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Environmental Assessment of Soil for Monitoring
Volume I: Indicators & Criteria

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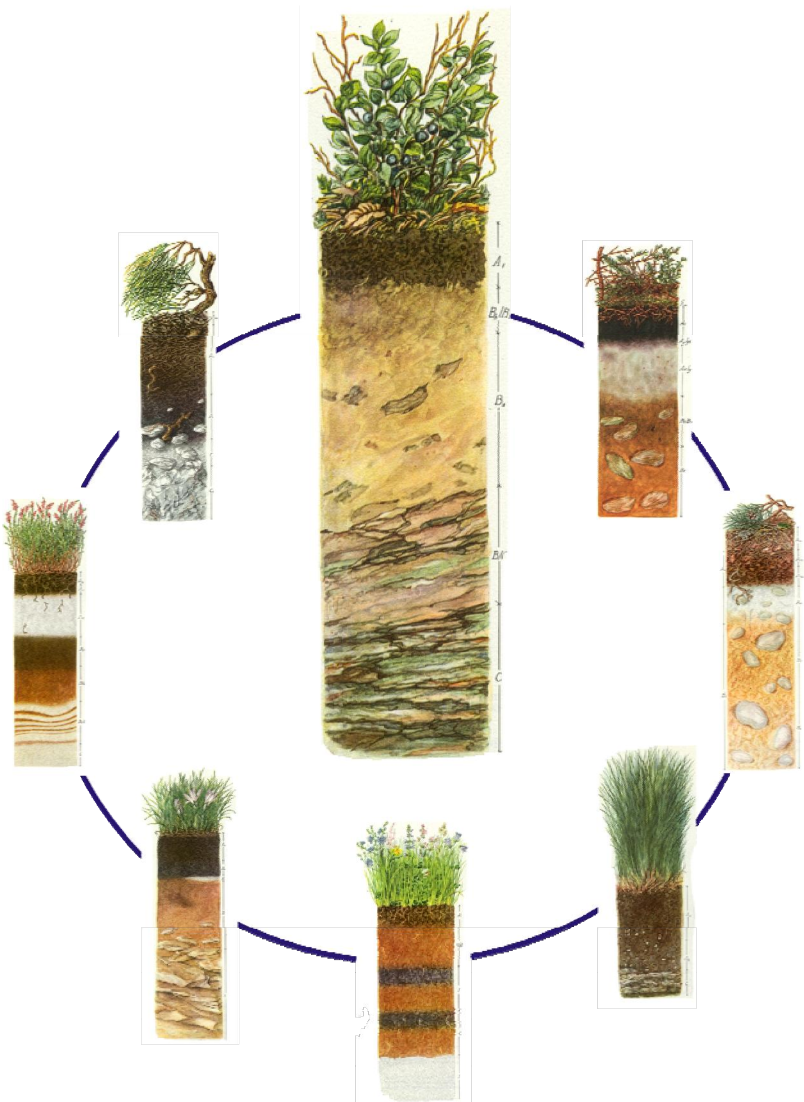

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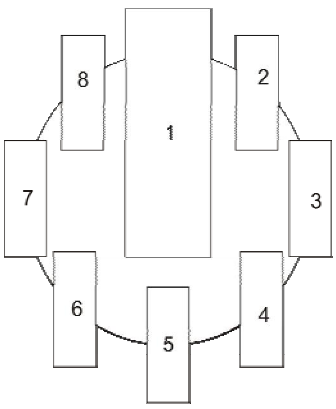

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Preface

The ENVironmental ASsessment of Soil for mOnitoring – ENVASSO – Project (Contract 022713) was funded, 2006-8, as Scientific Support to Policy (SSP) under the European Commission 6th Framework Programme of Research. The project's main objective was to define and document a soil monitoring system for implementation in support of a European Soil Framework Directive, aimed at protecting the continent's soils. The ENVASSO Consortium, comprising 37 partners drawn from 25 EU Member States, succeeded in reviewing soil indicators and criteria (Volume I) that are currently available upon which to base a soil monitoring system for Europe. Existing soil inventories and monitoring programmes in the Member States (Volume II) were also reviewed and a database system to capture, store and supply soil profile data was designed and programmed (Volume III). Procedures and protocols (Volume V), appropriate for inclusion in a European soil monitoring system, were defined and fully documented by ENVASSO, and 22 of these procedures were evaluated in 28 Pilot Areas in the Member States (Volume IV). In conclusion, a European Soil Monitoring System (Volume VI), comprising a network of sites that are geo-referenced and at which a qualified sampling process is or could be conducted, is outlined.

