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A biological classification concept for the assessment of soil quality: "biological soil classification scheme" (BBSK)

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Abstract

The protection of soils as habitat for soil organisms which is ascertained in the German soil protection act calls for the development of a broad, holistic approach with biological objectives. As a first step towards establishing a system that meets these criteria, two pilot studies have been conducted. The scope of these studies was to investigate whether there were characteristic soil fauna communities for specific sites or for pedologically defined groups of sites. We sampled the macrofauna groups earthworms, chilopods, diplopods, and isopods and the mesofauna groups enchytraeids, predatory mites (Gamasina), and moss mites (Oribatida). We could show that there were typical soil fauna communities that belong to specific site groups, e.g. acid forests or agricultural sites. The recorded patterns were more distinct the more taxa were incorporated in the analyses. The macrofauna alone gave good results but did not differentiate within the main site groups. Earthworms separated the open sites from the forests, whereas the arthropods differentiated within the forest sites. Mesofauna taxa added valuable information to the macrofauna results. We concluded that macro- and mesofauna together form site specific species assemblages that may be used for defining typical soil fauna communities for specific soils. This site specific soil fauna community can be used as a reference for assessing biological soil quality.
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1. Introduction

In our modern society soil has to meet several functions, e.g. to buffer pesticides, nutrients, and metals, to enable agricultural production, or to ground houses, streets, and railroads. In addition to these functions that are directly useful to man, soil also has to perform natural functions like being the substrate for natural vegetation and the habitat for soil organisms. In the German Federal Soil Protection Act of 17 March 1998 (BBodSchG, 1998) these variety of functions of soils are explicitly addressed. For each of these functions soil quality may be defined by very different criteria and approaches. The following paper discusses soil quality criteria for the function of the soil as a habitat for soil fauna.

There is a variety of methods for investigating soil biological parameters and some of these are proposed for soil monitoring programmes (see Römbke and Kalsch, 2000) in addition to chemical and physical investigations. Contrasting this the assessment of the habitat quality of soils is still in a preliminary

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stage, there is no commonly accepted procedure to evaluate the habitat function (Spurgeon et al., 1996; Dunger, 1998). It is evident after all that there is an urgent need for biological methods to assess the condition of the living system "soil". However, the habitat function can by no means measured by pedological properties but must be defined by biological parameters.

The concept we apply for that purpose is a biological soil classification scheme (BBSK), which relies on simple assumptions. They are: (1) That the composition of the soil fauna is mainly determined by the abiotic characteristics of sites. (2) That it is possible to find most important site parameters with the greatest influence on soil fauna. According to these assumptions sites with similar soils should have a similar soil fauna. So it should be possible to define a site specific reference soil fauna that can be used as baseline against an actual investigation. In a previous study (Römbke et al., 1997) we could show that it was possible to define site specific reference values (species composition or other community parameters) for many groups of the soil fauna.

Based on our assumptions and on the preliminary empirical results a four step procedure has been developed:

1. Site groups are defined by similar pedological and climatological parameters.
2. For each site group a specific soil fauna assemblage can be addressed that is the theoretical site specific reference community.
3. A site of interest is sampled for its soil fauna after it was classified to a site group due to its pedological and climatological characteristics.
4. The deviation between the reference and the actual sampled community is evaluated.

On the basis of single taxa, we have already tested our approach (Römbke et al., 1997, 2000, Dreher et al., 1999; Ruf et al., 1999). Comparable concepts are proposed for the UK (SOILPACS; Weeks, 1997) and are used in several Dutch investigations (Sinnige et al., 1992; Schouten et al., 2000).

We present the results of two surveys which were conducted to evaluate the concept of the BBSK. The approach was to include a variety of soil fauna taxa which belong to different size, life-form, and trophic groups. Therefore we studied the well known macrofauna taxa (macrosaphrophages and predators) and the poorly known and species rich taxa within the mesofauna (fungivors, microsaprophages, and predators).

