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Short Communication

Evaluation of Soil Biological Quality Index (QBS-ar): Its Sensitivity and Usefulness in the Post-Mining Chronosequence – Preliminary Research

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Abstract

We took 60 samples in the post-mining chronosequence with different stages of ecological succession (4 sites) in 2005 and 2006. In total, 2,740 specimens of soil microarthropods were extracted and classified according to the Biological Quality of Soil Index (QBS-ar). The number of taxa of microarthropods and QBS-ar values increased with succession. According to the increasing values of QBS-ar, the soils of the study sites can be ordered along the following sequence: the youngest part of the dump (the two-year-old site) (S I) – the four-year-old site (S II) – the ten-year-old site (S III) – the twenty-year-old site (S IV) (mean QBS-ar = 40; 94; 120; 140, respectively). The QBS-ar index indicated better soil biological quality in woodland sites. The correlation between QBS-ar values and time of chronosequence was presented.

Keywords: QBS-ar, soil quality, microarthropods, biomonitoring, coal dump

Introduction

When a natural system is modified by mining activities, major changes occur in the soil environment and its communities. The mine sites are suitable environments to study the primary ecological succession in environmental stressed conditions. Soil-dwelling animals have a significant role in colonization and succession processes, and they perform the central role in the restoration of degraded biological habitats [1]. Their presence can be used as an indicator of soil quality [2] and provide information different than chemical, physical, and microbial characteristics [3]. Soil biodiversity is probably most important for maintaining the ecosystem function in disturbed environments [4].

In recent years, different researchers have presented various soil quality index schemes based on invertebrate communities [5-9], but simple methods and indices of soil quality assessment are needed.

One of the main problems with the implementation of soil quality indices are difficulties in the classification of organisms at the species level, which needs to be sorted out by specialists and is time consuming. In the biomonitoring programme of soil quality, the species identification of soil organisms must be relative easy [10]. Based on this idea, the simplest index of soil quality was proposed by Parisi et al. [11] for different groups of soil microarthropods, named QBS-ar (Biological Quality of Soil). This index uses the concepts of biodiversity to evaluate soil quality. It is a new monitoring tool for soil evaluation [11].

Microarthropods are one of the most important inhabitants even in strongly disturbed soils. They can be used as

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bioindicators of mine-site soil condition and rehabilitation [12]. Information on microarthropod colonization and succession of mine sites is important in view of their role in soil formation and rehabilitation of soil habitat.

The biological soil quality was evaluated by using the QBS-ar index. It is based on the concept that the higher the soil quality, the higher the number of microarthropod groups well adapted to soil habitat [11].

The objective of this study was to test the simple index QBS-ar based on the presence/absence of different groups of soil microarthropods and their adaptation to soil habitats (i.e. specialization) [11, 13]. The QBS-ar method was applied to soils of central Italy in forests dominated by different species, growing at different elevations and influenced by various factors (forest cutting, grazing, trampling, and industrial activities and emissions) [14-17], in organic and conventional agriculture [18, 19], in a clay pigeon shooting range with increasing levels of heavy metal contamination [20], and in anthropogenic soils [21-23].

The aim of this study was to investigate the colonization rate and the formation of microarthropod community patterns in the post-mining chronosequence with different stages of ecological succession. In this paper, we discuss whether it is possible to use the QBS-ar index as a capable indicator for evaluating the extent of successional changes in post-mining chronosequences. We hypothesize that analysis of the microarthropod community with the QBS-ar method can be used to compare the successional stages at mine sites of different ages.

Experimental Procedures

Study Sites

The study sites were located in mining areas of the Silesian Upland in Piekary Śląskie (Poland). The Silesian Upland is one of the most degraded areas in Poland owing to the long-lasting mining influence. The study plots were located on a mine dump of the "Julian" coal mine. The coal dumps were created in the process of piling the residues from coal mining, mainly rocks and carbonaceous shale. The dump material presented extremely poor conditions for soil organisms. The soil forming process was very slow. The sites represented a series of plots with different successional stages of plant communities:

- Site I (S I) was placed on the youngest part of the dump (the two-year-old site). This area is covered by barren rock.
- Site II (S II) (the four-year-old site) with no horizon differentiation and a thin litter layer derived mainly from *Calamagrostis epigejos*, *Deschampsia flexuosa*, *Senecio vernalis*, without woody vegetation.
- Site III (S III) (the 10-year-old site) with woody vegetation, with a thin organic layer and litter cover from leaves of *Betula pendula* and *Populus tremula*.
- Site IV (S IV) (the 20-year-old site), with woody vegetation, with a thin organic layer and a large amount of litter derived from leaves of *Betula pendula*, *Populus tremula,* and *Robinia pseudoacacia*.

