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SOIL QUALITY EVALUATION OF SPOLIC TECHNOSOLS. CASE STUDY FROM THE ABANDONED MINING SITE IN IMPERINA VALLEY (BELLUNO, ITALY)

LA QUALITÉ BIOLOGIQUE DES SOLS (SPOLIC TECHNOSOLS) DANS LA ZONE MINIÈRE DE LA VALLÉE IMPERINA (BELLUNO, ITALIE)

QUALITÀ BIOLOGICA DEI SUOLI (SPOLIC TECHNOSOLS) NEL DISTRETTO MINERARIO DI VALLE IMPERINA (BELLUNO, ITALIA)

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Abstract

Mining, milling and smelting operations are major causes of heavy metal contamination and constitute an increasing threat to the environment. The objective of this work was to investigate the relationships between soil metal pollution, humus development and microarthropod community structure, using a Biological Soil Quality (QBS-ar) method. Humus and soil samples (0-30cm) were collected during spring 2011 from an abandoned mixed sulphides mining area in Northeast Italy, under both forest and grassland ecosystems. The mine site is contaminated by several heavy metals (Cd, Cr, Cu, Pb, Zn and Fe). Humus forms varied from Dysmoder and Amphimus to the more developed Oligomull. The QBS-ar values presented a wide range (between 65 and 162). Moreover, results demonstrate that in the forest ecosystem the microarthropod communities showed a high biodiversity (richness). On the other hand, we observed stable community structures (evenness) in grassland sites. Humus forms do not have a significant correlation with QBS-ar values and classes of soil biological quality. Anthropogenic activities influenced the microarthropod community, altering both quantity and quality of litter and chemical-physical structure of the microhabitats. Preliminary data obtained in this study suggest that the application of QBS-ar index could be a useful tool for monitoring surface mine soils.
Keywords: *heavy metals, soil biological quality, humus*

Résumé

Les opérations d'extraction et de fusion des minéraux sont les principales causes de pollution par métaux lourds. L'objectif de cet étude est de chercher les relations entre la pollution des sols, le développement de l'humus et la communauté des microarthropodes, en appliquant la table des qualités biologiques des sols (QBS-

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ar). La zone d'étude est située dans la Vallée Imperina (Belluno); elle présente une contamination diffuse par métaux lourds (Cd, Cr, Cu, Pb, Zn, Fe). Des échantillons d'humus et de sol ont été prélevés à une profondeur comprise entre 0 et 30 cm. Les formes d'humus trouvées varient depuis celles moins évoluées, Dysmoder et Amphymus, à celles plus évoluées, Oligomull. Les valeurs de QBS-ar obtenues sont comprises entre 65 et 162. Les résultats montrent que dans l'écosystème forestier les communautés des microarthropodes ont une haute biodiversité ; au contraire, dans l'écosystème de prairies les communautés semblent avoir une structure plus stable. Aucune corrélation n'a été identifiée entre les valeurs de QBS-ar et les classes de qualité biologique des sols. Il semble donc que les activités humaines aient influencé les communautés des microarthropodes altérant soit la quantité et la qualité de la litière, soit les caractéristiques physico-chimiques des micro-habitats. Les données obtenues suggèrent que l'application da la table QBS-ar pourrait se révéler un instrument utile pour le monitorage des sols pollués.
Mots-clés: *métaux lourds, qualité biologique du sol, humus*

Riassunto

Le operazioni di estrazione e di fusione dei minerali sono le principali cause di inquinamento da metalli pesanti. L'obiettivo di questo studio è di indagare le relazioni tra l'inquinamento del suolo, lo sviluppo dell'humus e delle comunità dei microartopodi, applicando l'indice di qualità biologica del suolo (QBS-ar). L'area di studio è situata nel distretto minerario di Valle Imperina (BL) e presenta una diffusa contaminazione da metalli pesanti (Cd, Cr, Cu, Pb, Zn, Fe). Sono stati prelevati campioni di humus e di suolo ad una profondità compresa tra 0-30 cm. Le forme di humus rinvenute variano da quelle meno evolute, Dysmoder e Amphymus, a quelle più evolute, Oligomull. I valori di QBS-ar ottenuti presentano un range ampio di valori, compreso tra 65 e 162. I risultati mostrano che nell'ecosistema forestale le comunità di microartropodi hanno un' elevata biodiversità; contrariamente, nell'ecosistema a prato le comunità sembrano avere una struttura più stabile. Non è stata individuata alcuna correlazione tra i valori di QBS-ar e le classi di qualità biologica del suolo. Sembrerebbe, pertanto, che le attività antropiche abbiano influenzato le comunità dei microartropodi alterando sia la quantità e la qualità della lettiera, sia le caratteristiche chimico-fisiche dei microhabitat. I dati ottenuti suggeriscono che l'applicazione dell'indice QBS-ar potrebbe essere uno strumento utile per il monitoraggio dei suoli contaminati.
Parole chiave: *metalli pesanti, qualità biologica del suolo, humus*

