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Soil mesofauna as bioindicators to assess environmental disturbance at a platinum mine in South Africa

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ABSTRACT

South Africa is rich in mineral resources and is one of the leading raw material exporters in the world. Mining is essential for economic development, but also has detrimental environmental consequences in the form of chemical waste products which are being dumped as tailings material. The aim of this study was to establish whether mesofauna could be utilized to assess the influence of the tailings disposal facility on the surrounding soil environment. The sampled soil was chemically analyzed and the extracted mesofauna identified. High metal concentrations on the tailings dam (Cu, Cr and Ni), apparently had the greatest influence on the soil mesofauna. Only a few mite species were abundant at the two sites on the tailings dam, representing the prostigmatic-, cryptostigmatic- and the mesostigmatic-taxa. Metal pollution is evident in the sites on the tailings dam facility and the number of species generally increased towards the more natural environment.

1. Introduction

Soil is one of the most valuable non-renewable resources in the world (De Bruyn, 1997; Bedano et al., 2006), forming an integral part of all terrestrial ecosystems. In South Africa soil is extensively exploited due to activities such as urbanization, agriculture and industry. The country produces 62 percent of the world's platinum and holds 75 percent of global reserves (Chamber of mines South Africa, 2003). Mining is essential for economic development, but has detrimental impacts, mainly in the form of waste products dumped on tailings disposal facilities (TDFs). In a previous study it was found that platinum TDFs contain high levels of metals such as Cu, Ni, and Cr (Maboeta et al., 2008), posing a range of potential environmental hazards for the surrounding environment. These and other metals can be analyzed using background concentrations from the Netherlands (VROM, 2000) and South Africa (Herselman et al., 2005) to determine the *Igeo* (Muller, 1969; Malkoc et al., 2010; Luo et al., 2012), the *PI* (pollution index) and the *IPI* (integrated pollution index) (Chen et al., 2005).

Metal pollution leads to an accumulation of metals, not only in the physical environment, but also metabolically in the soil biota (Van Straalen et al., 2001). Mesofaunal species are indicators commonly used to determine disturbance (Santos et al., 2010; Bedano et al., 2011). Many of these organisms live their entire lives in a few square meters of soil, making them good representatives of local conditions (Migliorini et al., 2004). Soil mesofaunal communities contain populations of different species that interact with each other and which might be influenced by environmental conditions. Few studies involving mining areas and the effect they have on the environment in South Africa have been conducted.

Taking all of the above into consideration, the aim of this study was to investigate the possibility of utilizing soil mesofauna to assess the influence of TDF's on the surrounding soil environment. Specific objectives included determining to what extent the TDF differs from the surrounding environment, if the TDF has an impact on the surrounding environment and if this impact can be seen in the mesofauna community.

2. Materials and methods

2.1. Site description, sampling and mesofaunal extraction

Soil samples were collected on a TDF at a platinum mine in the North-West Province of South Africa and in the area surrounding the TDF. It has the largest tailings footprint in the southern hemisphere, covering an area of 964 ha (Van Rensburg et al., 2004).

Six random soil samples (replicates per site) were collected at seven sites in the prevailing wind direction: 0- (site 1), 0.07- (site 2), 0.15- (site 3), 0.3- (site 4), 0.5- (site 5), 0.85- (site 6) and 1.35- (site 7) kilometers from the TDF. Replicates at each site were taken in a straight line parallel to the set of replicates at the next site and up to a depth of 15 cm. Site 1 was situated at the top of the TDF and site 2 on the slope. Although plant coverage was not quantified, it was observed

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that the TDF sites had less plant cover than the surrounding area. The vegetation surrounding the mining area is part of the greater Savanna biome (Acocks, 1988) and has been described by Low and Rebelo (1998) as the Clay Thorn Bushveld, with an average rainfall of 450–750 mm per year and temperatures varying between $-6\,^{\circ}$C and 40 °C, with an average of 19 °C.