Volume I identifies 290 potential indicators relating to 188 key issues for nine threats to soil identified in the Commission's Thematic Strategy for Soil Protection. These threats are: erosion, organic matter decline, contamination, sealing, compaction, loss of biodiversity, salinisation, landslides and desertification. Sixty candidate indicators that address 27 key issues, covering all these threats, were selected on the basis of their *thematic relevance*, *policy relevance* and *data availability*. Baseline and threshold values are presented and three priority indicators for each threat are identified. Fact sheets describe the priority indicators in more detail. Existing soil inventory and monitoring systems in the EU Member States have been evaluated (Volume II) to establish the extent to which the 27 priority indicators are represented.

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29 June 2008

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8 DECLINE IN SOIL BIODIVERSITY

The soil biota play many fundamental roles in delivering key ecosystem goods and services, and are both directly and indirectly responsible for delivering many important functions such as releasing nutrients from soil organic matter, forming and maintaining soil structure and contributing to water storage and transfer in soil (Lavelle and Spain, 2005).

Soil biodiversity is generally defined as the variability of living organisms in soil and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (UNEP, 1992). Decline in Soil Biodiversity is generally considered as the reduction of forms of life living in soils, both in terms of quantity and variety (Jones *et al.,* 2005). Within ENVASSO the term 'biodiversity' was expanded to include the biological functions of soil. The following definition is proposed for this threat: "reduction of forms of life living in soils (both in terms of quantity and variety) and of related functions" (see ENVASSO Glossary of Key Terms)..

Little is known about how soil life reacts to human activities but there is evidence that soil organisms are affected by the:

- soil organic matter content,
- chemical properties of soils (e.g. amount of soil contaminants or salts),
- physical properties of soils such as porosity (affected by compaction or sealing).

Biological organisms and related activities are central to most of soil functions. As it is known that many of the soil threats will affect soil biodiversity monitoring, its decline is crucial to maintain soil sustainability.

8.1 Key issues

For soil biodiversity two key issues were considered:

- Species diversity.
- Biological functions (e.g. organic matter decomposition and mineralization or release of nutrients in mineral form).

These related aspects of biodiversity need to be understood and monitored. Species diversity (e.g. total number of species, species richness, genetic diversity within species, distribution of individuals among those species) and biological function (e.g. organic matter decomposition and mineralization or release of nutrients in mineral form) complement one another. For example, assessing biological functionality does not describe species' diversity while on the other hand, the number and abundance of species does not directly assess functionality. When monitoring the decline of soil biodiversity both aspects should be considered (Table 8.1).

Table 8.1 Overview of key issue selection for Decline in Soil Biodiversity

	Key issue selection		Description
	In	Out	
Decline in soil Biodiversity	Species diversity		Diversity within species, between species and of ecosystems
	Biological functions		Maintenance and functioning of specific ecosystems or habitats

8.2 Indicators

This section describes the results of the indicator selection process, listing the selected indicators along with their advantages and disadvantages (Section 8.2.1). Secondly, as neither baselines nor thresholds for the selected indicators were proposed, a common approach to their derivation is discussed (Section 8.2.2). Thirdly, the data and user requirements for implementing the selected indicators in a European monitoring system are presented (Section 8.2.3), and finally, the three most important indicators (TOP3) are proposed (Section 8.2.4).

8.2.1 Indicator selection

The literature review underlined the diversity of methods and indicators used mostly by research teams to assess and sometimes monitor soil biodiversity (Andren *et al.,* 2004). As a summary the following indicators were included in the selection:

- Microflora (bacteria and fungi): diversity of species based on different methods (e.g. DNA or PLFA fingerprints), microbial activities, general parameters such as soil respiration or total biomass. (Fierer and Jackson, 2006; Nielsen and Winding, 2002; Ibekwe *et al.,* 2002, Kubat J., 2003)
- Microfauna: protozoan (Foissner, 1997) and nematodes (Ekschmitt *et al.,* 2001),
- Mesofauna: Collembola, Acari and Enchytraeids (Sousa *et al.,* 2005; Ruf, 1998; Jänsch *et al.,* 2005)
- Macrofauna: earthworms are mainly used (Römbke *et al.,* 2005) but also total macrofauna (at family level for all groups and at species level for ecosystem engineers like earthworms and ants). The activity of soil macrofauna is used as an index for soil diversity (Pérès *et al.,* 1998).
- Soil organic matter is also used as an indicator for biodiversity and soil functioning (Ponge, 2003)

Mathematical indices have also been developed to simplify field data and to improve communication of the results to non-scientists (e.g. maturity index (Bongers & Ferris, 1999), soil macrofauna index (Ruiz-Camacho, 2004), QBS index (Parisi *et al.,* 2005), PLFA index (Puglisi, 2005).