Introduction

Soil contamination by heavy metals may influence negatively soil health, which often limits and sometimes disqualifies soil biodiversity and decreases plant growth (Wahsha et al., 2012). Soil health is the continued capacity of the soil to function as a vital living system, providing essential ecosystem services. Within soils, all bio-geo-chemical processes of the different ecosystem components are combined.

These processes are able to sustain biological productivity of soil, to maintain the quality of surrounding air and water environments, as well as to promote plant, animal, and human health (Karlen et al., 2001). A common criterion to evaluate long term sustainability of ecosystems is to assess the quality of soil.
Recently, several bioindicators of soil quality and health have been reviewed (Chauvat et al., 2003; Parisi et al., 2005). Among them, microarthropods, due to their high sensitivity to respond to environmental changes, play a fundamental role in the dynamics of organic matter and in the fragmentation of soils, at different scales of time and space (Loranger-Merciris et al., 2007). Thus, they can also contribute to metal translocation through the ecosystem in polluted environments. The Soil Biological Quality index (QBS-ar), which is based on microarthropod groups present in the soil (Parisi et al., 2005), may be applied to assess its biological quality: the higher is the number of microarthropod groups adapted to soil habitats, the higher is soil quality. The aim of this work was to investigate the relationships between soil metal pollution; humus development and microarthropod community structure of anthropogenic soils (Spolic Technosols) at abandoned mine sites.

Study area and Sampling

The area under consideration in this study is an abandoned mine site located in the region of Belluno (North-east Italy), with an altitude ranging between 543 m and 990 m above sea level, and oriented in the SW-NE direction along the Imperina creek valley (Fig. 1).

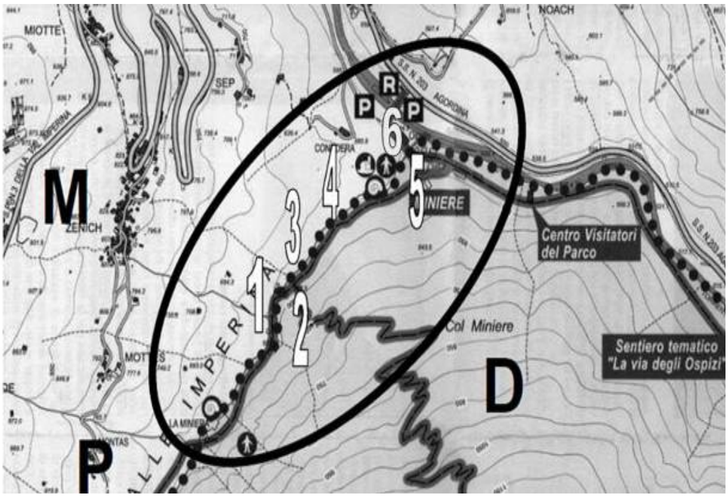

Figure 1

Location of the studied area and sampling sites of Imperina Valley. M = Metamorphic basement P = Phyllite- D = Dolomite. Sites 2, 4 and 6 are under grassland coverage, while sites 1, 3, and 5 are under forest (spruce).