2. Sites, material, and methods

2.1. Case study I

In a first pilot study we surveyed 11 forest sites in south-west Germany (Baden-Württemberg). All of these were included in a monitoring programme for investigating the impact of air borne pollutants on forest ecosystems. The chosen sites cover a broad spectrum of potential impact of air borne pollutants, from close to industrial centres to more pristine rural landscapes. Site parameters are published in LfU (1993) and Römbke et al. (1997). We sampled for 2 years, twice in spring and in autumn. Sample size for the microarthropods was 25 cm × 25 cm in four replicates for the organic layers and 25 cm^2 to a depth of 10 cm for the mineral soil in eight replicates per date. Extraction was done horizontalwise on a standard Berlese funnel system. Enchytraeids were sampled by a corer (25 cm^2 surface) and extracted by a modified O'Connor system. Earthworms were handsorted in the litter layer and expelled from the mineral soil by a formol solution. Macrofauna was caught in Barber traps during the vegetation period in two consecutive years. Taxa identified on species level were: Carabidae, Isopoda, Chilopoda, Diplopoda, Lumbricidae, Enchytraeidae, Oribatida, and Gamasina. They all cover different size classes and positions in the food web. The soil parameters were measured by standard methods (pH in $CaCl_2$; organic matter content as loss of ignition) or were made available by the "Landesanstalt für Umweltschutz Baden-Württemberg, Karlsruhe". Soil parameters used to classify sites to ecologically similar groups were pH-value, organic matter content, *C*/*N* ratio, soil moisture, and soil texture. All parameters themselves were classified into 4 or 5 groups, mainly according to the Kartieranleitung, 4th ed. (AG Boden, 1994), in the other cases according to the criteria given by Dreher et al. (1999).

This study served as a pilot project in which methods for classifying fauna and soil parameters were

Table 1
Site parameters for the 15 investigated sites in the second study (the first 10 are forests, the next four grasslands (last letter G) and the last an arable field (last letter A); SBB and CRM are the least acid forests)

	Texture	pH (in $CaCl_2$)	Precipitation (mm per annum)	Soil moisture "nFKWe"	*C/N*	SOM (%)
SBB	Lt2	5.1	940	93	25.7	21.7
CRM	Lts	5.9	800	139	13.6	12.5
NIB	Uls	3.9	1120	255	14.4	11.5
SCF	Lts	3.2	833	139	23.7	12.0
TAM	Us	3.1	784	257	17.9	17.0
MEM	Su3	3.5	950	171	19.0	14.0
LUB	Sl3	2.8	730	134	23.9	2.5
EHE	Sl3	3.1	720	137	16.2	7.1
BBK	S	3.4	600	95	20.8	9.7
BEK	Su3	3.2	596	89	25.9	7.6
SCG	Sl4	4.8	833	191	10.1	9.0
BRG	Tu3	4.6	828	122	11.2	7.9
AKG	Ut4	4.9	722	205	9.3	8.0
SBG	Lt2	5.7	940	76	7.6	3.8
SBA	Ls2	5.4	940	83	10.4	4.1

elaborated. Reference values were defined by the experts for each taxa separately. Deviations from the reference values were classified in "−" (clear deviation between reference and actual value), "±" (some differences, but not clear), and "+" (no deviation within 30% range). For more details see Römbke et al. (1997).

2.2. Case study II

The second study was conducted in a more realistic framework as it can be expected when a soil classification concept is used routinely by governmental agencies. Sampling was done only once in late autumn/early winter 1998 and we did not use Barber traps. All other methods were applied accordingly. We sampled 15 sites all over Germany, 10 of which were forests, 4 grasslands and 1 arable field (for more details see Römbke et al., 2000). Site parameters are given in Table 1. Taxa identified to species level were Isopoda, Chilopoda, Diplopoda, Lumbricidae, Enchytraeidae, Oribatida, and Gamasina. Nematoda were identified for three sites, only.

In the second study we invented a community approach, although each fauna taxon was also analysed separately (cf. Römbke et al., 2000). Community analysis was done by an indirect gradient analysis (correspondence analysis) with the software CANOCO and by cluster analysis with the software TWINSPAN.