Spontaneous vegetation at sites III and IV consisted of *Calamagrostis epigejos*, *Deschampsia flexuosa*, and *Senecio vernalis,* with isolated individuals of other species (*Lotus corniculatus*, *Epilobium angustifolium*). Vegetation growth at these sites was patchy.

Samples for QBS-ar Calculation

The QBS-ar index was applied, which was proposed by Parisi et al. [11] for soil microarthropods. It does not calculate either the quantity or quality of microarthropod communities in soils. The QBS-ar is based on the life-form approach. It is based on the identification of the collected microarthropods into different morphotypes, with each type receiving the ecomorphological index (EMI) and applied by separating the organisms into groups with homogeneous morphological characteristics. This is done on the basis of the ecomorphological index tables. QBS-ar is a summation of EMI-values. The score ranges from 1 (epiedaphic, surface-living forms) to 20 (euedaphic, deep-soil living forms). The most adapted microarthropods from a group determine the overall EMI score for that group. The QBS-ar of a sample is a sum of EMIs of a given sample. Some groups (for example Diplura and Symphyla) have a single EMI value = 20, because all species from these groups show a similar level of adaptation to the soil. Others groups had a range of EMI values (for example Coleoptera, EMI = 1-20), because in these groups there were species with different soil adaptation levels (higher EMI scores were assigned to species more adapted to the soil habitat). The most highly adapted microarthropods belonging to a group determine the overall EMI score for that group. Description of the QBS method can be found in Parisi et al. [11].

Samples for QBS-ar calculation have been collected in the same season when the soil was wet and not after heavy rain. In May 2005, 10 soil cores and in May 2006 five soil cores (10 cm x 10 cm x 10 cm) were taken at each of the sites. A total of 60 soil samples were collected and extracted for soil invertebrates. Fauna was extracted using the Berlese-Tullgren funnel for seven days. Arthropods were preserved in 75% ethanol. Extracted specimens were counted under a stereomicroscope at low magnification and identified at the order level.

We calculated the mean (and standard deviation SD) density of microarthropods and QBS-ar-values using conventional statistical formulae with Statistica 8 software. Moreover, for each S site in chronosequence, we calculated the mean values between 2005 and 2006, and correlated the four means with the time of chronosequence, applying a logarithmic regression model. R^2 measures the fitness of the data to the regression equation. A high determination coefficient (R^2) means the regression model had a good correlation.

Results

These data represent the preliminary results. A total of 2740 microarthropods from 10 different taxa (Acari, Araneidae, Blattaria, Coleoptera, Collembola, Chilopoda,

Table 1. Mean (individuals m^{-2}) and Standard Deviation (SD) of the numbers of individuals and ecomorphological index (mean EMI) for microarthropods occurring at the study sites in 2005 and 2006.

	EMI S I_{2005}	EMI S I_{2006}	N_{SI}±SD	EMI S II_{2005}	EMI S II_{2006}	N_{SII}±SD	EMI S III_{2005}	EMI S III_{2006}	N_{SIII}±SD	EMI S IV_{2005}	EMI S IV_{2006}	N_{SIV}±SD
Diplura										20	20	7±2
Collembola	10	20	180±25	20	20	680±187	20	20	1033±79	20	15	1993±43
Blattaria				5		13±9	5	5	27±7	5	5	53±21
Coleoptera (adults)				15	7	33±14	20	20	53±14	20	20	53±21
Hymenoptera	5		27±5	5	5	140±6	5	5	220±43	5	5	213±32
Diptera (larvae)				10	10	67±12	10	10	120±54	10	10	153±34
Acari	20	20	686±63	20	20	2693±206	20	20	4126±153	20	20	4960±97
Araneidae	5		20±4	5	5	100±45	5	5	93±27	5	5	127±21
Chilopoda				20	20	60±37	20	20	120±34	20	20	193±15
Diplopoda							20	10	7±2	20	20	20±5
QBS-ar	40	40	913±52	100	87	3786±234	125	115	5799±120	145	135	7772±322

