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Distribution patterns of plant species around North Mara Gold Mine in Tanzania

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ABSTRACT
Elevated heavy metals are toxic to many plants. There are many known edaphic factors affecting alteration of vegetation patterns. This study aimed to determine the relationship between bioavailable heavy metals and distribution patterns of plant species. Three parallel line transects of 3500 m long and 100 m apart were established opposite the mine wastes. Sampling was done at every 100 m up to 700 m and from the last 500 m. Numbers of plant species were systematically recorded using nested quadrats per transect and soil samples were collected at each point. The soil samples were analyzed for evidence of bioavailable heavy metals (copper, lead, chromium, zinc, cadmium and nickel) using an Atomic Absorption Spectrophotometer. Canonical Correspondence Analysis showed that levels of lead, chromium, cadmium and nickel negatively influenced distribution patterns of the plants. However, the Monte Carlo Permutation test showed that the measured metals did not have a significant influence on distribution patterns of the plants. It is likely that distribution patterns of the plants were also influenced by some other factors that were not currently investigated in this research. In terms of conservation as the main priority, waiting for evidence of the influence of heavy metals to have an obvious and significant effect on plant patterns may mean that an ecosystem has already undergone serious damage.

Keywords: bioavailable heavy metals, distribution patterns, gold mine, plant species, soil

INTRODUCTION
The concept of a suitable habitat for the establishment of plant communities is the basis of plant ecology. In other words, a prevailing vegetation type in an area is one best adapted to the existing environmental conditions. However, the effect of habitat deterioration often results in heterogeneous trends. At present, the imminent challenge in plant ecology is to develop understanding of how patterns and processes vary within environmental gradients (Rydgren et al. 2003). Metal toxicity in soil and consequent shifts in patterns of plant distribution is influenced by changes to the habitat that render a gradual shift in the environmental condition from a suitable to an unsuitable state. Soil contamination by heavy metals is one of the stresses that have an impact on the dynamics of plants in terms of space that results in complex and unpredictable patterns.

The North Mara Gold Mine is in the Lake Victoria Gold Field of Tanzania, which lies within the greenstone belt and sedimentary ore. The greenstone belt is contaminated

with heavy metals such as copper, zinc, lead, cadmium and chromium; while nickel is found in sedimentary ore (Ahaeusser 1984). Although the release of heavy metals into the biosphere may occur naturally for example from volcanic eruption, an absence of these natural events means that their release is from the breaking and crushing of sulfide minerals in mining areas (Peng et al. 2006). These minerals are present in the parent rocks of the North Mara Gold Mine (European Union-Southern African Development Community Investment Promotion Programme (ESIPP) 2006). Crushing and breaking minerals during the process of mining exposes heavy metal-contaminated sulfide rocks to the surface. Oxidation of sulfur by air forms sulfur dioxide and ultimately produces sulfuric acid (acid mine drainage), which solubilizes and mobilizes heavy metals as leachates because of the low pH that has been created. As a result, toxic heavy metals enter an ecosystem leading to geoaccumulation, bioaccumulation and biomagnification. Recently, there was breakage of containments/overflow of the tailing dam that caused leakage above and below the ground in the North Mara Gold Mine (The Guardian 2009). In these situations plant populations respond differently to the prevailing conditions depending on a species tolerance to adverse environmental conditions that have been imposed on a habitat. The negative impact of heavy metals resulting from metal-mining wastes on the distribution of plant species has not been widely documented (Bagatto and Shorthouse 1999). Similarly, around North Mara Gold Mine there was little documentation on how heavy metals contribute to distribution patterns of plant species. This study therefore, aimed to determine the influence of bioavailable heavy metals on distribution patterns of plant species.