3. Results

3.1. Case study I: south-west Germany

In our first pilot study we could show that soil fauna gives hints to the ecological condition of forest soils (Table 2). Most fauna taxa gave comparable results concerning the condition of the sites. For example, sites 350 and 520 showed major deviations for many taxa. Interestingly, these are the two sites which seem to be affected by atmospheric emissions from an industrial area. In the mineral soil there were slightly elevated (350) or clearly elevated (520) concentrations of Pb, Cd, and Zn. Epiphytic lichens were severely damaged at both sites (LfU, 1993). On the other hand, at sites 130 and 140 there was no indication for a disturbance for any taxa. These sites are located in the eastern part quite far from urban regions. Despite of that general pattern, there seem to be more sensitive taxa (e.g. the predatory Gamasina) and others that are more indifferent (e.g. Carabidae). At many sites earthworms gave no unequivocal results because some species that were expected could not be recorded. A complete species list and detailed information on the protocol for establishing reference values can be found in Römbke et al. (1997). Macro- and mesofauna were both suited within the framework of our concept. We were able to define site specific reference values

Table 2
Results of the taxawise evaluation of 11 forest sites in south-west Germany[a]

Taxon	Site numbers										
	130	140	292	310	350	380	400	410	450	470	520
Lumbricidae	+	±	+	+	−	±	±	±	+	+	−
Enchytraeidae	+	+	+	+	−	+	+	+	±	+	−
Diplopoda	n.d.	+	n.d.	+	+	+	−	+	+	±	−
Chilopoda	n.d.	+	n.d.	+	+	+	+	+	+	−	−
Isopoda	n.d.	+	n.d.	+	+	+	+	+	+	±	−
Carabidae	+	+	+	+	−	+	+	+	+	+	−
Oribatida	+	+	+	+	−	±	+	+	+	+	−
Gamasina	+	+	+	+	−	±	+	+	+	−	−

[a] −: Clear deviation between reference and actual value; ±: some differences, but not clear; +: no major deviation; n.d.: not determined.

for each taxa separately derived from published data which served as baseline for the fauna we actually found. In this stage it was not possible to define a common framework of evaluation for all investigated soil fauna groups. The reference values have been presence or absence of species for the macrofauna, only. For the species rich mesofauna groups integrated parameters like distribution of systematic groups (Beck et al., 1997) or life history tactics (Ruf, 1998) were defined.

3.2. Case study II: out of the forests

In the second project we focussed on the community analysis. The results for the macrofauna taxa Lumbricidae, Chilopoda, Diplopoda, and Isopoda are shown in Fig. 1a and b. Agricultural sites were well separated from the forests by the investigated macrofauna and within the forests the least acid ones form a group of their own. The correspondence analysis by the species reveals that the difference between agricultural sites and the forests is based on earthworms, but that the arthropods differentiated within the forests. There were no characteristic earthworm species for forest sites, except the two *Dendrobaena* species (*D. octaedra*: DENO and *D. rubida*: DENR). The earthworm species that are responsible for the mull humus form at CRM also occurred at the agricultural sites and are hence not diagnostic for weakly acid forest soils. A complete species list is given in Ruf et al. (2000).

After integration of the mesofauna taxa into the analysis the pattern did not change dramatically. Both the correspondence and the cluster analysis for all taxa show a distinct separation within the main sites groups (Fig. 2a and b). The structuring soil parameters were the pH-value and the *C*/*N* ratio. The prediction model using only pH-value yields 100% right results for the first step in the cluster analysis and for the second step 92% right prediction using both parameters, pH and *C*/*N* ratio. Comparing the results of the macrofauna analysis with the analysis done with all investigated taxa, it is evident that the patterns are more distinct the more taxa are included. More details are revealed when mesofauna taxa are incorporated. Especially within the forest sites there is more differentiation due to the microarthropods (mainly Oribatida). The coniferous forest sites BEK, BBK, and SCF form a very close subgroup within the other acid forest sites (Fig. 2a). The agricultural sites are more clearly separated from the forests due to the mite taxa Gamasina and Oribatida. In the Gamasina there are specialised species that only occur at the agricultural sites, whereas in the Oribatida there are only few species that could exist outside the forests. The two marshy pastures (AKG and BRG) again form a subgroup because they are inhabited by a hygophilous community of mites and enchytraeids.

