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Soil Biological Quality Classes of Soils

SUMMARY FINAL REPORT

by

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Summarized important results of the study "Soil Biological Quality Classes of Soils"

1 Conclusion

The study aimed to elaborate a concept for the assessment of the soil function "Basis for life and habitat for ... soil organisms" as defined in the Federal Soil Protection Act (Bundesbodenschutz-gesetz, BBodSchG) of March 24, 1998. In the sense of the study the terms "soil biological quality of soils" and "soil quality" are used as synonyms. Contrary to other assessment concepts, which are based on the principal of ecotoxicological soil testing by testing representative organisms in the laboratory, the basic idea of the presented Soil Biological Site Classification (Bodenbiologische Standortklassifikation, BBSK) is the assessment of a site by comparing an expected soil biocenosis with the realistic biocenosis of the site. It is assumed that the biotic communities are substantially determined by abiotic factors (e.g. soil properties, climate, soil use). Concerning the measuring parameters to be applied, qualitative parameters (e.g. family or species spectrum) are preferred to quantitative parameters (abundances), which are frequently governed by short-term effects, for example climate. The measure for the assessment, therefore, is biodiversity. Prerequisite for a routine application of the system is the cartographical presentation of the expected community in dependence of the soil biologically relevant abiotic factors. Based on these factors, the area of the Federal Republic of Germany can be classified into soil biologically comparable environmental compartments (site types).

The R&D project included several study units:

I. Definition of site types

Objective: Tabular and cartographical classification of the area of the Federal Republic of Germany into sites types and their subdivision into groups of similar site types. This included the following work steps:

- Elaboration of basic dependencies between soil parameters and different groups of animals
- Definition of the most important soil factors and their classes of values ("Werteklassen") following the "Bodenkundliche Kartieranleitung" (4^{th} edition, AG Boden 1994)
- Classification of the area of the Federal Republic of Germany into site types, aggregation of the site types primarily following statistical methods.

II Derivation of expected data for selected groups of the soil fauna

The data were derived either on the basis of literature data or based on own investigations mostly performed at sites in the state of Baden-Württemberg.

III Examplary sampling of 15 sites

Samples were collected in ten forests, four grassland sites and an agricultural field. The determined soil animals were nematodes (examplarily at three sites) earthworms, enchytraeids, oribatides, isopods, diplopods and chilopods. These animal groups had been found suitable with respect to various parameters in the scope of the literature study "Soil fauna and environment" (Bodenfauna und Umwelt; Römbke et al. 1997). In addition, a functional parameter (bait lamina test) was considered in the present study.

IV Comparison of expected values and actual values

On the basis of the determined biotic communities (species, families) the actual values (e.g. indicator species, maturity-, diversity-, species identity- and dominance identity indices) were defined by means of animal group-specific evaluation procedures and, if available, compared with the expected values.

With respect to a further improvement of the BBSK concept the following conclusions can be drawn from the obtained results.

1.1 Site characterization

A central problem for the application of the site type system is the precision of spatial data used for site characterization. According to the current state of the evaluations the site types with the assigned spatial distributions and areas form a sort of virtual units supporting the users of the BBSK by selecting the investigation sites; they also give hints and arguments for the interpretation and generalization of obtained data. However, the system is not suitable for a reliable characterization of single sites at any location of a landscape or map. The second crucial point are the data characterizing the indicator soils (soils of primary relevance) relating to soil use. Indicator soils and the respective soil data are representative solely for the soil use referred to in

the respective legend unit of the soil map 1:1 mio (BÜK 1000), and do not apply for other forms of soil use.