The geological substrate consists of dolomite rocks (Dolomia Principale, Upper Triassic) on the right side of the valley and metamorphic basement (Pre-Permian) on the left side; while at the bottom, in unconformity with the previous geological formations, the calcareous-arenaceous complex of Werfen (Upper Permian - Lower

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Triassic) outcrops. The vegetation cover is mainly composed of mixed forests (*Abies alba* Mill., *Picea abies* (L.) H. Karst., 1881, *Fagus sylvatica* L. and *Ostrya carpinifolia* Scop.), with clearances where herbaceous and shrubby vegetation prevails over the arboreal one. Part of the territory lies within the National Park of the Belluno Dolomites. The mineralized area, which is located along the tectonic contact between the metamorphic basement and the dolomite rocks, is a deposit of mixed sulphides, composed primarily of cupriferous pyrite, pyrite and chalcopyrite, with minor amounts of other metallic minerals. Mining activities took place in Imperina Valley from the 15th century until 1962, when works related to ore processing ceased (Fontana et al., 2010).

A preliminary soil survey was conducted in the period of spring-summer 2011. Six soil profiles were selected according to homologous geological, morphological and pedological conditions, vegetation coverage and anthropogenic impact and the same pedoclimate conditions. Soil pits were opened and samples were collected from the upper horizon at a depth of 0-30 cm for routine analyses, and 0-15 cm (O+A horizons) for QBS-ar test. Humus samples were also collected at each site with their corresponding soil clod and were classified in accordance with the French system of humus classification (Baize and Girard, 2008).

Once carried to the lab, routine soil analyses were carried out following the procedures described by Violante (2000). For QBS-ar evaluation, according to Parisi et al. (2005), the humus and soil samples were carefully placed on the mesh filter (2 mm) above the Berlese-Tullgren funnel for 14 days. The light (heat source) creates a temperature gradient over the soil sample. Thus, the soil organisms (microarthropods) will escape downward passing through the filter and finally will fall into a collecting flask containing a preservative liquid (75% ethyl alcohol). Afterwards, the fallen organisms were collected and identified by light microscope. Subsequently, each type of organisms found in every sample is evaluated according to its adaptation to soil edaphic environment (Eco-Morphological Index EMI), receiving a score from 1 to 20. Eu-edaphic (deep soil-living) organisms get an EMI=20, hemi-edaphic (intermediate) get a rate proportional to their degree of specialization, epi-edaphic (surface-living) organisms get an EMI=1. Some orders gain a single EMI value, because all species belonging to these orders are eu-edaphic. Other orders exhibit a variety of EMI values, because they have species with different soil adaptation levels. For the analysis of pseudo-total metal content in soils, 0.2 g of powder soil sample (0-30cm) was subjected to a complete digestion in 5 mL of *aqua regia* in the microwave (model 1600-Ethos, Milestone) in closed containers made of Teflon. After digestion, soil samples were analyzed by flame atomic absorption spectrometry (AAS).

Results and Discussions

Soils were classified as Spolic Technosols according to the World Reference Base for Soil Resource, 2006. Full information on soil characteristics is available in Wahsha et al. (2012). Waste soils are shallow, sandy loam in texture and typically unsaturated with respect to water; they have low cation exchange capacity and

relatively high hydraulic conductivity that favours oxidation and alteration processes. Most pH values are acidic (range 4.5 - 7.8 depending on the lithology of parent material), which favours metal mobility. Organic carbon content is highly variable (4 - 41 g kg^{-1}), with the lowest values at the most contaminated sites.
Table 1 summarizes the results of the average of the total concentrations of Cd, Cr, Cu, Pb, Zn and Fe in the soils tested. The concentrations of most of the investigated metals in the soil samples were significantly higher (ANOVA $p < 0.05$) than the reference values, and almost above the toxicity threshold according to the Italian legislation (D.L. 152/2006). The area is almost not contaminated by Cr except site 3 which has a Cr concentration above toxicity threshold (113 ± 5 mg kg^{-1}). Instead, there is a contamination by Zn, Cu, Pb and Fe, which present very high concentrations, particularly at sites affected by intense mining activities (e. g. sites 1, 3, 5) and ore processing (site 4).