There are no reported monitoring networks which fully include biodiversity, except in the Netherlands where the monitoring system includes both diversity of species and soil biological functioning (Rutgers *et al.,* 2005). The Dutch soil monitoring network is a stratified grid according to land use (about 160 locations are sampled for biological determinations every 6 years). Nevertheless in other EU countries (e.g. Austria, Czech Republic and Hungary) biodiversity indicators (e.g. soil respiration, Gamasid mites, earthworms) are already included or experimental studies are starting in order to complement soil monitoring networks (France, Germany).

Within the scope of this work it was not possible to review all possible indicators (more than 90 were identified) and it was decided to regroup them according to classical soil ecology definitions under two identified key issues, to give the following scheme (see Figure 8.1).

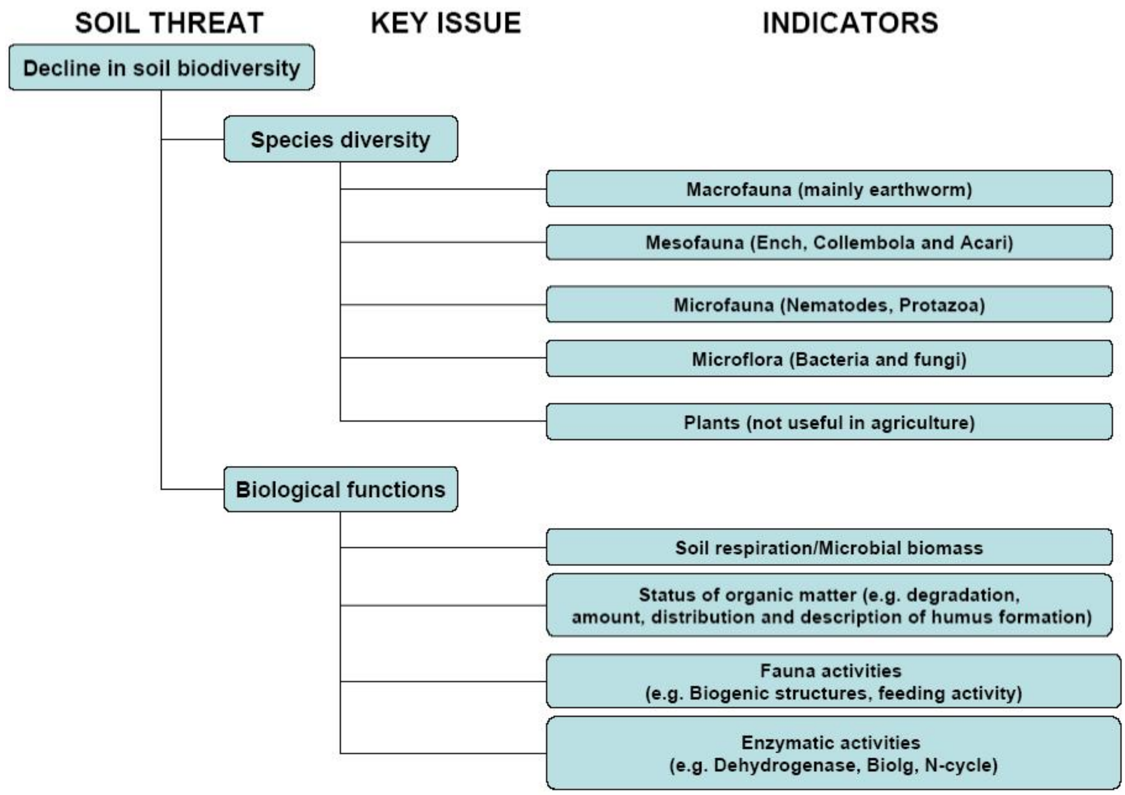

Figure 8.1 Key issues and indicators for Decline in Soil Biodiversity

A numerical ranking system for the proposed indicators was employed. Each indicator was ranked during 2 meetings involving 6 to 10 experts on soil biodiversity. The highest ranking selection criteria were:

1. **Significance of the indicator** (indicator based on 'sound science') - all candidates were considered as significant except plants since their natural abundance is meaningless in agriculture
2. **Acceptance of the methodology** - indicators with standardized methods were favoured
3. **Measurability and costs** - all available indicators for assessing soil biodiversity are both time-consuming and expensive, requiring labour intensive sampling, identification and quantification but nonetheless those that are more straightforward and relatively cheaper were preferred. (Research is progressing to develop software and/or technical guides allowing easier identification. Furthermore identification of soil species from DNA extracts is being developed)

Based on such criteria, the following indicators were selected: soil macrofauna, soil mesofauna, soil microflora for the first key issue (species diversity) and soil respiration as well as the status of organic matter for the second key issue (biological functions). Indicators identifying the status of organic matter are included in the TOP3 indicators chosen in the chapter covering the threat 'Decline in soil organic matter' (Chapter 4).