The described weak points of the system are basicly due to the applied data base. Concerning the precision of data the system probably could be considerably improved if further development of the digital soil map by the BGR (Bundesanstalt für Geowissenschaften und Rohstoffe, Federal Agency for Geosciences and Mineral Resources) would include soils of secondary relevance (Begleitböden) and the respective soil data in addition to the indicator soils. The usefulness of such an improvement of the BBSK will also depend on the common parameters of the indicator soils and the soils of secondary relevance with respect to characteristic pedological data (factors). If common characteristics should mainly refer to a soil systematic classification without sufficient similarity of characteristic top soil data, further development of the BBSK could be problematic in so far as it could result in a strongly enlarged inventory of secondary (subordinal) legend units in form of the soils of secondary relevance and respective data. The systematic use or classification of these additional data might request modifications of the described strategy.

With respect to problems related to soil use a potential for improvement would be given if

- data with a clearly defined relation to soil use were available and if,
- in addition, a respectively adapted set of site factors could be defined depending on soil use.

On a medium-term basis the BGR plans the elaboration of more strongly soil use-related data. A first map referring to forest soils (so-called "Wald-BÜK"), is currently under development in a cooperation between the BfH (Bundesanstalt für Forst- und Holzwirtschaft: Federal Agency for Forestry and Timber Industry) and the BGR. The approach is based on the data of the BZE (Bodenzustandserhebung im Wald: investigations on the state of soil conditions in forests) in combination with the digital BÜK 1000. According to so far available information, the map and data set seems a suitable tool for the elaboration of a forest-specific site characterization system. Future application in the scope of the BBSK concept is therefore possible.

A major advantage of this basic tool would be the clearly use-related structure on the one hand and the consideration of different forms of raw humus on the other hand. A possible approach could consider the combination of five humus forms (according to L. Beck and E. Belotti (unpublished)) with e.g. three stock types (coniferous, deciduous and mixed forest). The obtained

different site types or site-related humus types will then have to be compared with respect to an expected similarity of organisms (biotic communities) occurring in the humus forms of different regions (highlands, hill countrys, plains, several substrates). The procedure will either result in a cartographic or spatial assessment or in the description of examplary sites or reference sites (e.g. raw humus under spruce at a highland site on a podsol), which can then be used to classify investigated sites. Before the possibilities resulting from the application of the "Wald-BÜK" can be finally assessed, however, a thorough investigation of the structure of the system and the data base is needed.

Discussing the results of the site characterization and their application to the investigated sites in the scope of the study shows that practical application and validation of the BBSK requires an assessment of the respective site by qualified personnel. For each site assessment it has to be critically proved whether or not a typical scenario is given. For a number of situations some of which are given in the following, the BBSK should not be applied or should be applied only after a thorough investigation of the scenario:

- very stony soil
- extreme site conditions with respect to the relief (e.g. escarpment) or exposure
- preceding extraordinary and intensive impacts on the respective site by a factor other than the routinely determined five factors (e.g. regular flooding, recent liming or fertilization measures, windbreak).

Important aspects to be considered for an improvement of the BBSK – from the point of view of a site characterization – can be described with the following central questions mostly demanding an investigation of representative sites:

- Does the investigated site really correspond to the indicated site type?
- Is a clear classification of the scenario (factors, site types) by experts possible?
- What is the outcome of a comparison between an "expert judgement" at the investigated site and the result of a site characterization for the respective site or region?
- Is it possible to elaborate a sort of quality management system despite the wide scope of discretion?
- What can be the basic concept of a training and "standardization of sites" for future users of the system?

- In what way can parameters relevant for a site characterization be integrated into routine measuring programmes (e.g. BDF (Bodendauerbeobachtungsflächen: soil monitoring sites))?

1.2 Biological characterization

A Selection of organisms

Expanded sampling was performed for oribatides, gamasina, enchytraeids, earthworms, isopods, chilopods and diplopods. At three sites nematodes were sampled additonally. Due to their frequency and with respect to their habitat and way of life it is recommended to include nematodes and collemboles (representatives of the micro and mesofauna) into further investigations. The inclusion of microorganisms - though soil biologically important - is not possible at present, since the existing methods to determine microbial diversity are still under development and not yet available for routine application.