Table 1 - *Concentration of metals in soils of Imperina Valley. Cd, Cr, Cu, Pb, Zn and Fe are expressed as mg kg^{-1}. All the values are mean of five replicates ± S.D. DL = Detection limits.*

Site	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**	**Fe**
1	1.4±1.2	11±1	3511±19	20977±69	1722±24	491263±250
2	0.85±0.5	31±3	2822±40	14147±95	1096±11	320437±178
3	<DL	113±5	491±28	196±44	490±6	61087±95
4	4.35±1.1	14±2	4098±36	12124±56	2513±13	578632±229
5	5.14±0.7	81±3	411±42	314±51	394±10	48446±307
6	0.98±0.6	<DL	1894±35	11280±37	2717±20	47571±287
Italian average	0.53	100	51	21	89	37000
International average	0.30	200	20	10	50	--

Table 2 shows a summary of the QBS-ar values, humus forms, and soil pH results.

Table 2 - *Summary of the QBS-ar, humus forms and soil pH results.*

Site	**QBS-ar**	**QBS CLASS**	**NUMBER OF BIOLOGICAL FORMS**	**EU-EDAPHIC GROUPS**	**HUMUS FORMS (Organic horizon)**	**pH**
1	132	6	11	Acarina, Protura, Pseudoscorpionida	OLIGOMULL	8.0
2	86	3	8	Acarina, Collembola	HEMIMODER	7.5
3	162	6	12	Protura, Coleoptera	AMPHIMUS	5.5
4	96	4	8	Acarina, Symphyla, Collembola,	OLIGOMULL	7.0
5	120	5	8	Acarina, Chilopoda, Collembola	DYSMODER	5
6	65	4	4	Acarina, Chilopoda, Collembola	AMPHIMUS	6.5

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The QBS-ar values fall within a wide range (between 65 and 162). Significant differences in QBS-ar values between forest (average 139.33 ± 21.63) and grassland (average 82.67 ± 16.26) sites were recorded. According to Parisi et al. (2005), QBS-ar values between 100 and 200 identify a stable ecosystem with good quality. Sites 1, 3 and 5 under forest have good soil biological quality, since they have QBS-ar values higher than 100, but it should be noted that usually the values of QBS-ar in the forest soils are at least equal to 130; only site 1 and site 3 exceed this value. On the other hand, sites 2, 4 and 6, which are under grassland coverage, present medium soil biological quality, since they have a low QBS-ar value in comparison to the forest coverage. It was possible to assign QBS-ar values to different classes of soil biological quality (range between 3 and 6). The lower QBS-ar class indicates a state of suffering of the soil, and this has been observed in site 2 (where the effects of ore mining accumulated over the centuries).

The formation of humus seems to be dependent on both the type and amount of leaf litter, the soil pH and the contamination of soil matrix. Humus varied from Dysmoder (site 5) to Hemimoder (site 2) and Amphimus (sites 3 and 6) to the more developed humus forms, Oligomull (sites 1 and 4).

Several studies have investigated the relationships between microarthropod communities and humus forms; however, most of these studies focused only on one microarthropod group (Chauvat et al., 2003; Grgič and Kos, 2005). In this study, instead, we consider several groups of microarthropods, since it is likely that different microarthropod groups contribute diversely to soil ecological functions. Conversely, the EMI score is not equal for the same taxon, and this might explain why we could not find any significant relation between the development of humus and the QBS-ar value, as expected.

The composition and abundance of microarthropods at the investigated sites is reported in Table 3.

The eu-edaphic groups (Acarina and Collembola) were found in five sites; they have a relative percentage abundance of 57.3% and 11.2% on average, respectively. Among insects, in five relieves, the average abundance of Coleoptera is 6.8% while Hymenoptera is 8.9%. In two relieves we could observe the presence of Protura and Pseudoscorpionida as eu-edaphic groups, but with low abundance average (1.9% and 1.5% respectively). Among the Myriapoda in four relieves there were Chilopoda with average of 7.8%. Finally, among the holometabolous larvae, we could find the presence of both Diptera (4.6%) and Coleoptera (6.6%).

Heavy metals have been reported (Zhang et al., 2009) to disturb the ecosystem structure and functioning for long time, and the results of this study largely agree with published data. Yet, heavy metal contamination of soils has harmful effects on soil microarthropod biodiversity. QBS-ar values appeared to decrease significantly ($p < 0.05$) with respect to soil pollution by heavy metals. The correlation matrix (R^2) between heavy metals in soil and QBS-ar values showed that QBS-ar values were negatively correlated with Fe (-0.102), Pb (-0.384), Cu (-0.405) and Zn (-0.702). Conversely, our QBS-ar values indicate a significant positive correlation with Cr (0.298) and Cd (0.55).