We found site specific communities in the second investigation. The main separating parameter was the land use (forest vs. agricultural use). The second most important parameter was the pH-value and the third the *C*/*N* ratio. In grasslands the moisture regime was the major factor.

4. Discussion

In both studies we could show that soil fauna communities differentiate between different site types and

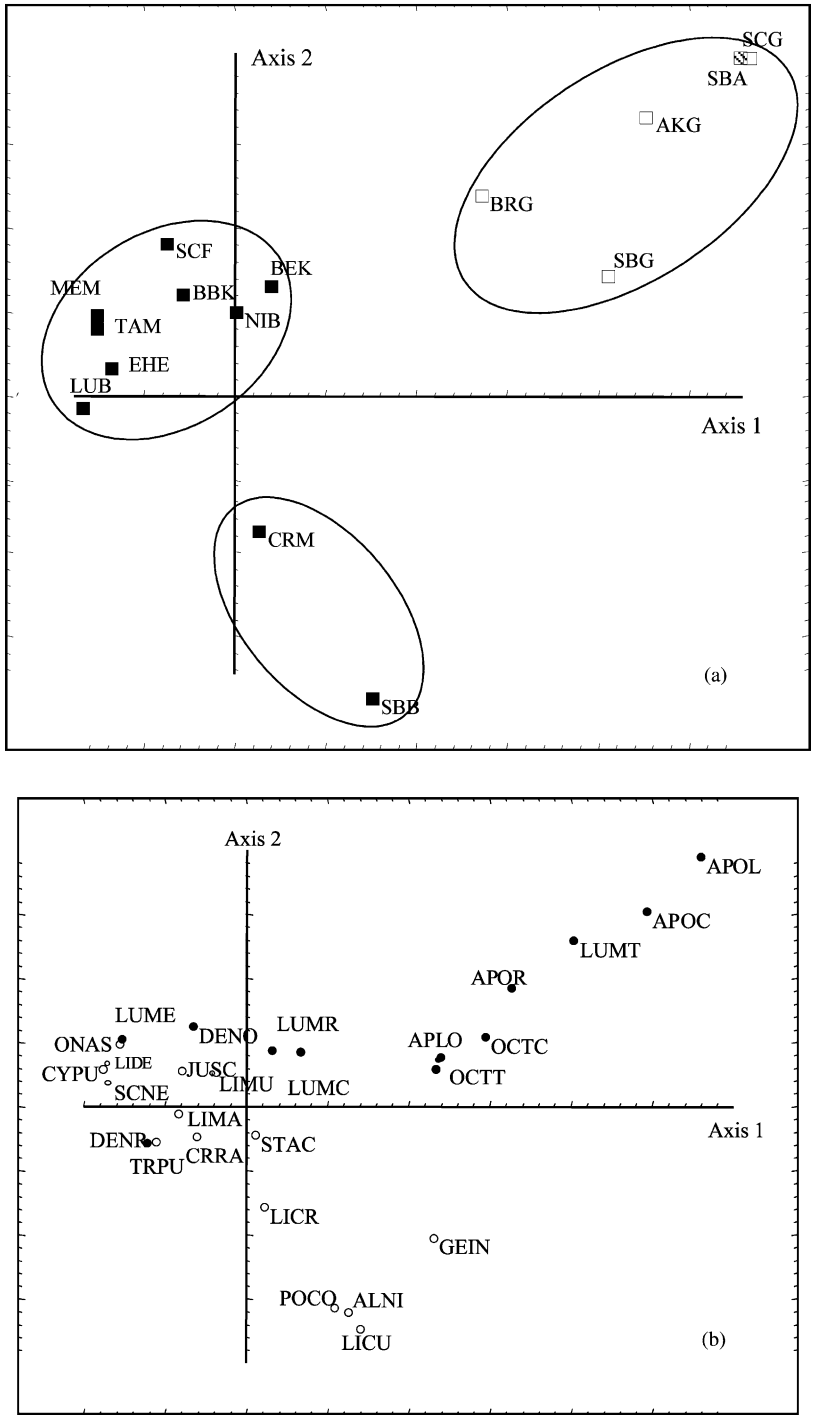


Fig. 1. Correspondence analysis for the macrofauna taxa Lumbricidae, Diplopoda, Chilopoda, and Isopoda. For site parameters refer to Table 1. (a) Sites, grouped according to their fauna assemblage; black squares: forest sites, open squares: pastures, hatched symbol: arable field. (b) Species, grouped according to the assemblage on each site; filled circles represent earthworms, and the empty circles are arthropods.

