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Variations in floristic diversity with distance around North Mara gold mine in Tanzania

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Abstract
Plant-heavy metal interactions and resultant variations in plant diversity are widely documented. However, such information was scanty at the study area. Three parallel line transects, each of 3500 m, 100 m apart were established opposite the mine wastes. Data were collected at Kwinyunyi (within 1 km from mine wastes) and at Masangora (within 3 km from mine wastes). Abundance of plant species was systematically recorded using nested quadrats; also, soils were sampled at each point. Soils were analyzed for bioavailable heavy metals by Atomic Absorption Spectrophotometer and for pH. The highest diversity index, richness and evenness were recorded within 1 km from mine wastes, while, the lowest diversity index and richness of plant species were recorded within 3 km from the waste. The lowest evenness of plant species was recorded within 1 km from mine wastes. T-test showed that the diversity, richness and evenness of plant species were not significantly different between Kwinyunyi and Masangora ($p > 0.05$). The levels of bioavailable chromium, cadmium, lead and nickel were above the internationally permissible ones. This study probably confirms that the ecosystem is robust and resilient in that plant communities sometimes adapt to conditions despite of alarmingly high levels of heavy metals.

Keywords: bioavailable heavy metals; diversity; evenness; plant species; richness.

INTRODUCTION

Biodiversity or biological diversity describes the total variety of living organisms that exist on earth. Conveniently, it is considered at three levels, namely; genetic diversity, species diversity and ecosystem diversity (International Union for the Conservation of Nature and Natural Resources, IUCN, 1990). Thus, plant diversity refers to the variation within the plant kingdom and, like biological diversity, it is often measured at three levels namely, genetic diversity, species diversity and ecosystem diversity. Species diversity has two basic components; richness (number of species in a given area) and evenness (relative abundance) (Magurran, 2004). Species evenness (*e*) is a measure of the degree to which all species share dominance in an area. Evenness measurement has been proposed by Pielou (1966).

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According to Hill (1973), richness fundamentally regulates variation in evenness and diversity. This is because, richness and evenness are very closely related (Stirling and Wilsey, 2001), and normally governed by edaphic factors (Ma, 2005), including heavy metals. Richness and evenness are combined in diversity indices, for example, Shannon-Wiener diversity index which is commonly used. The index monitors the probability of whether the next sample will contain the same species as the previous sample or whether the next sample will be a new species (Magurran, 2004). The index depends on both species richness and evenness, although they weigh rare species differently (Hill, 1973). Stability of the community is a function of its species diversity, that is, the higher the value of the diversity index, the greater will be the community structure.

Despite the countless values of plants, survival is greatly threatened by human activities including wastes from metal-mining (Mtui *et al*., 2006; Menon *et al*., 2007). Gold mining areas host a diversity of habitats and plant communities depending on biotic and abiotic factors (Brooks *et al*., 1992; Malaisse *et al*., 1999). For

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example, presence of plant species in specific locations is caused by environmental factors, *viz*., land topography, soil type, drainage, climate and the level of stress in a given area (Imevbore *et al*., 1981). Elevated levels of heavy metals render toxicity which reduces plant survivorship, recruitment, reproductive success, migration and, influences mutation rates and consequently genetic diversity of the populations exposed to mine wastes (Fox, 1995).

At species level however, the responses of plants exposed to elevated levels of heavy metals differ depending on the species, sometimes populations (Bradshaw *et al*., 1990). Thus in relations to their responses to high levels of heavy metals, plants are grouped as accumulators, excluders or indicators for heavy metals (Baker *et al*., 1990). Accumulators and excluders are plants capable of surviving the negative influence of elevated levels of heavy metals, while indicators are negatively influenced by such levels (Baker *et al*., 1990). For example, in Finland there was a complete death of sensitive plant species within 1 km from a Cu-Ni smelter (Kiikkilä, 2003). This implies that areas with higher levels of heavy metals are likely to have their diversity, richness and evenness reduced more than those with lower levels of heavy metals. In that situation areas that are closer to the source of pollution will likely to be higher polluted than those that are far away, when point source pollution is in place. Point-source pollution is pollution that comes from a specific source, while, non point-source pollution is pollution that comes from many sources rather than from a single specific source.