Diplopoda, Diplura, Diptera, and Hymenoptera) were extracted from soil samples. The number of taxa of microarthropods increased with the age of sites (4, 8, 9, 10, respectively). Acari, Collembola, Hymenoptera, and Araneidae were found at each site, but the numbers of individuals from different taxa were very different. Mites were by far the most abundant taxa in the samples (Table 1). The highest numbers of mites were collected at sites III and IV (4126±153 individuals m^{-2}, 4960±97 individuals m^{-2}, respectively). The lowest number of mites was found at site I (686±63 individuals m^{-2}). Acari accounted for 68% of total soil microarthropods found at all four sites and between 60-79% of the microarthropods at each site. The other microarthropods collected during this study were present in low numbers. Blattaria, Coleoptera (adults), Diptera (larvae), and Chilopoda occurred at three sites. Diplopoda were found only at sites III and IV. The euedaphic forms, well adapted to soil life (Diplura) were scarcely represented at site IV.

Total density at the oldest site (7772±322 individuals m^{-2}) was more than eight times higher than the density of the youngest part of the dump (913±52 individuals m^{-2}).

At the three studied sites, the higher QBS-ar values were observed in the samples from May 2005 (Fig. 1). The analysis shows significant differences in QBS-ar values at sites I, II, and III. The QBS-ar values increased with succession. Fig. 2 shows the relation of QBS-ar values as a function of chronosequence time. Logistic regression produces a more efficient regression equation (R^2=0.9474).

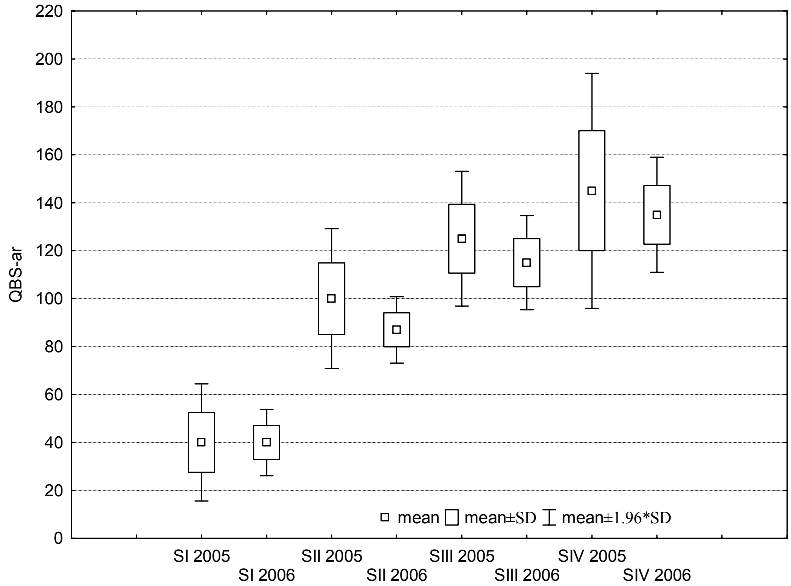

Fig. 1. QBS-ar values for different sites in 2005 and 2006.

According to the increasing values of QBS-ar, the soils of the study sites can be ordered along the following sequence: S I - S II - S III - S IV (mean QBS-ar = 40; 94; 120; 140, respectively).

Discussion of the Results

Soil fauna is particularly sensitive to environmental changes occurring during spontaneous succession at post mining sites [24]. Rusek [25], when studying the soil animal communities along a successional gradient, observed an increase in the diversity of both plant and soil communities. The impact of soil invertebrates on the soil structure is so significant that they are reckoned as ecosystem engineers. The coexistence of a number of different organisms creates more heterogeneity, thus it creates conditions for the maintenance of a high variety of organisms [26]. The microarthropod community is positive feedback on improved soil quality [27].