B Characterization of the biotic communities of the soil

Sampling of the investigated sites first resulted in comprehensive lists of organisms, in general species lists. In the scope of data evaluation the available information had to be aggregated or correlations to standard parameters had to be determined. To be able to compare the soil fauna determined at the sampled sites with each other or with expected values (i.e. a "virtual" site characteristic soil animal community including the species spectrum and further properties, as e.g. diversity), different approaches were applied depending on the investigated group of organisms. One possibility was the application of statistical procedures to determine indicator values (gamasina). Another approach included the calculation of maturity indices (nematodes, gamasina), classification according to r/K triangle (gamasina), the determination of species and dominance identity (oribatides), diversity index (gamasina, oribatides) and the direct comparison of determined and expected data (enchytraeids, earthworms). Further attempts aimed at a comparison of expected and actual values by comparing the occurrence of indicator species (gamasina, enchytraeids, earthworms) and the abundance of the respective animal group with mean values known from literature.

At the present time a decision on which assessment method could be recommended for the respective sampled animal group is not yet possible. Based on an investigation of soil arthropod communities Van Straalen (1998) comes to the conclusion that out of nine approaches discussed in the literature a combination of an ecophysiological classification (e.g. according to pH prefer-

encies) and multivariate statistics is most suitable for a classification of soil organisms. In a comparable procedure expected values were derived for various groups of animals. In a second step the present study combined the information obtained for one species group at one specific site to an index. This approach should be critically used: While the use of simple indices (e.g. Sörensen, Renkonen) is suitable for the comparison of two sites (i.e. for comparing expected and actual values) and might also be applicable for similarity analyses, diversity indices (representing values for very high numbers): Shannon-Wiener Index, Mühlenberg, 1993) should be applied only as an additional information in the scope of an "expert knowledge": the strong aggregation of information makes an assessment more difficult, and the respective index value is often misleading and regarded as an assessment value. In the scope of future investigations a unification of evaluation methods for the single animal species should be attempted.

C Use specific compilation of a test battery of animal groups to be determined

In the present study all animal groups were determined at all selected sites (exception: nematodes). The investigations made clear that it is not senseful to recommend the same inflexible battery of animal groups for determinations at all investigated sites, since the occurrence of single groups of organisms is strongly influenced by soil use (e.g. oribatides are seldomly found at agriculturally treated areas, whereas they are one of the most species rich animal groups in forests). Therefore, the most important criterium for the selection of organisms to be sampled at an investigated site should be landuse. Considering this, possible batteries of animal groups can be divided into three categories: for euedaphic animals (e.g. many enchytraeids, earthworms, collemboles) a high correlation with the abiotic factors of the topsoil, on which our site characterization is based, exists. Therefore, they are suitable for the three main types of soil use (forest, grassland and agricultural land). Hemiedaphic animals (e.g. many collemboles, most oribatides and gamasina, many myriapodes) need habitats with looser soil structures than usually found in the topsoil; accordingly their preferred habitat is the litter. They are therefore especially suitable for the characterization of forest and, with some restrictions, for grassland sites, whereas their suitability for agricultural land is restricted (this especially applies for oribatides). Epedaphic animals (most carabides, some myriapodes, and, in general, many animals of the macrofauna) are principally less dependent on the abiotic factors of the topsoil, but preferably are indicators for climatic, vegetation related factors and frequently biogeographical relationships.

Based on the present results the following preliminary recommendations can be made:

	Soil use		
group of organisms	forest	grassland	agricultural land
nematodes	+	+	+
oribatides	+	+	-
gamasina	+	+	(+)
enchytraeids	+	+	+
earthworms	+	+	+
isopods	+	(+)	-
chilopods	+	(+)	-
diplopods	+	(+)	-

+: suitable; (+) restricted suitability; -: not suitable

D Determination levels

The elaboration of classification systems as a first stage requires the determination of animal groups down to a species or family level (procedure of the present study) to determine respective interrelationships between site factors and living communities with sufficient precision. The objective of the BBSK concept is to make possible the application by a great number of institutions and to present results in defined periods of time relevant for practical application.

