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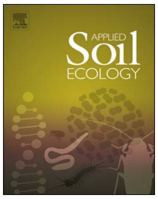

# Humus Index as an indicator of the topsoil response to the impacts of industrial pollution

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## ABSTRACT

Industrial pollution by heavy metal has negative consequences for soil biota that, in turn, result in a change in the topsoil morphology. The Humus Index, which is based on the morphological description of topsoil horizons and classification of humus forms, can be used as a quantitative score to assess the biological activity of polluted soils. In our study, we examined the advantages and shortcomings of the Humus Index as an indicator of the biological activity of soils compared with other indicators when analysing the impact of industrial pollution. We analysed index changes in response to industrial pollution and estimated the variability of the index values at differing spatial scales.

The effect of air pollution from the Middle Urals Copper Smelter (Russia) on the spectrum of humus forms was examined in the southern taiga spruce-fir forests. Twenty-three study plots were located in background (30–20 km from the MUCS), buffer (7 km and 4–5 km) and impact (3–0.5) zones. At each study plot, 5–7 round miniplots were examined. Diagnosis of humus forms were performed in the field according to the European Humus Forms Reference Base (Zanella et al., 2011a, 2017a). The replacement of zoogenic Mull humus forms by nonzoogenic Mor humus forms (Humus Index increase) with increased pollution has been shown. Humus Index correlated with heavy metal concentrations and thickness of forest litter. The humus form spectra of background and impact areas did not overlap. The diversity of humus forms and the range of Humus Index values were low in the impact and background zones and were wide in the buffer zones at all investigated spatial scales: within a single miniplot (0.5–2 m scale), within study plots (tens of meters scale), and within the pollution zone (kilometre scale). The high informative value, reliability and low work input, compared with other methods of assessment of soil biological activity, allow the Humus Index to be an effective indicator of the impacts of industrial pollution on the soil biota and a useful tool for environmental monitoring.

## 1. Introduction

Industrial pollution by heavy metals, particularly from non-ferrous metal processing factories, poses a serious threat to the environment. Although in recent years, emissions have been reduced in Europe and North America due to factory closures or the use of improved technologies (Pacyna et al., 2007), emissions in other countries, such as China, have remained high or even increased. Metals are usually retained in the topsoil for a long time, exercising a lasting negative effect on the biota for many years after factory closure (Tyler, 1978; Barcan, 2002). For this reason, the environmental issue of soil pollution by heavy metals remains topical.

It is well recognised that heavy metal pollution (especially in combination with soil acidification), has dramatic consequences for soil biota. In particular, the abundance and feeding activity of soil macroinvertebrates are reduced (Filzek et al., 2004b), with some groups of macroinvertebrates (e.g. earthworms, potworms, snails) completely disappearing at high levels of pollution (Bengtsson et al., 1983; Vorobeichik, 1998; Nahmani and Lavelle, 2002). In addition, the abundance and diversity of soil microarthropods (Rusek and Marshall, 2000; Kuznetsova, 2009) and microorganisms (Ruotsalainen and Kozlov, 2006; Mikryukov et al., 2015), as well as soil enzymatic activity (Wang et al., 2007) declines. As a result of such negative processes, the rate of organic matter decomposition as a whole (Strojan, 1978; Freedman and Hutchinson, 1980; Berg et al., 1991; Zwoliński, 1994; McEnroe and Helmisaari, 2001; Kozlov and Zvereva, 2015) and cellulose decomposition in particular (Vorobeichik, 2007; Vorobeichik and Pishchulin, 2011) is reduced. One of the most considerable consequences that can be observed by the naked eye, may be the increased thickness of the forest litter (Strojan, 1978; Coughtrey et al., 1979; Freedman and Hutchinson, 1980; Vorobeichik, 1995), which is accompanied by an overall change in its structure and topsoil morphology

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(Kaigorodova and Vorobeichik, 1996).

Effective indicators of soil pollution by heavy metals are needed. Despite the broad range of available methods for soil health assessment, there are few indicators that are informative, reliable, easy to interpret, rapidly measurable and involve low cost (e.g. Stone et al., 2016).

A few previous studies have specifically studied soil profile morphology changes in response to industrial pollution (Kaigorodova and Vorobeichik, 1996; Dijkstra, 1998; Gillet and Ponge, 2002; Filzek et al., 2004a; Ciarkowska and Gambuś, 2005; Arocena et al., 2012). With the exception of one characteristic – the thickness of the forest litter – none of these previous reports have suggested the use of individual morphological characteristics as indicators of state of soil biota. This may be explained by two reasons: 1) each single morphological characteristic of soil may be of limited informative value individually, meaning that several morphological characteristics need to be assessed in combination to be useful as an indicator of a certain soil process; 2) morphological characteristics describe changes at a qualitative level and are therefore difficult to formalise for quantitative assessment.