MATERIAL AND METHODS

The Study Area

The study was located around the North Mara Gold Mine in Tarime district of the Mara region in Tanzania. The site is about 100 kilometers east of Lake Victoria and 20 kilometers south of the Kenya-Tanzania border. There are three opencast mines in the area, *viz*., Nyabirama, Nyabigena and Gokona (Euroamerican Data Corporation (EDC) 2006). Sampling was done at Matongo village near the North Mara gold mine, located between latitudes 1º28' S and 1º27' S and longitudes 34º29' E and 34º28' E. A global positioning system (GPS) was used to record the coordinates of each sampling point that were then located a map of the study area (Figure 1). The vegetation of the area was open grassland with patches of shrubs such as *Acacia albida* Bentha., *Lantana camara* L. and *Albizia harveyi* Fourn.

Plant sampling

Sampling was done using three parallel line transects of 3500 m long and 100 m apart. They were established opposite the tailing dam surrounded by waste rock. Data were collected from every 100 m up to a distance of 700 m from the mine wastes and from the last 500 m. This distance of 2300 m was skipped in each of the three transects in order to assess how far the distribution of plant species had been affected. At each site, coverage and abundance of plant species was systematically recorded using nested quadrats according to Stohlgren et al. (1995). That is, a 10 m x 5 m quadrat was used for trees, 4 m x 3 m quadrat nested in the 10 m x 5 m quadrat was for sampling shrubs and saplings, and 1 m x 1 m quadrat nested in the 4 m x 3 m quadrat was used for sampling herbs and grasses. Coverage of various grass species was determined by the point-frequency frame according to Kershaw

(1973). The point-frequency frame was the recommended framework for application in an area dominated by open grassland (Kent and Coker 1994). Plants were identified using keys or comparison with herbarium specimens.

Soil Sampling

In each of the largest quadrats (10 m × 5 m), where plant species had been sampled, three soil samples of approximately 5 g each were also collected at least passing through all the three previously established quadrats. At each sampling point three samples were separately collected at depths of 0 – 15 cm and at 15 – 30 cm, which represented the ranges of rooting depths of the 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 quadrat were mixed to constitute a composite sample for subsequent analysis. The composite samples were separated and kept in polythene bags, labeled, and properly sealed to prevent contamination and loss of moisture. The composite samples were analyzed for pH and heavy metals in the department of Botany, University of Dar es Salaam.

Laboratory Analyses

For determination of bioavailable heavy metals, fresh composite soil samples were used according to the methods outlined by Allen (1989). Soil suspensions were prepared by adding 140 ml of distilled water to 20 g of soil, followed by 10 ml of Diethylenetriaminepentaacetic acid (DTPA), and then shaken gently. DTPA was used as a chelating agent to concentrate 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 then analyzed for copper, lead, chromium, zinc, cadmium and nickel. To prevent contamination all the glass and plastic laboratory wares were washed in dilute nitric acid and distilled water. Levels of the heavy metals were detected using an Atomic Absorption Spectrophotometry, according to the method cited by Allen (1989). Analysis of 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 to analyze the heavy metals.

Relationship between bioavailable heavy metals and the distribution of plant species

In vegetation studies, ordination arranges vegetation samples in relation to each other in terms of their similarities based on species composition and/or their associated environmental variables (Kent and Coker 1994). The software available in canonical correspondence analysis 3.10 (CANOCO) renders methods that could be used successfully to explain variation of the influences of environmental variables on plant species data (ter Braak 2005).

Canonical Correspondence Analysis (CCA) was used in this study to identify a linear combination of environmental variables that increases dispersion of the species scores NOT their diversity. This is because CCA selects the best weights for environmental variables, finally giving the first, second, third and fourth CCA axes. Ordination axes are known to account for major variations among species data (Kent and Coker 1994). The position of each environmental arrow with respect to each axis indicates how closely correlated the axis is with that environmental factor.