For this purpose, a stepwise approach should be most suitable. First, an orientating analysis (aggregated information) should be done. In this step the living community is determined at a relatively high level (e.g. abundances, feeding types). The determination level is chosen with respect to the organism group. Requested knowledge can be acquired quite easily. In case deviations from expected results are observed at this investigation level, a more detailed investigation of the site should follow in a second step (detailed analysis). The requested determination level will again depend on the determined animal group. Determinations at this level require more comprehensive knowledge so that cooperation with specialists may be needed.

Future research work in the field has to focus on the elaboration of respective stepwise systems in dependence of the animal group. Furthermore, it has to be checked whether or not the determination of soil organisms can be facilitated (at any level) by the elaboration of currently

relevant keys for identification (if possible in an electronical form), since most of the available keys are out-of-date and, moreover, originally have not been designed for an application in the scope of a soil biological classification concept (e.g. restricted to the genus or family level).

E Functional parameters

In addition to the determination of biodiversity on the basis of different animal groups the bait lamina test was applied as a further functional parameter. An advantage of the test is its easy applicability and the information-yield via the activity of the organisms. However, as the test results depend on weather conditions (movement of the organisms into deeper soil layers with resulting modification of grazing profiles and formation of dormant stages due to unfavorable weather conditions) this test should be not more than an additionally used structural parameter to support the interpretation of unexpected values with respect to an overall site assessment. In case unexpected values are found not only for animal groups, but also for the bait lamina test, the impact on the site is to be weighted higher than in case unexpected values are determined for only one measuring parameter.

F Enlargement of the data base

The establishment of valid biological quality criteria for site types requires the availability of a comprehensive data base including suitable soil parameters. Therefore, future intensified cooperation with the resposible persons of BDFs, which already turned out to be helpful in the present study, can be an important basis. As a first stage of future cooperation, parameters which are already applied in the scope of the BDF programmes with respect to the soil fauna or regarding chemical-physical parameters and climate, including unpublished parameters, should be listed. In a second step recommendations should be defined indicating which additional parameters should be determined to profit from available data for the elaboration of the BBSK.

The investigation mainly focused on the determination of all animals occurring in the samples; between six and nine samples were tested for each soil depth. Enlargement of the data base should also include investigations to clarify whether or not the use of mixed samples or sub-samples, a procedure which is already established for microbiological investigations, is possible without a loss of information at least for representatives of the mesofauna. This would contribute to a remarkable reduction of the sample volume to be evaluated and accordingly to a substantial lowering of cost. Before such a simplification is recommended as a standard, however, the

variation of results for the respective area, the mean values resulting from the investigation of individual samples and the results obtained from investigating solely one mixed sample have to be determined. It has to be guaranteed that the distinction between single site types or site groups is still possible using the simplified procedure.

A further aspect to be considered for an enlargement of the database is that the amount and quality of availabe data considerably differs for the different types of soil use and for different regions. So far, soil organisms have been determined mainly in forests, whereas samplings in agricultural land and grasslands have been carried out rarely. Contrary to regions in the south of Germany, where numerous investigations have been performed, much less data have been evaluated in the eastern states of Germany. Future investigations, therefore, should focus on the compilation of a more uniform data base. Furthermore, it has to be noted that results obtained from only one sampling in most cases are not a sufficient data base for a precise definition of expected values. For this purpose, several samplings are imperative.

G Quality assurance

A prerequisite for the application of the BBSK concept by a great number of investigators is a comprehensive quality assurance. It has to be guaranteed that the validity of all data established is comparable. This can be achieved by a central training of the responsible persons and by the elaboration of comprehensive instructions of work.

H Impact scenarios

First of all, the "soil biological site characterization" aims at the characterization and classification of sites by investigating living communities. It is the basis for a data bank combining abiotic and biotic parameters and progressively including spatially important site types by covering the whole range of site factors, including types of soil use, their definition and classification. Considering these objectives, the BBSK already fulfills requirements resulting from the practical implementation of soil protection legislation, i.e. the BBSK data base contributes to a soil biological assessment of areas, which is a prerequisite for assessments in the frame of zoning maps, the definition and indication of nature preserves, decisions on compensatory measures, etc.