To overcome such shortcomings in regard to morphological characteristics, it is expedient to use the Humus Index (Ponge, 2003; Ponge and Chevalier, 2006), that is based on the European morpho-functional humus form classification (Zanella et al., 2011b). Humus Index is the ordinal number of a given humus form in the arranged list of these forms. First, this index integrates manifold morphological characteristics of the topsoil, reflecting the features of the decomposition process; second, the index transforms narrative information into quantitative data. An important convenient feature of the European classification for operational purposes is that, unlike other systems, it has been developed for field use with clear diagnostic criteria for humus forms (Zanella et al., 2011a). The feasibility of using the Humus Index in environmental investigations is supported by a case study of stand and soil development under different forestry practices (Ponge and Chevalier, 2006).

Another case study that would be important for calibrating the index and solving other methodological issues, impact regions may be considered, i.e. areas close to sourse of pollution (Vorobeichik and Kozlov, 2012). Such studies, provided the correct experimental design is in place, offer the opportunity to investigate the impacts of pollution "in pure form", not only with two contrasting impact levels (control and heavily pollution), but also across a broad range of gradually increasing doses of pollutant feed into ecosystems (Vorobeichik and Kozlov, 2012).

We have already shown the viability of using the Humus Index for one of the such impact region – around the Middle Urals Copper Smelter (MUCS) (Korkina and Vorobeichik, 2016). In the present study, we used much comprehensive data that allowed us not only to describe the index change trend with more certainty, but also allowed us to assess its variability and develop recommendations for sampling design and the required number of topsoil profiles to be studied in the test area.

The goals of our study were: 1) to analyse index changes in response to industrial pollution; 2) to analyse the level of spatial variability of the index values at differing spatial scales. We test the hypothesis that with increased pollution, the index grows considerably, i.e. Mull humus forms are replaced by Mor forms as the source of pollution is approached. Besides we examined the advantages and shortcomings of the Humus Index as an indicator of the biological activity of soils compared with other indicators when analysing the impact of industrial pollution.

## 2. Theoretical background

The main purpose of the Humus Index is to transform qualitative information into quantitative data. As suggested earlier (Ponge, 2003), the index is defined as follows: humus forms are arranged in a sequence according to the increasing role of large soil saprophages in organic matter decomposition and increasing decomposition intensity. The Humus Index is the ordinal number of the humus form in the sequence. Such sequences can be built for different series of forms, identified at the first level of European morpho-functional classification (i.e., by hydromorphic characteristics). However, the problem of the homology of such sequences arises. For example, Hydro or Para humus forms can be found among Terrestrial humus forms in the same studied plots. In such cases, humus forms similar in biological activity but in different series (Terrestrial humus forms and Para- or Hydro forms) should be assigned the same index.

**Table 1**
Correspondence between Humus Index value and humus forms in soils formed on non-calcareous parent material.

| Index value | Terrestrial | | Intergrades | |
|---|---|---|---|---|
| | systems | forms | Terrestrial and Para systems | Terrestrial and Histic systems |
| 1 | Mull | Eumull | | |
| 2 | | Mesomull | | |
| 3 | | Oligomull | Rhizo-Mull, Ligno-Mull, Bryo-Mull | Hydro Mull |
| 4 | | Dysmull | | |
| 5 | Moder | Hemimoder | | |
| 6 | | Eumoder | Rhizo-Moder, Ligno-Moder, Bryo-Moder | Hydro Moder |
| 7 | | Dysmoder | | |
| 8 | Mor | Hemimor | | |
| 9 | | Humimor | | |
| 10 | | Eumor | Rhizo-Mor, Ligno-Mor, Bryo-Mor | Hydro Mor |

Therefore, a unified scheme for numbering humus forms is needed. As far as we know, the earlier Humus Index was applied only to single series of humus forms, namely for typical Terrestrial humus forms. We developed a modified version of the Humus Index that includes different classification branches (Table 1). A sequence of Terrestrial humus forms was used as the main series and Para- and Hydro Intergrades were then added into it. Next, homologues (i.e., forms that have the same index in different series) were determined according to a set of diagnostic horizons. While similar series can be built for Histo and Epihisto forms, the numbering of their indices is independent of Terrestrial forms because they are diagnosed by other horizons. This is our first attempt to build such a scheme; however, it has already been applied to Terrestrial and Hydro forms and tested in practice by carrying out the present research.

A multicriteria comparison of different biological indicators can typically be performed only as "rough" qualitative expert estimates (e.g., Stone et al., 2016). We provided such expert assessments of the features of some of the indicators (Table 2). If, as a criterion of a good indicator, the correctness of using the parameter for analysis of industrial pollution impact is used, then, as compared with other field methods of assessment of soil biological activity, the Humus Index possesses a number of undisputable benefits: 1) high informative value – impact areas will be clearly differentiated from background areas (this is demonstrated in our study); 2) transparent interpretation – it is closely linked by cause-and-effect relationships rather than just correlation relationships with agents, conditions and the results of decomposition processes (this is principle of humus form classification that based on morphological evidence of biological activity); 3) reliability – interfering factors have little influence; 4) conservatism – it assesses an average situation in space and time, but not individual points and not a single snapshot as provided by other methods; 5) low labor intensity (and thus low cost).

In general, the possibility of erroneous interpretation of the Humus Index in relation to pollution is low. This is one of the advantages of this index compared with other possible indices, where the possibility of such erroneous interpretation is high due to a number of reasons: 1. Bell