The species indicators belong to ecological groups which reflect the size of organisms. As an example, soil macrofauna integrates all organisms that can be seen visually (from 2 to 10 mm), including ants, earthworms, spiders and insect larvae. In principle all soil organisms and the biological functions which they provide are important and should be assessed. However, for reasons of practicability it was decided to select a minimum set of representative ecological groups (priority level I, Table 8.2) to act as surrogates measures for overall decline in biodiversity. (It should be noted that an increase in biodiversity may also be the sign of a disturbed ecosystem). Depending on the availability of resources and any specific requirements, this minimum set of indicators could be extended in some regions (priority level II and III, Table 8.2). The minimum recommended set of indicators (priority level I, Table 8.2) is to be based on:

i) For species diversity, earthworm diversity and biomass (or Enchytraeids if earthworms are not present) and Collembola diversity.
ii) For biological functions, microbial respiration.

Table 8.2 Priority level of indicators for Decline in Soil Biodiversity

Key issue	Groups of species	Level I (all core points of the monitoring network)	Level II (all core points or selected points depending on relevance to specific issues and availability of resources)	Level III (optional)
Species diversity	Macrofauna	Earthworm Species	All macrofauna	
	Mesofauna	Collembola species Enchytraeids (if no earthworms)	Acari sub-orders	Activity based on litter bags or on bait lamina
	Microfauna		Nematode diversity based on trophic guilds	Proctista
	Microflora		Bacterial and fungal diversity based on DNA / PLFA extraction	
	Plants			For grassland and pastures
Biological functions	Macrofauna			Macrofauna activity (e.g. biogenic structures, feeding activity)
	Mesofauna			Mesofauna activity
	Microflora	Soil respiration	Bacterial and fungal activity	

8.2.1.1 Species diversity

8.2.1.1.1 BI01 Earthworm diversity (identified at species level) and biomass

Advantages:

i) This measure of the diversity of earthworm species is directly relevant to the soil threat Decline In Biodiversity and the key issue 1.
ii) Earthworms are regarded as the main soil engineers and changes in their abundance and community structure modifies several soil properties such porosity and density, as well as functionalities, for example recycling and distribution of organic matter.
iii) Earthworms are the largest soil invertebrates, which makes them easier to sample and to identify with minimum knowledge.
iv) There are existing national datasets from which baselines and other criteria may be interpreted.
v) They are already measured in some soil monitoring networks.
vi) Easily understood and communicated to non-experts.

Disadvantages:

i) Sampling, identification and enumeration of earthworms is time-consuming and expensive.
ii) Earthworms cannot be used as the only surrogate for the decline in biodiversity
iii) They are not included in all soil monitoring networks.

Conclusion:
The primary indicator for species diversity is earthworm diversity (or Enchytraeids if earthworms are not present) identified at species level and fresh biomass. Sampling should be performed according to the ISO method 23611-1 (2006). For Enchytraeids the sampling method is ISO DIS method 23611-3 (2006). This indicator should be combined with the second one (BI02) in order to estimate the diversity of soil invertebrates.

8.2.1.1.2 BI02 Collembola diversity (identified at species level)

Advantages:

i) A measure of the diversity of Collembola species is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) Collembola are primary agents in the soil organic matter decomposition process, acting as dispersal agents for fungal spores and bacteria and promoting fungal succession during decomposition, while changes in their abundance and community structure modify the kinetics of litter degradation.
iii) When performing soil ecological assessments, Collembola are one of the most frequently used ecological groups as they are sensitive to changes in land-use practices and landscape composition and structure.
iv) There are existing national datasets from which baselines and other criteria may be interpreted.
v) There is some evidence that it may be possible to simplify Collembola identification since good correlations have been observed between species level and family level.
vi) They are already measured in some soil monitoring networks.

Disadvantages:

i) Collembola determination will require soil sampling followed by species identification and thus will be time-consuming and expensive.
ii) Collembola can not be used as the single surrogate for decline in below ground biodiversity.
iii) They are not included in all soil monitoring networks.
iv) Requires relative expertise

Conclusion:
The secondary indicator for species diversity is Collembola diversity identified at species level and sampled according to the ISO 23611-2 method (2006). Together with BI01 it will give a picture of the status of soil organisms.