In the present study CCA was used to determine the effect of bioavailable heavy metals on distribution patterns of plant species. CCA was used to calculate the

correlation coefficients between environmental variables (levels of bioavailable heavy metals) and ordination axes. The CCA analysis in this study had less restriction, in that there was room for the inclusion of maximum environmental variables. Furthermore, CCA was selected because there were no superfluous (insufficient) environmental variables that could have caused arch effects hence there was no need for more options of detrending the CCA. In this study, for the purpose of saving space in the species ordination axes the names of species were abbreviated (Table 1).

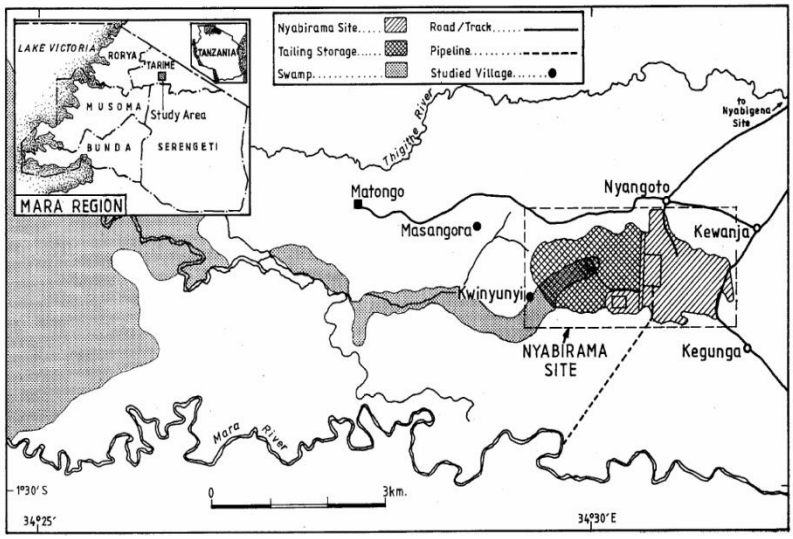


Figure 1. Location of the sampling area around North Mara Gold Mine

Table 1. Abbreviations of names of species used in Figure 2

Species	Abbreviation	Species	Abbreviation	Species	Abbreviation	Species	Abbreviation
Abutilon mauritianum	*Abut mau*	*Bidens pilosa*	*Bi pi*	*Crinum papilosum*	*Crin pa*	*Digitaria ciliaris*	*Di abys*
Acacia albida	*Acac alb*	*Biophytum abyssinicum*	*Bi aby*	*Crotolaria microcarpa*	*Cr mic*	*Duosperma crenata*	*Du cren*
Acacia drepanolobium	*Aca drep*	*Boerhavia diffusa*	*Bo dif*	*Cynachum tuberosa*	*Cyn tub*	*Eleusine indica*	*El ind*
Acacia sieberana	*Aca seib*	*Brachiaria brizantha*	*Br briz*	*Cynodon dactylon*	*Cy da*	*Emilia javanica*	*Em coc*
Acacia senegal	*Acac sen*	*Carica papaya*	*Ca pa*	*Cynotis foetida*	*Cyn fo*	*Eragrostis aethiopica*	*Er aet*
Acacia seyal	*Acac sey*	*Cassia mimosoides*	*Ca mim*	*Cyperus articulatus*	*Cy art*	*Eucalyptus species*	*Eu glob*
Aerva lanata	*Aerv lan*	*Casuarina equisetifolia*	*Ca equ*	*Cyperus exaltatus*	*Cy aur*	*Euphorbia hirta*	*Euph h*
Agave sisalana	*Ag sis*	*Chloris gayana*	*Ch ga*	*Cyperus obtusflorus*	*Cy obt*	*Ficus natalensis*	*Fi nat*
Ageratum conyzoides	*Ag con*	*Commelina africana*	*C afri*	*Cyperus rotundus*	*Cy rot*	*Fimbristylis bisumbellata*	*Fi bis*
Albizia harveyi	*Al har*	*Commelina benghalensis*	*Co ben*	*Dactyloctenium aegypticum*	*Da aeg*	*Flueggea virosa*	*Fl vir*
Alysicarpus glumaceus	*Aly gl*	*Grewia microcarpa*	*Gr mic*	*Indigofera cuneata*	*In cun*	*Leocas nepetifolia*	*Leoc nep*
Aristida adoensis	*Ar ado*	*Gutenbergia rueppelii*	*Gu rue*	*Indigofera volkensii*	*In vol*	*Leonotis nepetaefolia*	*Le nep*
Vangueria infansta	*Va inf*	*Harpachne schimperi*	*Ha sch*	*Ipomoea batata*	*Ip bat*	*Ludwigia actovalvis*	*Lu oct*
Corchorus olitorius	*Cor ol*	*Harrisonia abyssinica*	*Ha aby*	*Ipomoea cornea*	*Ipo co*	*Ludwigia stolonifera*	*Lu sto*
Corchorus tricularis	*Co tri*	*Heliotropium steudneri*	*He ste*	*Jasminium flumenens*	*Ju flu*	*Mellinis repens*	*Mel re*