Microarthropods were scarce, both in abundance and QBS-ar values. The youngest stage of spontaneous succession was inhabited mainly by Acari and Collembola. These groups of microarthropods are known to be important in the early stages of succession [23]. At the beginning of ecological succession (site I), Hymenoptera and Araneidae were found in very low abundance in only 2005. The youngest study sites presented the lowest QBS values that ranged from 40 at site I to 94 at site II. The QBS-ar average values increased according to different successional stages and revealed better soil biological quality at woodland sites. The increasing values of the QBS-ar index correspond to increasing habitat complexity. The diversity of microarthropods increased as soil development proceeded. In the case of soil microarthropods associated with woodlands, the increased amount of organic matter in the top soil layers provides more food and more habitat diversity for succession. This study indicated that areas with wooded sites may provide better environmental conditions, which have remarkable effects on microarthropod diversity. These results are in agreement with the concept of Parisi et al. [11] that the higher the soil quality the higher the number of microarthropod groups well adapted to soil habitats. Menta et al. [23] hypothesized that the microarthropod community in the soil of a solid waste disposal site was affected by the soil structure and by the absence of well-structured vegetation cover.

Menta et al. [23], when studying the soil microarthropod communities at the solid waste disposal site and at two protected and undisturbed sites (grassland, wood), observed a limited microarthropod community and lower QBS-ar values (QBS-ar= 40-71, mean QBS-ar=56).

Arable lands show lower QBS-ar values than permanent grasslands and forest soil, and among arable lands, the agricultural system determines the significant differences in QBS values [29]. Agricultural soils are often characterized by values less than 100, forest soils and rich, organic grassland soil have values >200 [14].

The euedaphic forms (well adapted to soil life), as Symphyla, Pauropoda, and Protura, were entirely absent and Diplura, Diplopoda, and Chilopoda occurred only in some soil samples. Chilopoda have high densities in early successional phases of beech forests, during which there is no extreme fluctuation of soil humidity and temperature because of dense vegetation cover [28].

The index presented here proved that microarthropod diversity can be used as an indicator of soil quality in anthropogenic systems. Based on this preliminary assessment, we may conclude that the soil quality index QBS is a useful tool for assessing overall soil condition in a chronosequence of coal mining areas. On the other hand, biological indicators like QBS-ar could also be subject to seasonal changes and timing of sampling [30]. We observed that QBS-ar values (site II-IV) in 2006 were smaller than in 2005. These years were rather similar in terms of their averaged climatic conditions.

Unfortunately, most of these data have not been correlated with soil properties as it would be necessary for a correct ecological assessment. Further studies will provide useful information to verify our results and consider standardization of this method for soil biomonitoring.

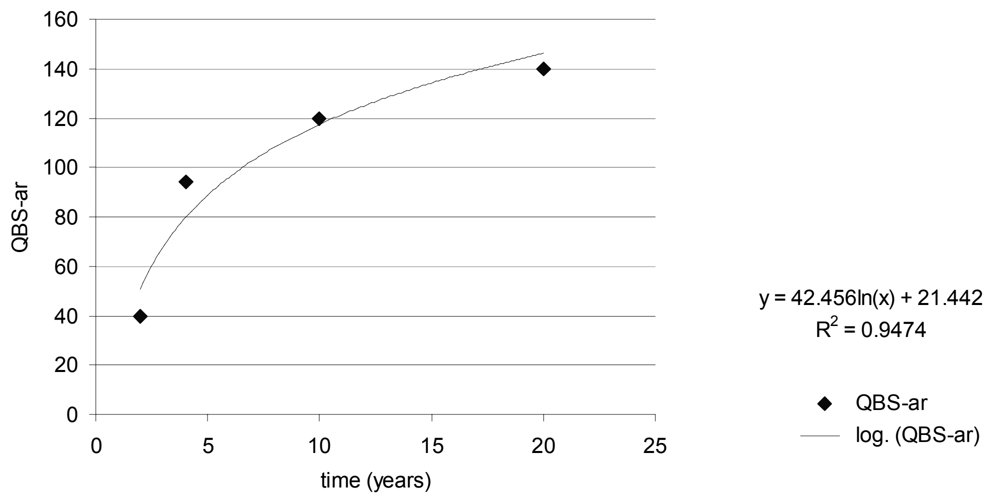

Fig. 2. Regression (log) between QBS-ar values and the time of chronosequence.

Conclusions

The QBS-ar index proved to be a sensitive tool in the evaluation of microarthropod diversity in the post-mining chronosequence. Further investigations should consider more accurate experimental procedures that take into account differences in soil characteristics. The QBS-ar index can be helpful for completing data obtained by other indicators (physical and chemical indicators) in order to evaluate soil quality.

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