8.2.1.2 Biological functions

8.2.1.2.1 BI03 Microbial respiration

Advantages:

i) Microbial respiration is relevant to the soil threat Decline in Soil Biodiversity and the key issue ‘biological functions’.
ii) Microbial respiration is considered to be a critical process in the soil system; it is correlated with degradable organic matter and soil microbial biomass.
iii) Microbial respiration of soils is easy to measure and standard protocols are already available.
iv) There are existing national datasets to support interpretation of baselines and thresholds.
v) It is already measured in some soil monitoring networks.
vi) It is relatively easily understood and communicated to non-experts.

Disadvantages:

i) Microbial respiration is a broad measure of soil system activity and provides little information about the activity of specific communities of soil micro organisms.
ii) Microbial respiration can not be used as the single surrogate for decline in below ground biodiversity.

Conclusion:
The indicator for species diversity is based on the measurement of microbial respiration (basal and induced) according to ISO methods 16072 and 17155 (2002). This method is widely used to characterize the status and activity of soil microbes as well as the available pool of organic carbon.

8.2.1.3 Supplementary indicators for species diversity and biological functions

This minimum set can be then be supplemented by additional measurements depending on specific issues that need investigation and availability of resources. The following groups of organisms or functions are proposed (priority level II, Table 8.2), reflecting those included in existing monitoring networks. Other additional indicators (not described here) may be usefully included in monitoring which is directed to specific issues and research investigations (priority level III, Table 8.2).

8.2.1.3.1 BI00 Microflora diversity

This indicator is based on PLFA and DNA extraction.

Advantages:

i) Diversity of bacteria and fungi is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) Microflora have many critical roles in soil functions; they support biogeochemical cycles and the growth of plants.
iii) This is already measured in some soil monitoring networks
iv) There are some national datasets which can be used for interpretation of baselines and thresholds.

Disadvantages:

i) Microflora diversity determination is much less labour-intensive than others which rely on identification and enumeration of organisms but will require expensive equipments.
ii) The sampling and extraction methods are not yet standardized.
iii) Interpretation of the results can be difficult in terms of effect on soil function.

8.2.1.3.2 BI01-1 Macrofauna diversity

This indicator is identified at family level. Soil macrofauna contain Lumbricidae (usually the most important taxon), followed in decreasing order by Formicidae, larvae (Coleoptera + Diptera), Coleoptera, Arachnidae, Gastropoda and Myriapoda. Some other groups may be present but in very low numbers, such as Hemiptera, Isopoda, Dictyoptera, Orthoptera, Isoptera and Dermaptera.

The assessment of soil macrofauna can be done by the species richness of earthworms (Lumbricidae) and ants (Formicidae), together with the number of other families present (a strong correlation with species diversity exists). Since many macrofauna species tend to have rather restricted areas of distributions and/or low densities that make their discovery rather infrequent, families appeared to be the best indicator of diversity, especially when comparisons have to be made over large geographical areas. Ants and earthworms, however, may be identified at species level because there are fewer species than other families and because their grouping into a single unit ignores their functional diversity. In addition, practical keys exist for the identification of these invertebrates.

Advantages:

i) The diversity of macrofauna families is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) Soil macrofauna play a major role in different soil functions, including microbial activation, nutrient cycling, soil aggregation, humus formation and organic matter recycling.
iii) As the different group of organisms integrated in this indicator have different feeding habits and exploit all resources available in the litter and soil it is anticipated that each group will react differently to soil pressures making this indicator sensitive to a range of soil changes.
iv) As organisms are identified at family level instead of species level, their identification and enumeration will be more straightforward for the non-specialists.
v) It is relatively easily understood and communicated to non-experts.

Disadvantages:

i) Macrofauna determination will require soil sampling followed by species/families identification and thus will be time-consuming and expensive.
ii) Standard sampling methods do not exist.
iii) This has not been included in existing soil monitoring networks and only a few national dataset are currently available or are being acquired. Consequently, there is a lack of data for interpreting baselines and thresholds.

8.2.1.3.3 BI02-1 Acari diversity

This indicator is not identified at species but at higher levels and sampled according to the ISO 23611-2 method (2006).

Advantages:

i) The diversity of Acari is directly relevant to the soil threat Decline in Soil Biodiversity and key issue 1.
ii) Organisms within different sub-orders (e.g. Gamasida, Oribatida) have different feeding habits and exploit all resources available in the litter and soil. It is anticipated that each sub-order will react differently to soil pressures making this indicator sensitive to a range of soil changes.
iii) As organisms are identified at a higher level (not species level) their identification and enumerations will be more straightforward for non-specialists.
iv) It is already measured in some soil monitoring networks.