Table 3 - *Eu-edaphic groups, order and classes with their EMI score and abundances in selected sites of Imperina Valley. Ab= abundance, EMI= Eco-morphological Index.*

		1		2		3		4		5		6	
		EMI	Ab. %	EMI	Ab. %	EMI	Ab. %	EMI	Ab. %	EMI	Ab. %	EMI	Ab. %
Aracnida	Acarina	20	74,5	20	80,4	20	75,4	20	38,7	20	41,7	20	33,3
	Araneae	5	2,1	1	0,4	1	0,8	0	-	0	-	5	13,3
	Opiliones	10	2,1	0	-	0	-	0	-	0	-	0	-
	Palpigrada	0	-	0	-	0	-	0	-	0	-	0	-
	Pseudoscorpionida	20	2,1	0	-	20	0,8	0	-	0	-	0	-
Crustacea	Isopoda	0	-	10	2,6	0	-	0	-	0	-	0	-
Myriapoda	Chilopoda	20	2,1	0	-	20	0,8	0	-	20	8,3	20	20
	Diplopoda	0	-	0	-	0	-	0	-	0	-	0	-
	Pauroposa	0	-	0	-	0	-	0	-	0	-	0	-
	Symphyla	0	-	0	-	20	0,8	20	3,2	20	4,2	0	-
Insecta	Blattaria	0	-	0	-	0	-	0	-	0	-	0	-
	Coleoptera	20	2,1	10	6,6	15	1,6	10	19,4	15	4,2	0	-
	Collembola	10	6,4	20	5,2	20	6,4	20	3,2	20	12,5	20	33,3
	Dermaptera	0	-	0	-	0	-	1	3,2	0	-	0	-
	Diplura	0	-	0	-	0	-	0	-	0	-	0	-
	Embioptera	0	-	0	-	0	-	0	-	0	-	0	-
	Hemiptera	1	2,1	10	2,6	1	4	0	-	0	-	0	-
	Microcoryphia	0	-	0	-	0	-	0	-	0	-	0	-
	Hymenoptera	5	2,1	5	-	5	0,8	5	16,1	5	16,7	0	-
	Orthoptera	0	-	0	-	0	-	0	-	0	-	0	-
	Protura	20	2,1	0	-	20	0,8	0	-	0	-	0	-
	Psocoptera	0	-	0	-	0	-	0	-	0	-	0	-
	Thysanoptera	1	2,1	0	-	0	-	0	-	0	-	0	-
	Zygentomata	0	-	0	-	0	-	0	-	0	-	0	-
	Other holometabolous	0	-	0	-	0	-	0	-	0	-	0	-
Larvae of	Coleoptera	0	-	10	2,2	10	4	10	16,1	10	4,2	0	-
holometabolous	Diptera	0	-	0	-	10	0,8	10	-	10	8,3	0	-
insect	Lepidoptera	0	-	0	-	0	-	0	-	0	-	0	-
	QBS-ar value	132		86		162		96		120		65	

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The presence of Acarina, Symphyla, Protura and Collembola is important, being considered metal-tolerant (Migliorini et al., 2004): for example, Symphyla seem to be quite affected by high lead concentrations and our results show a decrease in their abundance in areas with high concentrations of Pb, Zn and Cu.

Conclusions

The anthropogenic influence related to mining activity on soils of the studied area is evident. Former activities proved to affect the microarthropods community altering both quantity and quality of litter and the chemical-physical structure of the microhabitats. We found in the study area a moderate soil health status of the surface horizons due to the ecological success of secondary recolonization after abandonment, although affected by heavy metal contamination. Even if we could not find a statistical difference between QBS-ar and humus forms / ecosystem type, there seem to be different structures of microarthropods communities in terms of richness and evenness.

We hypothesize that 50 years of biological restoration of the mine site could have improved the microarthropods biodiversity, driving humus development towards a better ecosystem functional stability.

QBS-ar index proved a useful tool to evaluate soil biological health. However, there is an increasing need for further research focusing on soil health restoration assessment, combining QBS-ar index with soil bio-physical-chemical indicators.

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