Crabbea velutina	*Cr vel*	*Hibiscus cannabinus*	*Hi can*	*Justicia anselliana*	*Jus an*	*Microchloa kunthii*	*Mi kun*
Dactyloctenium germinatum	*Dact ge*	*Hibiscus micranthus*	*Hi nic*	*Justicia betonica*	*Ju bet*	*Monsonia angustifolia*	*Mo ang*
Desmodium barbatum	*De bar*	*Hirpisium diffusum*	*Hir di*	*Kigelia africana*	*Ki afr*	*Musa sapientum*	*Mu sap*
Dichanthium anullatum	*Di anu*	*Hoslundia opposita*	*Ho opp*	*Launaea cornuta*	*La cor*	*Ocimum kilimandscharicum*	*Oci ki*
Fuirena cylindrica	*Fu umb*	*Hygrophylla auriculata*	*Hyg au*	*Lannea stuhlmaii*	*La stu*	*Ocimum suave*	*Oc sua*
Gomphrena celosioides	*Go cel*	*Hyparrhenia filipendula*	*Hy fil*	*Lantana camara*	*Lan ca*	*Oldenlandiia corymbosa*	*Ol cor*
Grevillea robusta	*Gr rob*	*Hyparrhenia rufa*	*Hyp ru*	*Leersia hexandra*	*Le hex*	*Opuntia vulgaris*	*Op vul*
Grewia bicolor	*Gre bi*	*Imperata cylindrica*	*Imp cy*	*Typha capensis*	*Ty cap*	*Vernonia amygdalina*	*Ve amy*
Ormocarpum kirkii	*Or kir*	*Sesanum angolense*	*Se ang*	*Tagetes minuta*	*Te min*	*Vernonia glabra*	*Ve glab*
Panicum coloratum	*Pa col*	*Setaria incrassata*	*Se inc*	*Tephrosia pumila*	*Tep pu*	*Vernonia poskeana*	*Ve posk*
Pemmisetum parpareum	*Pe par*	*Setaria sphacelata*	*Se sph*	*Tephrosia villosa*	*Te vir*	*Waltharia indica*	*Wal ind*
Polygonum senegalensis	*Po sen*	*Spermacoce sinensis*	*Sp sin*	*Tridax procumbens*	*Tr pro*	*Sporobolus pyramidalis*	*Spo py*
Phyllanthus amarus	*Phy am*	*Sida acuta*	*Si acu*	*Thunbergia alata*	*Th ala*	*Sclerocarya birrea* subsp. *multifoliata*	*Sc bir*
Rhynchosia minima	*Rh min*	*Sphaeranthus gomphrenoides*	*Sp gom*	*Triumfetta rhomboidea*	*Triu rh*	*Teclea nobilis*	*Te nob*
Ruellia patula	*Ru pat*	*Sphaeranthus kirkii*	*Sp kir*	*Trichodesma zeylanicum*	*Tric ze*	*Senecio abyssinicus*	*Se aby*
Pluchea dioscoridis	*Pl dis*	*Solanum incanum*	*So inc*				