Disadvantages:

i) Acari determination requires soil sampling followed by identification and enumeration and is time-consuming and expensive.
ii) The determination is relatively difficult compared, for example, to that of Collembola. Furthermore it seems that the taxonomy of the sub-orders is still being developed.
iii) Requires specialist expertise

8.2.1.3.4 BI02-2 Nematode diversity

This indicator is based on trophic guilds (e.g. fungivore, bacterivore, phytophage) and sampled according to the ISO DIS 23611-4 method.

Advantages:

i) Diversity of nematodes is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) As nematodes have different feeding habits it is anticipated that they will react differently to soil pressures making this indicator sensitive to a range of soil changes.
iii) This is already measured in some soil monitoring networks.

Disadvantages:

i) Nematode determination requires soil sampling followed by trophic guilds identification and is time-consuming and expensive.
ii) Even if based on the trophic habits and not on species identification, determination requires specialist expertise.

8.2.1.3.5 BI03-1 Microflora activity

This indicator is based on enzymatic reactions.

Advantages:

i) Diversity of enzyme activities is relevant to the soil threat Decline in Soil Biodiversity and the key issue 2.
ii) Microflora have many critical roles in soil functions; they support biogeochemical cycles and the growth of plants.
iii) This is already measured in some soil monitoring networks.
iv) There are some national datasets which can be used for interpretation of baselines and thresholds.
v) It can be explained relatively easily to the non-expert.

Disadvantages:

i) Microflora activity determination will require soil sampling followed by the analysis of several activities (it seems that an automation of the measurement is feasible).
ii) The measurement method is not yet standardized (except for the dehydrogenase activity).
iii) Interpretation of the results can be difficult.

8.2.1.4 Conclusion

This minimum set of TOP3 indicators (BI01, BI02 and BI03) should be measured at least at core sites within a monitoring network. Sampling must be done in the same season, preferably in spring or autumn, to allow temporal comparisons. The time between two measurements should preferably be 3 years, but not longer than 5 years as soil biota will react quickly to soil pressures (Table 8.3).

Supplementary indicators were added in Table 8.3 (BI00, BI01-1, BI02-1, BI02-2 and BI03-1) as these are already performed in some EU monitoring systems or because, depending on available resources, they will increase knowledge on the decline in soil biodiversity.

Table 8.3 Overview of proposed indicators for Decline in Soil Biodiversity

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability (S or M)	Monitoring type (gen or risk)	Frequency (years)	Spatial resolution
BI00	Species diversity	Are there changes in the diversity of soil micro organisms?	Microbial and fungal diversity	Number of genotypes kg^{-1} soil (DM)	Impact	M	G or R	3 to 5 years	EU or National based on a grid or a stratified system Point data
BI01	Species diversity	**Are there changes in the diversity of soil macrofauna?**	**Earthworms diversity and fresh biomass**	**Number m^{-2}, g fresh weight m^{-2}**	**Impact**	**M**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI01-1	Species diversity	as above	Macrofauna diversity at family and/or specie levels	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI02	**Species diversity**	**Are there changes in the diversity of soil mesofauna?**	**Collembola diversity (Enchytraeids diversity if no earthworms)**	**Number m^{-2}**	**Impact**	**M**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI02-1	Species diversity	as above	Acari diversity	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI02-2	Species diversity	as above	Nematode diversity	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI03	**Biological functions**	**Are there changes in soil functioning?**	**Microbial respiration**	**g CO_2 kg^{-1} soil (DM)**	**Impact**	**S**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI03-1	as above	as above	Microbial activity based on enzymatic reactions	g substrate metabolized kg^{-1} soil (DM)	Impact	M	G or R	3 to 5 years	As above or point data

DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response / Applicability: S = short-term, M = medium-term / Monitoring: G = generally, R = in risk areas only
TOP3 indicators in bold letters

8.2.2 Baseline and threshold values

For Decline in Soil Biodiversity a minimum set of 3 indicators has been chosen including measurements of species diversity (key issue 1) and of biological functions (key issue 2). However, if no earthworms are expected or measured due to soil conditions, e.g. pH, then Enchytraeids should be measured. Whatever the indicator, it is not possible to define single baseline or threshold values for all soils within all land uses because the diversity and activity of soil organisms are strongly dependant on climate, land use, soil type and management practices. It is possible, however, to adopt a common approach to the derivation of baseline and thresholds.

Baseline values

A baseline for temporal comparisons might simply be defined by reference to measurements made at a point in time at existing or historical monitoring sites. This approach needs to be taken with caution, as different soil conditions as well as a lack of harmonised measurements is likely to lead to misleading estimates of temporal change.

