume in the groundwater did not reach Jauá Lake, which maintained its original characteristics and has been considered to represent a reference site (da Silva et al., 2000).

2.2. Rehabilitation plan and monitoring

In 1992, a rehabilitation program was initiated to restore groundwater and surface water quality as well as to reduce the levels of contamination regarding to acidification (da Silva et al., 2000, 1999a, 1999b; Gomes, 1994). Initially, 34,000 Mg of residues were removed; groundwater was continuously pumped out to reduce the contamination plume, which was discharged through a marine outfall; and 16,400 m^3 of industrial waste and approximately 15,500 m^3 of domestic waste were hydraulically encapsulated in the dune (da Silva et al., 2000, 1999a, 1999b; Gomes, 1994). The residues confinement consisted of a cover layer with three sub-layers of soil, composed of a 20 cm uniform eolian sand, 40 cm of a poorly compacted layer of residual soil, product of the weathering of a granite/gneiss bedrock and, a 60 cm of compacted material similar to the previous one, from top to bottom. The water collected by the drainage system was removed through a peripheral drain installed around the system.

In 2003 data of the monitoring wells installed in the area indicated a decrease in pH, and ecotoxicity assays using surface waters indicated a reverse trend in toxicity reduction (see subsequent subsections). These results were immediately related to failures in the containment system performance and, between 2003 and 2004, a geotechnical investigation detected failures in the cover layers, as soil permeability values in the containment layers were high and, in some points tree roots were found further bottom layer, indicating poor system performance.

Having detected that, a new cover layer was set up by October 2005 after the removal of the sand and intermediate layers, using bentonite in the bottom layer to ensure low permeability and above the new compacted layer of soil, a 2 mm layer of high density polyethylene (HDPE) membrane was installed to produce a