RESULTS AND DISCUSSION

The results in figure 2 show a biplot of the CCA ordination diagram for species and heavy metals plotted on the first and second CCA axes. CCA gave more weight to the measured environmental variables that are indicated with much longer arrows. In addition, *Hyparrhenia rufa* (Hochst) Stapf., *Corchorus olitorius* L., *Setaria sphacelata* (Schummach) Moss., *Alysicarpus glumaceus* (Vahl.) DC., *Senecio abyssinicus* Sch. Bip. , *Acacia sieberana* DC. , *Bidens pilosa* L., *Polygonum senegalensis* L. correlated positively with cadmium and nickel, thus, these plant species were not affected by higher levels of these metals in their distributions. *Grewia microcarpa* L., *Albizia harveyi* Fourn. and *Spermacoce sinensis* (Klotzsch) Hiern. positively correlated with zinc; hence these plants were not affected by higher levels of zinc in the soil according to their distribution.

Furthermore, *Hoslundia opposita* Vahl., *Rhynchosia minima* (L) DC., *Hibiscus cannabinus* L., *Teclea nobilis* Del., *Aerva lanata* (L) Schultes., *Justicia betonica* (Nees) T. Anders., *Agave sisalana* Perr., *Dactyloctenium aegypticum* (L) Willd., *Monsonia angustifolia* A. Rich. positively correlated with copper and chromium. Therefore, these plant species were not affected by higher levels of these metals in the soil in their distribution. *Euphorbia hirta* L., *Tridax procumbens* L., *Cyperus obtusflorus* Vahl., *Emilia javanica* (Burm) Merr., *Boerhavia diffusa* L., *Commelina africana* L., *Carica papaya* L., *Eucalyptus* species, *Musa sapientum* L. etc correlated positively with lead, thus, these species were not affected by higher levels of lead in the soil according to their distribution.

The results from the weighted correlation matrix for CCA on the species data shown in Table 2 confirm the above stated correlations. Nickel correlated strongly with species axis 1 (all species considered) and environmental axis 1 (all environmental variables referred to) r = 0.7143 and r = 0.7906, respectively. Cadmium correlated weakly positively with species and environmental axes 1 r = 0.3263 and r = 0.3612, respectively.

The results shown in Table 2 also confirm correlations between copper and species axis 2 by r = 0.5123 and r = 0.6357 for environmental axis 2. Chromium correlated with species and environmental axes 2 r = 0.2756 and r = 0.342, respectively.

The results demonstrated that lead correlated weakly negatively with species and environmental axes 2 r = -0.1107 and r = -0.1373, respectively. Furthermore, cadmium weakly negatively correlated with species and environmental axes 2 r = -0.1877 and -0.2329, respectively. Zinc correlated negatively with species and environmental axes 1 r = -0.368 and r = -0.4074, respectively.

There were other CCA axes that have not been shown in Figure 2 (axes 3 and 4). Table 2 indicates the correlation coefficients for such axes; for example cadmium strongly positively correlated with species and environmental axis 3 by the correlation coefficients of 0.7176 and 0.8194, respectively. Also, chromium was negatively correlated with species and environmental axis 4 by the correlation coefficients of -0.4542 and -0.5871, respectively. Lead strongly negatively correlated with species axis 4 and environmental axis 4 by the correlation coefficients of -0.6498 and -0.84, respectively. Furthermore, nickel correlated negatively with species and environmental axes 4 by r = -0.2797 and -0.3615 respectively.

Table 3 summarizes the eigen values for the first four axes. The eigen values for all 4 axes were almost similar, indicating that all four axes are equally important in explaining

the variations in the studied plant species (distribution patterns).