Gold deposits in the vicinity of North Mara mine are associated with sulfide rocks that are contaminated with heavy metals such as copper, lead, zinc, chromium, cadmium and nickel (ESIPP, 2006). Mining of gold exposes heavy metals and sulfide of the rocks above the ground. According to Enger *et al*. (2004), sulfide rocks are oxidized by air to form sulfur dioxide, which forms sulfuric acid on contact with water/moisture; an acid mine drainage which lowers the pH of the environment. Acid mine drainage facilitates the solubility and leaching of both micronutrient elements and heavy metals which are very toxic to many plants (Krebs *et al*., 1998). Heavy metal pollutants also may result from improperly secured tailing dams. Cases of leakages, overflowing or breaking of containment banks and releasing of toxic cyanide and heavy metals from the tailings into the environment often occur (Knight, 2001). Recently, there was breakage of containments/overflow of the tailing dam and resultant leakages above and below the ground in North Mara Gold Mine (The Guardian, 2009).

With these views in mind, the present study aimed at investigating the variations in richness, evenness and diversity of plant species with distance from gold mine wastes.

MATERIALS AND METHODS

The study site

The present study was carried out around North Mara gold mine in Tarime district of Mara region in Tanzania. In this area, there are three opencast mines, *viz*., Nyabirama, Nyabigena and Gokona (Euroamerican Data Corporation, EDC, 2006). The study was carried out at Kwinyunyi and Masangora sites located between latitudes 1º28' S and 1º27' S and along longitudes 34º29' E and 34º28' E near Nyabirama opencast mine (Fig. 1 *[Supplementary data]*).

Kwinyunyi is 5m from the tailing dam on the side that is surrounded by waste rock piles, while Masangora is 3000m away. The study sites were open grassland with patches of shrubs such as *Acacia albida* Bentha., *Lantana camara* L. and *Albizia harveyi* Fourn (Fig. 2).



Figure 2: The study site (Source: Field work).

Vegetation sampling

Sampling was done using three parallel transects of 3500m long, 100m apart opposite the mine wastes. The sampling points were established from Kwinyunyi to Masangora in down slope from Kwinyunyi. This arrangement was chosen to assess floristic variations below slope since waste rocks are piled up and in this case acid mine drainage will always flow down slope exerting its influence. Data were collected at every 100m up to 700m at Kwinyunyi and the last 500m at Masangora. At each site, the number of individuals of all species encountered was systematically recorded using nested quadrats according to Stohlgren (1995). That is, 10mx5m quadrat was used for trees, 4 mx3m quadrat nested in the 10 mx5m quadrat was for

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sampling of shrubs and saplings, and 1mx1m quadrat nested in the 4m x 3m quadrat was used for sampling of herbs and grasses. The area being open grassland, a complete list of grasses, herbs and shrubs was compiled in the field. The point-frequency flame was not applied since this method neglects the less common species (Elzinga *et al*., 1998). Plants that were difficult to classify in the field were identified using keys or comparison with authentic herbarium materials in the department of botany at the University of Dar es Salaam.

Soil sampling

To determine the levels of bioavailable heavy metals, in each of the largest quadrat (10m × 5 m) where plant species had been sampled, three soil samples of approximately 5 g each were diagonally collected at least passing through all the three previously established quadrats. At each sampling point the samples were separately collected at depths of 0–15 cm and at 15–30 cm, which are ranges of the rooting depths of herbs and grasses, the area being open grassland. A soil auger was used during soil collection. The three soil samples from each depth in each sampling point were mixed to constitute a composite sample for the subsequent analysis. The composite samples were separately kept in polythene bags, labeled and properly sealed to prevent contamination and loss of moisture.

Laboratory analysis

Soil samples for pH measurements were prepared in a 1:1 fresh soil and distilled water ratio. The mixture was then stirred thoroughly so as to hydrolyze the ions and allowed to equilibrate for 30 minutes as described by Mclean (1982). The soil pH was measured by using a metrohm E 510 pH-meter.

Soils for detection of the levels of bioavailable heavy metals were prepared according to Allen (1989) where 140 ml of distilled water was added to 20 g of soils, followed by 10 ml of Diethylenetriaminepentaacetic acid (DTPA), and then shaken gently. DTPA is one of the chelating agents which concentrate the soil suspensions to form soluble complexes. The mixtures were then filtered through filter papers to give aliquots of 50 ml of the filtrates that were analyzed for copper, lead, chromium, zinc, cadmium and nickel. To prevent contamination, glass and plastic wares were washed with dilute nitric acid and distilled water. Analysis of the levels of heavy metals was done at the University of Dar es Salaam, College of Engineering and Technology; using a Perkin-Elmer 3100 Atomic Absorption Spectrophotometer. Standard Reference Material of National Institute and Technology; NIST, 2709 San Joaquin Soil was used for heavy metals that were analysed. To increase sensitivity during the analysis, impact beads were used in the spray chamber.