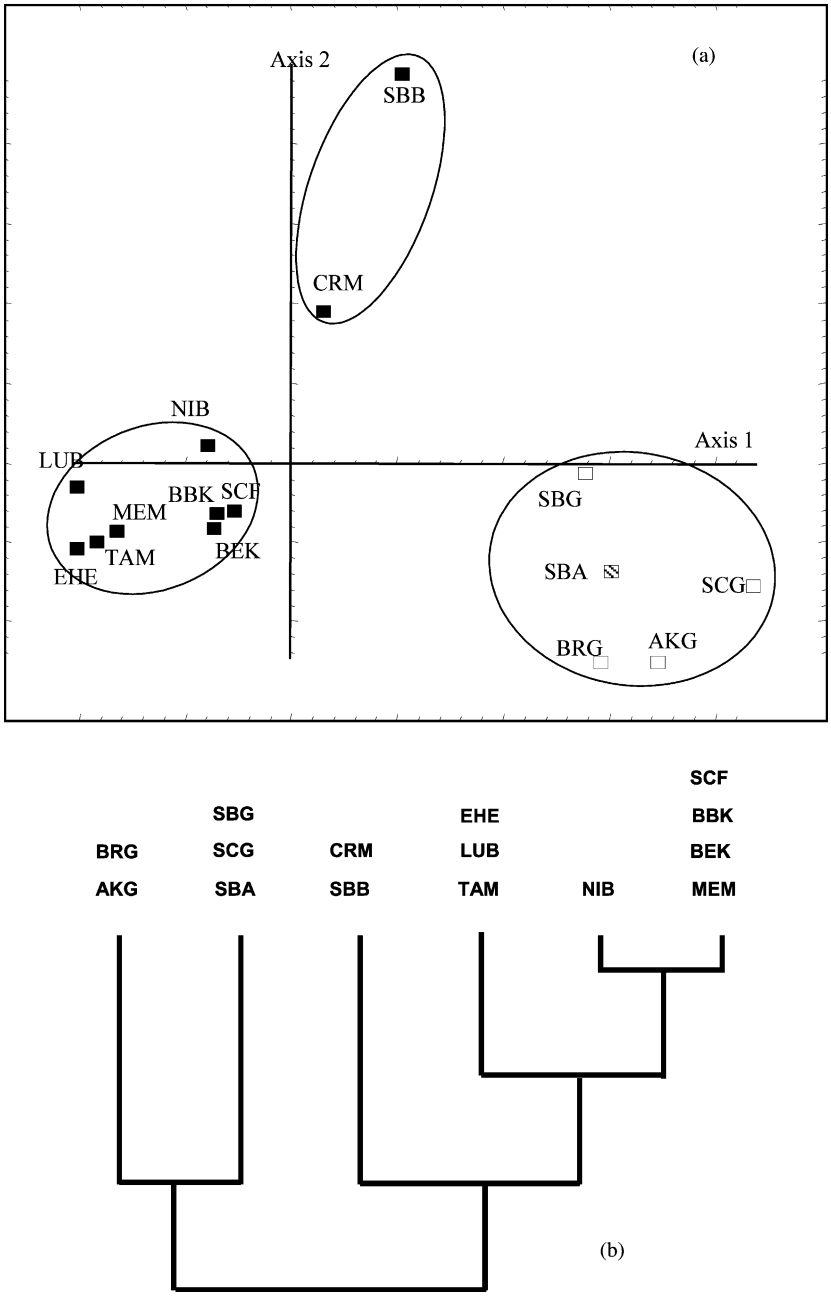


Fig. 2. Correspondence (a) and cluster analysis (b) for all taxa identified to species level. Black squares: forest sites, open squares: pastures, hatched symbol: arable field. For site parameters refer to Table 1.

different land use regimes. So groups of sites with similar features do have similar soil fauna, and on the other hand soil fauna can be used to characterise ecological site groups.