The classification of a site can help to identify deviations of or impacts on the site by comparing the derived expected values with the determined actual data. In a first step it is checked whether or not deviations from expected data exist. Then the determined deviation is further investigated to find out whether the parameters determined characterize a natural state of the site - which would require a modification of the expected values - or whether the unexpected result indicates a deviation of natural origin, as former adverse impacts (storm event, wind breakage, fire), or of anthropogenic origin. At the present state of knowledge modifications of expected results are expected to occur quite frequently.

A classification is only possible when sufficient knowledge is available to decide upon the significance of a deviation. Therefore, future investigations should not be restricted to samplings at unaffected sites, but in addition should include the investigation of affected sites in order to expand the data base and to derive/check expected values. To investigate the problem "Differentiation between affected and unaffected sites" only pairs of sites should be selected which are comparable regarding all soil biologically relevant parameters and which differ from each other only with respect to exposure.

2. Recommendations

2.1 Pedological and soil biological investigations

Study objective was the improvement of a concept for the assessment of the soil function "Basis for life and habitat for ... soil organisms" as defined in the Federal Soil Protection Act (Bundesbodenschutzgesetz, BbodSchG) of March 24, 1998. To achieve this, the concept of the soil biological site classification (BBSK), which originally had been elaborated at three forest sites in the state of Baden-Württemberg, was checked by investigating 15 sites in different regions of the Federal Republic of Germany. Already at the stage of proposal submission it was evident for sponsor and contractors that the elaboration of a data base for the described comprehensive approach (spatially as well as with respect to the concept) requires a considerable enlargement, and that this cannot be supported by one single authority. Therefore, the objective of the project can be subdivided – among others – into the following subunits:

- Proof of the applicability of the BBSK concept (e.g. with respect to types of landuse other than forest)
- Enlargement of the data base regarding the occurrence of soil organisms at specific sites and, accordingly, site types

- Recommendations for the methodology of soil ecological investigations to obtain, on a medium-term basis, differentiated data.

A Pedological characterization

Though the selection of the sites considered for the investigations was concentrated on sites for which a comprehensive pedological characterization could be expected (e.g. monitoring area of a federal state, EU Level 1 area), in a number of cases not all data requested for the soil biological site characterization were available (e.g. at several forest sites data on the C/N ratio in the topsoil were lacking). Considering the frequently very high number of measured parameters (e.g. parameters for nutrient supply based on forestry or agricultural requirements) it should not be problematic to include the following recommendations for the pedological characterization of monitoring areas and others. The respective methodology (especially according to DIN and ISO) is described in the conception for the establishment of soil monitoring areas (SAG (1993)):

- site characterization; i.e. obligatory field data (e.g. "Schlagkarteidaten")*;*
- all indicated data have to be differentiated for the soil layers (litter, topsoil);
- pH-value ($CaCl_2$);
- organic carbon content;
- total nitrogen content;
- C/N ratio derived from the determination of the two substances;
- grain size composition (soil type);
- for the determination of the usable field capacity of the effective vegetated soil depth (the indicated values can partly be estimated following the AG Boden (Work Group Soil (1994)):
  - horizon differentiation of the profile
  - density of layering
  - humosity
  - annual precipitation
  - for forest sites: humus form.

B Biological characterization

For a biological site characterization the animal groups listed in the following are principally suitable (including the methods used for their determination). Except for the collemboles, the

suitability of which is estimated on the basis of literature data, all recommendations are based on experiences gained in the course of this project or in preceding projects. The respective selection of the animal groups to be sampled strongly depends of the use of the site to be investigated and of the location (e.g. biogeographical region). Contrary to the recommendations of the SAG (1993) an inclusion of the microorganisms presently cannot be supported, as qualitative methods for determining microbial diversity are lacking. This also applies for functional methods, though these might be of relevance for the interpretation of potentially determined deviations of expected values. The determination level recommended for the macro and mesofauna is the species level, whereas for the nematodes only the family level is recommended at present. There is a need to investigate whether the determination level of the trophic group is sufficient for the nematodes.