Cumulative percentage variance of the species data showed that the first axis accounted for 4.2% of the total inertia (in the data set). Cumulative percentage variance of species-heavy metal relation which expressed the amount of inertia explained by the axes as a fraction of the total explainable inertia, indicated that the first two axes taken together displayed less than half (47.3%) of the variation that could be explained by heavy metals (Table 3).

Also, Table 3 indicated that, the first four CCA axes had high species axes-environmental axes correlation coefficients. However, Monte Carlo Permutation test after performing forward selections both automatically and manually showed that the measured heavy metals for the first four axes were not significant in explaining the distribution patterns of plant species ($F = 1.01$ and $P = 0.46$).

Plant distribution can be affected by several factors including elevated levels of heavy metals. The results of the present study collaborate with this fact. Figure 2 indicates that numbers of plant species were positively correlated with the measured heavy metals. These plant species were found in areas with elevated levels of those heavy metals; a possible indication that these particular plants were tolerant. Tolerant plant species grow and reproduce perpetuating their ecotypes, while sensitive species probably fail to do so and as a result their distribution patterns become less distinct.

Since the results in Table 3 show that the first four axes had more or less similar eigen values; all the four axes were significant in that they demonstrate variations in the vegetation data. The present study showed that bioavailable levels of nickel, lead and chromium negatively affected the distribution patterns of some plant species in the study area (the manner in which groups of species are spread out not their abundance). For example, species whose distributions were influenced by these heavy metals included; *Solanum incanum* L., *Jasminium flumenens* L., *Dichanthium anullatum* (Forssk) Stapf., *Tridax procumbens* L. that were negatively influenced by higher levels of chromium in the soil. Lead negatively influenced the distributions of *Flueggea virosa* (Willd.) Voigt., *Teclea nobilis* Del., *Hibiscus cannabinus* L., *Hoslundia opposita*. Nickel; *Albizia harveyi*, *Grewia microcarpa* L., *Ipomoea batata* (L) Lam., *Spermacoce sinensis* L. and cadmium influenced the distributions of *Aerva lanata* (L) Schultes., *Opuntia vulgaris* L., *Digitaria ciliaris* (Retz) Koel.

Based on the results of this study however, the studied heavy metals explain less than 50% of the factors that have an influence on plant distribution in the study area. Other factors such as nutrients, genetic influences as well as impacts from heavy metals that were not studied (e.g. arsenic and iron) that have been reported at Geita Gold Mine (Bitala 2008) probably explain the remaining proportion. These explanations agree with the lack of significance of the heavy metals studied on the distribution of plants as shown by the Monte Carlo Permutation test. This also can be explained by the fact that out of 9.61 of all the unconstrained eigen values that represented the overall inertia or variance in species dispersion, only 1.526 represented the amount of the total variation that can be explained by the measured heavy metals. Table 2 indicates that, both nickel and cadmium correlated strongly positively with species axes 1 and 3 respectively by the correlation coefficients of 0.7143 for nickel and 0.7176 for cadmium. This demonstrates that areas with higher levels of nickel and cadmium had a positive influence on plant

species that were tolerant to these two metals, examples of such plants are; *Hyparrhenia rufa, Corchorus olitorius, Setaria sphacelata, Alysicarpus glumaceus, Senecio abyssinicus, Acacia albida, Bidens pilosa, Solanum incanum* and *Polygonum senegalensis*. Such interaction promotes dominance resulting in the disruption of an even distribution pattern of the plants.

Indigenous people around the North Mara Gold Mine are mixed farmers, however, palatable species such as *Hyparrhenia rufa* (Nees) Stapf., *Acacia sieberana* DC., *Bidens pilosa* L., *Setaria sphacelata* (Schummach) Moss., *Solanum incanum* L. etc. were found to be positively influenced by nickel and cadmium presenting the possibility of heavy metal contamination of the food chain.