Sampling was done four times over a period of ten months, i.e. during August (cold and dry), December (hot and humid), March (hot and wet) and May (cool and dry) to determine what influence seasonality had on the different variables. Mesofauna was extracted from the soil samples using a Berlese–Tullgren funnel (Evans et al., 1961). The collected material was then stored in 75 percent ethanol, after which it was sorted and identified. Taxa were plotted in species lists and divided into functional groups (Table 1), *viz.* mycophagous organisms (MP) which feed mainly on fungi (Walter, 1988; Evans, 1992; Walter and Proctor, 1999; Kang et al., 2001; Addison et al., 2003; Gormsen et al., 2004; Kaneda and Kaneko, 2004); predatory organisms (Pred) which mainly prey on other living organisms (Walter, 1988; Evans, 1992; Walter and Proctor, 1999); saprophagous and omnivorous organisms (SO) which feed mainly on dead or decaying plant and animal material (Evans, 1992; Picker et al., 2002); mycophagous, bacteriophagous and microalgivorous organisms (MBM) which feed mainly on fungi, bacteria and algae (Evans, 1992; Walter and Proctor, 1999); and lastly the plant parasitic and herbivorous organisms (Ppar) which feed mainly on living plant material (Evans, 1992; Walter and Proctor, 1999; Picker et al., 2002).

2.2. Chemical, physical and statistical analysis

Soil samples were analyzed by means of methods modified from Thi Vu et al. (2004) and Wayland and Crosley (2006). An ICP-MS system (Agilent 7500c) was used to determine concentrations of selected metals (Table 2). These metal concentrations were then further calculated by utilizing background concentrations from the Netherlands (VROM (2000)) and South Africa (Herselman et al., 2005) to determine the *Igeo* (Muller, 1969; Malkoc et al., 2010; Luo et al., 2012), the *PI* and the *IPI* (integrated pollution index). The *Igeo* was determined using the equation below, where *Cn* represents the measured elemental concentration, *Bn* the background value of a specific element and 1.5 a constant to take natural fluctuations into account. The geoaccumulation index (Muller, 1969; Malkoc et al., 2010; Luo et al., 2012) classifies sites based on the following scale: $Igeo \leq 0$ unpolluted environment, $0 < Igeo \leq 1$ unpolluted to moderately polluted, $1 < Igeo \leq 2$ moderately polluted, $2 < Igeo$ 3 moderately to strongly polluted, $3 < Igeo \leq 4$ strongly polluted, $4 < \mathrm{I}\ Igeo \leq 5$ strongly to extremely polluted, and $Igeo > 5$ extremely polluted.

$$I_{geo} = \log 2\left(\frac{C_n}{1.5B_n}\right)$$

The *PI* was calculated as follows and classifies sites based on the following scale: $PI \leq 1$ low level of pollution, $1 < PI \leq 3$ intermediate level of pollution and $PI > 3$ high level of pollution

$$PI = \left(\frac{C_n}{B_n}\right)$$

The integrated pollution index or *IPI* is defined as the mean value of the *PI* of an element and classifies sites as follows: $IPI \leq 1$ low level of pollution, $1 < IPI \leq 2$ intermediate level of pollution and $IPI > 2$ high level of pollution.

In addition, total rainfall for the entire study period was noted. The pH and percent organic carbon content (Nelson and Sommers, 1982) for each sample was determined, as well as the sand, silt and clay content (SSC) and these are summarized in Table 3. The latter was determined by means of the hydrometer-method (ASTM (1961)). Certain physical attributes like soil temperature at each site, the plant cover in the area, as well as the moisture content of the soil samples were not measured.

The results for the chemical component in the soil and the species data were analyzed by means of the Canoco software programme (Ter Braak and Smilaue, 1994) and results are represented as an RDA ordination diagram (Fig. 1). Sigmastat software was used to calculate statistical differences for the metal concentrations between sites and also over time.