Another way to define baseline values is to use the procedure developed in the Netherlands monitoring network where reference situations have to be selected (depending on land use, soil type, climatic conditions, biogeographical region) according to expert judgement. Such reference situations are calculated as the minimum, or the maximum or the mean values for selected indicators. As an example it is possible to select a certain number of organic farms as a reference situation for all organic farms. Various endpoints, e.g. the mean value of earthworm abundance, can be calculated for the selected farms. Subsequently, any measurement made on other organic farms may then be compared with this reference/baseline.

The key to being able to discern with a given confidence whether any indicator is showing improvement, decline or no change, is to adopt a sufficient spatial and temporal sampling density. This depends on being able to define in advance acceptable detection limits for temporal change (such work is already in discussion and will be included in an ISO standard dedicated to field sampling designs for soil organisms).

Threshold values

The simplest threshold will be nil, meaning that no organisms belonging to the target group are found at specific sites (it should be noted that in some cases, depending on the soil characteristics, this is the normal situation, e.g. earthworms in very acidic soils). Another approach could be to define a threshold as an unacceptable deviation from the baseline value or from the 1^{st} (t_0) measurement. In the latter case, natural variations have to be taken into account.

Defining natural variations

Depending on various factors, setting of acceptable/unacceptable deviations may need information about the natural variations in the diversity and activity of an organism. This can be assisted by combining existing data sets that are available at the national level. Although there is a lack of data from true monitoring networks, there is substantial data from national transect or monitoring plots (e.g. UK, D, F, DK) and some at European level (e.g. from European research projects such as BIOASSESS). Further data may also be useful from the many field experiments made on the effect of various soil threats on soil biodiversity (e.g. contamination). The following data sets have been identified but others may be available from the following sources:

- The Dutch soil monitoring network which includes the diversity of microbes, nematodes, potworms, earthworms, mites, springtails and measurement of soil processes at about 160 locations within cropped land and grassland
- The EU BIOASSESS project which covers the diversity of macrofauna, of Collembola, and of carabids in 8 EU countries within a gradient of land use change at landscape level (from semi-natural forest to mixed cropping)
- German monitoring plots which include the diversity of earthworms and Enchytraeids within three main land uses (forest, grassland, crops) plus measurements of soil respiration and microbial biomass, mainly at permanent plots at crop sites

- The Hungarian soil monitoring network which covers measurement of respiration, cellulose activity and deshydrogenase activity on 1236 points (865 in arable land and grassland, 183 forest and 188 special points).
- The Danish farm survey which covers the diversity of soil invertebrates within 4 farming systems (organic farming, integrated forage / grain farming, conventional farming)
- A French land use/land practice survey which includes the diversity of soil earthworms within different land uses (e.g. vineyard, mixed farming/breeding and pasture), land practices (e.g. with and without ploughing, rotation crop), land managements (organic farming, integrated agriculture, conventional agriculture) and under different climatic conditions (from the western to the eastern part of France and also in the south of that country).
- A Portuguese study of the diversity of Collembola in several forest stands representing the dominant tree species in Portugal, and for some forest types, different management practices.

When using data from these and other sources, it should be remembered that data with different origins may not be completely comparable due to differences in sampling methods, bearing in mind that ISO sampling standards have only been published quite recently (2005; 2006). Nevertheless it seems that data sets of some organism groups from different countries may be comparable (e.g. endogeic earthworms). These datasets should be collated according to soil type, land use and climate.

Interpretation of measurements of species diversity and activity to a indicator values
Estimation of indicator values can be achieved straightforwardly from the area, or the number, of monitoring sites where the threshold is exceeded and reporting this in terms of a % of monitored land where a significant change in soil biodiversity has been observed. Clearly interpretation of indicator values requires definition of a baseline.

8.2.2.1 Conclusion

Within the timeframe of the project and due to the lack of data it was impossible to define baseline or threshold values. Nevertheless an approach was proposed but will require further work as follows:

- collecting existing national or EU data on soil biodiversity in order to identify already covered situations (e.g. soil type, climate, land uses),
- new measurements based on the proposed standardized methods on locations where no data already exits,
- data treatment to select baseline or threshold values. This will also require the definition of natural variations at the European level which means that the selection of reference sites (representing land use, soil type, climatic conditions, bio-geographical region) should be done according to expert judgement.

8.2.3 Data and user requirements

As soil diversity and biological functioning are related to soil type and associated properties (e.g. pH, SOM), climate (e.g. dryness), land use (e.g. forest, grassland, crops) and land practices (e.g. tillage, use of pesticide and of fertilizers), the following information is needed for data interpretation:

1. General habitat characterization:
   i) Detailed geographical characterization (including georeferencing of monitoring sites),
   ii) Land use (e.g. forest, grassland, crop sites, urban sites) and land practices (including vegetation),
   iii) Climate data (annual means and minimum and maximum of temperature and precipitation),
   iv) Groundwater level and, if appropriate, distance to nearest surface water.