Rashid *et al*. (2007) also documented a negative influence of elevated heavy metals on the distribution of plant species that resulted in patchy plant distribution patterns in Pakistan. In Nigeria, Anoliefo *et al*., (2008) reported on a number of plant species that were highly distributed in heavy metal contaminated areas.

CONCLUSION

CCA aimed to address the extent of influence of the measured heavy metals on distribution patterns of plant species. Insufficient sampling of all environmental variables might have affected the Monte Carlo Permutation test indicating that the heavy metals did not significantly influence the distribution of plant species around North Mara Gold Mine. However, a CCA figure was not obtained by chance; rather it provided a representation of the distribution of plant species in relation to the measured heavy metals.

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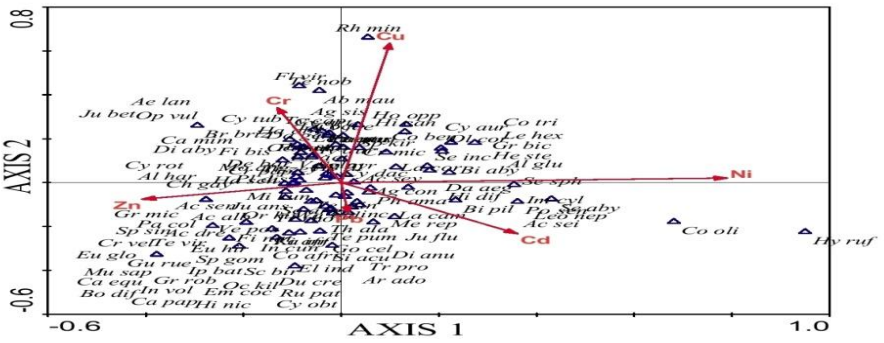


Figure 2. Biplot of a CCA ordination diagram for species and 6 heavy metals plotted on first and second CCA axes

Table 2. Weighted correlation matrix for CCA

	S A1	S A2	S A3	S A4	E A1	E A2	E A3	E A4	Cu	Pb	Cr	Zn	Cd	Ni
S A1	1													
S A2	-0.009	1												
S A3	-0.0213	0.0235	1											
S A4	-0.0636	0.0909	-0.0654	1										
E A1	0.9034	0	0	0	1									
E A2	0	0.8059	0	0	0	1								
E A3	0	0	0.8758	0	0	0	1							
E A4	0	0	0	0.7736	0	0	0	1						
Cu	0.0903	0.5123	0.2221	-0.1424	0.1	0.6357	0.2536	-0.184	1					
Pb	0.0127	-0.1107	0.1559	-0.6498	0.014	-0.1373	0.178	-0.84	0.4006	1				
Cr	-0.1174	0.2756	0.2349	-0.4542	-0.1299	0.342	0.2683	-0.5871	0.2485	0.2383	1			
Zn	-0.368	-0.0611	-0.2269	0.1586	-0.4074	-0.0758	-0.259	0.2051	0.3372	-0.0063	-0.062	1		
Cd	0.3263	-0.1877	0.7176	0.2829	0.3612	-0.2329	0.8194	0.3657	-0.0335	-0.1477	-0.1354	-0.3522	1	
Ni	0.7143	0.0168	0.1341	-0.2797	0.7906	0.0208	0.1531	-0.3615	0.5023	0.4709	0.1867	-0.0409	0.2269	1

[1] Note: S = species E = environmental A = axis Weight = sample total

Table 3. Summary of the first four axes for CCA of the species data

Axes	1	2	3	4	Total inertia
Eigen values	0.4	0.322	0.29	0.209	9.16
Species-environmental correlation	0.903	0.806	0.876	0.774	
Cumulative % variance of species data	4.2	7.5	10..5	12.7	
Cumulative % variance of species-environmental relation	26..2	47..3	66..2	79..9	

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