Data analysis

Species diversity index at different distances was assessed using the Shannon-Wiener index (Kent *et al*., 1994), and Pielou's (1966) evenness index (*e*) of the different distances was calculated as:

$$H' = -\sum_{i=1}^{S} Pi \ln Pi$$

$$e = \frac{H'}{H'max} \text{ but } H'_{\max} = ln\, S, \text{ then } e = \frac{H'}{ln\, S}$$

Where: H' : Shannon-Wiener diversity index; *S*: number of species; *Pi*: the proportion of abundance found in the i^{th} species and ln: natural logarithm. *e*: evenness index.

To test whether richness, evenness, Shannon's diversity index differed between the two sites, t-test was performed.

RESULTS

Table 1 *[Supplementary data]* shows the mean Shannon-Wiener diversity index, richness, evenness of plant species and bioavailable heavy metals sampled along three transects at 13 different distances from gold mine wastes. The mean species diversity index (H') ranged between 1.6±0.1 and 2.3±0.2, with the lowest diversity index recorded at a distance of 3400m from the mine wastes and highest diversity recorded at 105m from such waste. The mean species richness ranged between 6±0.5 and 15±4, with the lowest richness recorded at a distance of 3400m from the mine wastes and highest richness recorded at 105m from the waste. Furthermore, species evenness ranged between 0.29±0.06 and 0.48±0.04, with the lowest evenness recorded at a distance of 605m from the mine wastes and highest diversity recorded at 105m away from gold mine wastes.

Also, the results in Table 1 show that, the levels of bioavailable lead, chromium, cadmium and nickel were above the ranges of permissible bioavailable heavy metals (Allen, 1989; Fifield *et al*., 2000).

T-test showed that, there was no significant difference in the diversity of plant species between Kwinyunyi and Masangora (t=0.59, p=0.57 and D.F.=11). Richness of plant species between Kwinyunyi and Masangora was also not significantly different (t=0.98, p=0.35 and D.F.=11). Furthermore, the evenness of plant species as well did not differ significantly between the two sites (t=0.58, p=0.57 and D.F.=11).

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Soil pH in the study area ranged from 4.74 - 6.86 in the 0 -15cm layer and 5.24-7 in the 15-30 cm depth (Table 2 *[Supplementary data]*). According to the classification proposed by Brady *et al*. (1999), the pH in the upper soil layer ranged from strongly acidic to slightly acidic levels while that in the lower soil layer ranged from slightly acidic to neutral

DISCUSSION

The results on the highest and lowest diversity index, richness and evenness at different distances suggest that the quadrats situated close to the mine wastes suffered maximally due to heavy metal pollution load. As a result, sensitive species have disappeared creating vacated niche for a large number tolerant species with almost even number of individuals per species. The probable plant species include hydrophytes such as *Hygrophylla auriculata* (Schumach) Heine., *Typha capensis* Pers., *Cyperus exaltatus* L. etc. that dominated the area close to the mine wastes source and are identified as heavy metal tolerant (Mganga *et al*., 2011). That is, opportunistic, more tolerant species with time become abundant close to the mine wastes. On the contrary, distant areas from mine wastes probably had lesser pollution load in which natural vegetation still exists.

Argument on pollution load is given on the ground that, some of the heavy metals analyzed in the this study were present in the levels exceeding the internationally permissible ones, *viz*., chromium, cadmium, lead and nickel (Table 1). The levels of these heavy metals were comparatively higher at Kwinyunyi than at Masangora, suggesting point source pollution. The levels of bioavailable heavy metals are probably elevated by the low soil pH at the study area.

These results are in agreement with Nunes (2007) who reported higher plant species diversity and richness closest to the Tsumeb smelter in Namibia. In addition, according to Molles (1999) high species diversity occurs where there is a combination of more different species and where the numbers of individuals in the total population are more equitable distributed among the species. Consequently, the difference in Shannon-Wiener diversity index (H') for communities reflects the differences in species evenness and abundance (Molles, 1999).

The results on species diversity and richness are in agreement with that of Nunes (2007), who observed no significance difference in plant species diversity and richness inside and outside the Tsumeb smelter in Namibia.

On the contrary, an increase in plant species diversity, richness and evenness with increasing distance from the source of pollution was reported by McClenahen (1978), Narayan *et al*. (1994) and Salemaa *et al*. (2001) in the United States of America, India and Finland respectively.

Despite the alarmingly high levels of bioavailable chromium, cadmium, lead and nickel, statistically, the floristic diversity was the same within 3 km from the gold mine wastes. This probably confirms that the ecosystem is robust and resilient in that plant communities sometimes adapt to conditions despite of alarmingly high levels of heavy metals. However, this poses a challenge to environmental ecologists since for conservation purposes we do not want to lose any species because we do not know the specific values attached to that particular species

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