The organisms suitable for the three forms of landuse – at least in Central Europe - are the same groups which are recommended by the SAG (1993) as obligatory or complementory for the soil biological investigation of monitoring areas. Groups occurring in only forests, or partly occurring in grasslands, can be used for further characterization.

Animal group	**Determination Method**
<u>all types of landuse:</u>	
earthworms	handpicking combined with formalin extraction
collemboles	core sampling with subsequent dry extraction
nematodes	core sampling with subsequent centrifugation
enchytraeids	core sampling with subsequent wet extraction
<u>single forms of landuse:</u>	
oribatids	core sampling with subsequent dry extraction
isopods, diplopods, chilopods	handpicking with manual search of specific sites

The sampling design at the site to be investigated should be as follows: On an area of two cross-shaped transects of 20 m length each, a total of six samples for handpicking (50 * 50 cm) and nine core samples are taken and transferred to the laboratory for further treatment (depending on the weather the handpicking can also be done in the open field). The core samples should be divided into two subsamples: forest samples should be divided into samples from litter and from the topsoil (0 – 5 cm); the other samples should comprise 0 – 5 cm and 5 – 10 cm depth of the

topsoil. The samples should be taken in a season when the soil organisms are active under consideration of the respective regional conditions. In Central Europe these periods are in spring (approx. march to may) and in autumn (approx. september to november). As relatively large areas are needed for sampling, the samples should not be taken in the center of a monitoring area.

2.2 Open questions

In the scope of the present R&D project various problems, which are of relevance for the improvement of the BBSK concept, could not yet be solved satisfactorily. The remaining problems (including proposals for a further proceeding) are summarized in the following paragraphs.

A Evaluation of the soil biological data

The large number of evaluation methods presently applied for the different animal groups (e.g. multivariate statistics, identification of indicator species, calculation of maturity or diversity indices and direct comparisons between expected and actual values) seems confusing. The further evaluation of the available data material cannot aim at a unification of the different approaches "at any price" (each procedure has its own advantages and disadvantages), but the objective should be the definition of selection criteria.

B Approach for the analysis of the soil living community

Due to the unsufficient data basis it has not been possible so far to decide on which identification or determination level is most efficient for the respective animal group in the scope of the soil biological site characterization . On a medium-term basis it should be investigated whether a two-step procedure starting with the determination of the living community at a high level (e.g. abundances, feeding types) followed by a detailed analysis at the species level is feasible. The determination of soil organisms can be simplified by elaborating current determination keys, since many of the available keys are out of date.

C Use of mixed samples

It has to be checked whether the use of mixed samples, which are already routinely applied in the scope of microbilogical investigations, is also applicable for the mesofauna without a loss of information. This would contribute to a considerable reduction of the sample volume and costs for testing.

D Enlargement of the data base (regions, forms of landuse)

So far, sampling concentrated on forest soils. Accordingly, the determination of soil organisms in agricultural fields and grassland (especially in northern and eastern Germany) has to be considerably increased. For the determination of expected values repeated sampling is imperative.

E Quality assurance

A prerequisite for the application of the BBSK concept is a comprehensive quality assurance comprising the compilation and evaluation of data. This can be achieved by a central training of the involved persons and by elaborating comprehensive instructions of work (e.g. in analogy to the taxonomic training workshops organized by the work group Quality Assurance in the scope of the "Bund/Länder-Messprogramm Nord- und Ostsee" (Federal/State Measuring Programme North and Baltic Sea); see UBA (Federal Environmental Agency) Annual Report 1998, p. 111). These are then implemented by experts in soil science or soil biologists/pedologists.

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