3. Results

3.1. Soil chemical analysis

The concentration of Co increased ($p < 0.05$) away from the TDF, while Cr, Cu and Ni concentrations were highest ($p < 0.05$) on the TDF. The metals exceeding the low levels of pollution based on the scales of *PI* and to a lesser extent the *Igeo*, were Cu, Ni, Cr and Co (Table 2). During August 2005 and December 2005, Cu and Ni had the highest pollution levels based on these equations, especially the sites on the TDF. The same tendency was seen for March 2006 and May 2006 with regards to these two metals, but sites were generally less polluted according to these calculations. Pollution levels of Cd, Pb and Zn were the lowest of all metals analyzed (Table 2). Seasonal variation for the metals can also be seen in the soil data and the metals which had the highest seasonal variation are Ni, Cr and Cu ($p < 0.05$).

3.2. Soil mesofauna

Two of the most prominent groups of soil mesofauna found throughout the sites were mites and collembolans (Table 1). Certain species have dominated the most disturbed sites based on the number of organism per species and include the prostigmatic mites *Speleorchestes meyeri, Coccotydaeolus sp., Pronematus ubiquitus* and *Bakerdania sp.,* the cryptostigmatic mites *Hypozetes sp.* and *Scheloribates sp.,* and the mesostigmatic mites *Protogamasellus sp.* and *Rhodacarus sp.* (Table 1).

Dominance shifted somewhat in sites 3 to 7. The taxa Prostigmata, Cryptostigmata, Mesostigmata and Collembola were all prominent in these sites, but so was the Symphyla. Dominant species included *Coccotydaeolus sp.*, *Speleorchestes meyeri*, *Eupodes parafusifer*, cf *Jacotella sp.* and *Cosmochthonius sp.*. Collembola included Entomobryidae *sp.1*, Sminthuridae *sp.1*, Isotomidae and Poduridae *sp.1* (Table 1).

The general tendency is that sites 1 to 3 have a lower number of organisms and lower number of species ($p < 0.05$) than sites 4 to 7 (Table 1). Comparison of the mesofaunal data for the different sampling occasions indicated that the winter sample of August 2005 had the lowest ($p < 0.05$) number of species. The number of species generally increased ($p < 0.05$) with time to give a very high number of species for May 2006 compared to sampling during other times of the year. Increases ($p < 0.05$) in the number of species between August 2005 and May 2006, ranged from an approximate 5 percent to about 70 percent.

An RDA ordination diagram was used to illustrate the relationship of the metals with the different functional groups of organisms as mentioned above and also the different sites (Fig. 1). Longer lines of the metals indicated that those metals had the highest concentrations ($p < 0.05$) and ultimately had the greatest effect on the other variables. These included Cd, Cr, Cu, Ni and Zn, which had a direct and notable influence on the MP, SO and MBM functional groups as shown in Fig. 1. These metals also had an influence on the *P*par and *P*red groups, but to a lesser extent. It is also evident that sites 4 to 7 had a higher number of species than the other sites ($p < 0.05$). Sites 5 to 7 were the sites on which seasonal variation had the greatest influence ($p < 0.05$).

4. Discussion

Metals present in the soil (Cu, Ni and Cr) were the highest on the TDF, which is consistent with findings of a previous study on platinum TDFs (Maboeta et al., 2006). Copper, Ni, Cr and Co exceeded the *PI* and in some cases the *Igeo* (Table 2) and these sites can therefore be seen as polluted to some extent. Seasonal variation ($p < 0.05$) was observed in the soil data. A decrease in soil metal content was observed in the samples taken for March 2006 and May 2006 when compared to samples from August 2005 and December 2005. This is the case for most of the metals in the soil samples. Copper showed the greatest decrease in concentration over the total study period, as well as Ni but to a lesser extent. Generally, the March 2006 data had the lowest ($p < 0.05$) metal content of all the sampling incidences (Table 2) and may be due to rainfall during the preceding period. Increased rainfall could initiate leaching of some of the metals in the soil.