2. Soil properties, differentiated by soil horizon:
   i) pH-Value ($CaCl_2$),
   ii) Soil organic carbon content,
   iii) Total nitrogen, C/N-ratio,
   iv) Texture (sand, silt, clay),
   v) Cation-Exchange Capacity (CEC),
   vi) Assessment of the usable field capacity of the root layer.

3. Contamination and anthropogenic stresses:
   i) Concentration of heavy metals and organics (e.g. persistent organic pollutants and pesticides),
   ii) Any other kind of anthropogenic stress like soil compaction

Based on the discussion above, it is concluded that it will be difficult to compare the biodiversity data from different countries. Nevertheless comparisons of data between different land uses within the same climate/soil region may be usefully made as well as the comparison of relative results (expressed as a % deviation from the initial measurement) between countries.

Table 8.4 Summary of data and users requirements for Decline in Soil Biodiversity

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
BI01	Earthworms diversity, abundance and biomass of species (Note: species composition of Enchytraeids and abundance of species may substitute this indicator if no earthworm is expected)	EU data needed to further define baseline and threshold values	Many more sites measuring the status of soil biodiversity in EU Member States	To be discussed and evaluated if a grid or a stratified network is needed	EU27	3 years	high	Species name Number individuals m^{-2} g fresh weight m^{-2}	15-25% relative change
BI02	Species composition of Collembola, abundance of species	EU data needed to further define baseline and threshold values	Many more sites measuring the status of soil biodiversity in EU Member States	To be discussed and evaluated if a grid or a stratified network is needed	EU27	3 years	high	Species name Number individuals m^{-2}	15-25% relative change
BI03	Soil microbial biomass Soil microbial respiration	EU data needed to further define baseline and threshold values	Many more sites measuring the status of soil biodiversity in EU Member States	To be discussed and evaluated if a grid or a stratified network is needed	EU27	3 years	high	Resp: g CO_2-C h^{-1} kg^{-1} soil (DM); Cmic: g Cmic kg^{-1} soil	Resp: 0.05; Cmic-SIR: 2.0; Cmik-CFE: 10.0

8.2.4 TOP3 indicators

Table 8.5 TOP3 indicators for Decline in Soil Biodiversity

Key issue	Key question	Candidate indicator	Unit	ID
Species diversity	What is the state of the diversity of soil macrofauna in Europe?	Earthworms diversity and fresh biomass	Number m^{-2}, g fresh weight m^{-2}	BI01
Species diversity	What is the state of the diversity of soil mesofauna in Europe?	Collembola diversity (Enchytraeids diversity if no earthworms)	Number m^{-2}, g fresh weight m^{-2}	BI02
Biological functions	What is the state of biological soil functioning in Europe?	Microbial respiration	g CO_2 kg^{-1} soil (DM)	BI03

BI01 – selected for estimating the species diversity in soils because earthworms are known to be the main soil engineers. Changes in their abundance and community structure modifies several soil properties such porosity and density, as well as functionalities, for example recycling and distribution of organic matter. Their sampling is already standardized and many soil studies include the measurement of their abundance and diversity.

BI02 – selected for estimating the species diversity in soils because Collembola are primary agents in the soil organic matter decomposition process. Changes in their abundance and community structure modify the kinetics of litter degradation. Their sampling is already standardized and many soil studies include the measurement of their abundance and diversity.

BI03 – selected for estimating the biological functioning of soils because microflora is involved in all catabolic reactions in soils. Microbial respiration is considered to be a critical process, correlated with degradable organic matter and soil microbial biomass. Microbial respiration is easy to measure and standard protocols are already available.

This minimum set of indicators represents the two selected key issues (species diversity and biological functions) and includes organisms with different:

- sizes (macro and mesofauna, microflora),
- habitats (e.g. soil micro/macroporosity, soil litter, burrows, rhizosphere)
- feeding habits,
- functions in soils (e.g. soil engineering, primary degradation of organic matter, mineralization of organic matter).

With such diversity it is anticipated that each indicator may react differently to soil pressures making this set sensitive to a range of soil changes (e.g. compaction, contamination, loss of organic matter, erosion).

Due to lack of standardization, but also to lack of interest, soil biodiversity has up to now been poorly explored whereas its contribution to soil functions is known and recognized. Thus it has not been possible to propose baseline and threshold values for the selected indicators at European scale. This will become possible if the TOP3 indicators are measured with the already standardized sampling protocols on all cores points of existing EU monitoring networks and/or if existing data on the TOP3 indicators across the EU are collected, harmonized and treated in order to propose baseline/threshold values and increase knowledge on the Decline in Soil Biodiversity.

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