But still the definition of reference values is ambiguous. To predict the occurrence of a certain species at a definite site where it could dwell is a risky task, especially for species rich taxa like Oribatids, predatory mites or enchytaeids. Within these taxa there are very rare species that may not be discovered even in a favourable habitat simply because their numbers are too small to be found with reasonable effort. The difference between sites according to the species composition may appear larger than it really is ecologically. Species may react very specifically, differences are emphasised and shared characters neglected. Reasons for that are manifold: ecosystems represent singular unities which cannot occur exactly identical twice. Each ecosystem has its own history, its very specific characteristics, its surroundings, past and present disturbances. To draw general conclusions we have to find parameters that are not part of this singularity but belong to a whole class of sites or ecosystems and are not restricted to a very specific place and time. To meet this challenge one idea is to define parameters that integrate over species like taxonomic groups, life history tactics, dispersal strategies, or feeding guilds. These parameters are less variable and are more predictable on the level of pedologically similar site groups. Examples for the application of integrated taxonomical parameters are given by Beck et al. (1997) and Maraun and Scheu (2000) for Oribatid mites. Life history tactics for oribatids are distinguished and classified by Siepel (1995) and Behan-Pelletier (1999), for predatory mites by Ruf (1998), and for nematodes by Bongers (1990), and Yeates et al. (1993) classify nematodes to trophic groups.

The contrasting idea to this taxawise integration over species rather is to analyse the whole community of soil fauna and to classify this community. Each taxon gives its own valuable information but the community approach seems to be more differentiated (Sinnige et al., 1992; Spurgeon et al., 1996). Temporal variability in forest soil communities is shown to be low by Bengtsson (1994). This is especially true, when the analysis is related not to species level but to higher taxa. Therefore, a community approach like it is presented here is evidently well suited for bioindication and deserves further elaboration (see also Van Straalen, 1997).

A tiered or hierarchical procedure that relies on macro- as well as on mesofauna taxa has the advantage of incorporating the well known and in terms of energy turnover important species and not neglecting the species that are more sensitive to pollutants and other disturbances. In a first step, earthworms and macroarthropods are suited for characterising the community. Microarthropods and Enchytraeids can be used in a second step because these species rich but taxonomically difficult groups have a higher potential for differentiation. Site specific reference values on a community basis can serve as a benchmark for the habitat quality of soils. Further effort should be spent to the following items:

- Reduction of site parameters, not all are equally important. The main discriminating factor is the land use practise, then pH and *C*/*N* ratio which seem to be key factors structuring the soil fauna community. Further studies have to illuminate whether there is a land use specific hierarchy of the most important soil factors.
- Further definition of specific communities for each abiotically characterised site group. Each site group has to be identified in its spatial dimension and distribution in the landscape.
- Development of criteria for the assessment of a disturbance: What are threshold values at the community level, whose deviation has to be considered as being serious?
- Standardisation of guidelines for the practical performance of this concept for assessing biological soil quality.

5. Conclusion

In addition to the community approach the elaboration of taxa specific parameters to assess soil quality should also be continued. The definition of functional groups and life history tactics seems to be most promising (Siepel, 1994; Van Straalen, 1997). The community analysis is done by multifactorial statistics, indirect or direct gradient analysis. The distinguished groups can be defined as assemblages that occur under specific environmental conditions, similar

to associations in plant sociology. This approach was applied in a comparable way by Graefe (1993) and Graefe and Belotti (1999) for the Annelida and can easily be transformed to the whole community. An example of how this can be accomplished is the RIVPAC classification and prediction system (Wright et al., 1993) for running waters. To transfer this system for assessing soil quality in an accordant manner, much more reference sites have to be studied. However our results indicate that this is a manageable task.

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