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## Biodiversity and soil functioning—from black box to can of worms?

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### Abstract

A symposium during the 16th Congress of Soil Science, held in Montpellier, France, 20–26 August 1998, was entitled 'Biodiversity and Soil Functioning'. This viewpoint paper highlights some of the issues presented and discussed. © 1999 Elsevier Science B.V. All rights reserved.

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### 1. Biodiversity and soil functioning

The question in the title has to be answered with a yes—we have new methods and results, but we cannot yet answer the more important question: 'What are the effects of biodiversity on soil functioning?'. However, we are making progress and we already have some partial answers.

Biodiversity (Wilson, 1988) is commonly defined as the number of species present, and this simple definition is usually sufficient: high biodiversity = many species present and low biodiversity = few species present. There are also information-theory-based definitions of diversity that include population size of each species and take the species distribution into account, i.e. a more even distribution = higher diversity. How-

ever, in spite of its newly discovered power even to produce fundamental laws of physics (Matthews, 1999), information theory is not strongly linked to the term 'biodiversity'. Instead, this term seems to be linked to a sense-of-wonder—it seems almost mandatory that we shall be overwhelmed by the high number of species found, and without doubt do everything we can to maintain a high biodiversity.

What then are the reasons for maintaining a high biodiversity? The official answers to this question can be found in Agenda 21, a document from the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992 (Section 2, Chap. 15):

*Our planet's essential goods and services depend on the variety and variability of genes species, populations and ecosystems. Biological resources feed and clothe us and provide housing, medicines and spiritual nourishment. The natural ecosystems of forests, savannahs, pas-*

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*tures and rangelands, deserts, tundras, rivers, lakes and seas contain most of the Earth's biodiversity. Farmers' fields and gardens are also of great importance as repositories, while gene banks, botanical gardens, zoos and other germplasm repositories make a small but significant contribution. The current decline in biodiversity is largely the result of human activity and represents a serious threat to human development.*

We interpret the first sentences to mean that we as humans depend on the biology of our planet and need its biological resources. Human activity can maintain or even increase biodiversity, but usually our activities decrease biodiversity.

These statements are not particularly controversial, even for a sceptical scientist (although soil biodiversity is not explicitly mentioned). However, the final claim that [we already know that] “the current decline in biodiversity . . . represents a serious threat to human development” is not without controversy.

Governments shall also: “*Promote broader international and regional cooperation in furthering scientific and economic understanding of the importance of biodiversity and its functions in ecosystems;*”

This quotation indicates that we need to increase our understanding of “the importance of biodiversity and its functions in ecosystems,” and also implies that biodiversity per se has ‘functions’ in ecosystems as well as ‘importance’. Exactly what degree of importance (and for what) is not yet clear, but international and regional co-operation should be promoted to increase our ‘scientific and economic understanding’. Our scientific understanding of biodiversity is rapidly increasing, but we find it questionable to postulate that biodiversity has ‘importance’.

The view that a high biodiversity increases ecosystem stability and improves its functioning has a lot of order and beauty—every organism has a place (or a niche) and nothing is redundant (Linnaeus, 1760; Ehrlich and Ehrlich, 1981, see also Agenda 21 quotations above, that may point in this direction). There are also experimental results that can be interpreted as supporting this view, e.g. Naeem et al. (1994). However, careful re-evaluation may yield quite different interpretations (Huston, 1997).

Instead, there is a growing mass of evidence indicating that most organisms are redundant from a functional viewpoint (Lawton and Brown, 1993; Andrén et al., 1995), that there are a limited number of functions that have to be performed within an ecosystem, and that the total number of species participating as well as the exact species composition does not affect the process rates much (Grime, 1997; Andrén et al., 1999).

Since we have used the term in the title, we will also try to define ‘soil functioning’. First, this term is closely related to ‘soil quality’ (the capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health; Doran and Parkin, 1994) as well as ‘soil health’ and ‘soil fertility’. A well-functioning soil has a reasonably high quality and maintains its fertility (usually meaning its ability to sustain and promote plant growth). Thus, the definition by Doran and Parkin (1994) also works well for ‘soil functioning’.

## **2. Form black box to can of worms—and beyond**

### *2.1. New methods increase the resolution*

Biodiversity in the soil, particularly bacterial biodiversity, is much higher than previously imagined. Recent advances in techniques, many of nucleic acid-based, have given us the tools for inspecting the black box of soil biodiversity. For example, even in 200-year-old volcanic soils, bacterial species richness was very high (Tiedje et al., 1999). This species richness probably is due to the spatial heterogeneity of the soil. At least for bacteria, the high diversity can be found even at very small scales; the genus *Nitrobacter* was found to have at least as many serotypes in a 50, as in a 250  $\mu\text{m}$ -side cube (Grundmann and Gourbière, 1999). Soil heterogeneity is not only due to soil texture, layering, etc. but also to current influence of biological activity. Marilley and Aragno (1999) found, using 16S rDNA sequencing, that bacterial communities were quite different close to roots and in the bulk soil, respectively. Presence of plant roots decreased bacterial biodiversity, and *Pseudomonas* became dominant.

## 2.2. The environment, but also organisms, control biodiversity

The environment also controls biodiversity at a much larger scale. In extreme environments, such as hot deserts or the dry, cold valleys of Antarctica, only few species can survive. The simple nematode communities in these environments can be used to generate insights that can be applied to more complex and common communities and ecosystems (Wall and Virginia, 1999).

Even if we are not convinced of the overall ‘importance’ of biodiversity per se, it is unquestionable (?) that our planet as we see it has been, and is being, modified by organisms to a great extent. Metabiosis, when one organism modifies the environment before another organism can live in it, is apparent at many scales, both in space and time (Waid, 1999). For example, decomposers in the soil reduce O<sub>2</sub>-concentrations so anaerobes can thrive, and the activity of cyanobacteria began transforming the biosphere through O<sub>2</sub> production a very long time ago—preparing the stage for oxygen breathers, including *Homo sapiens*.

## 2.3. The experimental approach

Since most ecosystem and their soils harbour a high biodiversity, simple laboratory experiments with few species or even extremely simple natural ecosystem will not give all the answers. Manipulating complex systems may give answers to questions about the relations between biodiversity and function. Agriculture is a widespread manipulation of ecosystems, and it can be put to good use for biodiversity research. For example, Coutinho et al. (1999) using RAPD DNA fingerprinting, found that the diversity of rhizobia was significantly reduced by cultivating soyabean compared with original pasture plots. Biodiversity did not differ between tilled and untilled soyabean plots. However, the actual rhizobial strain composition differed between till and no-till.

A more specific manipulation, repelling microarthropods from chestnut oak litter using naphthalene, was performed in two tropical and one temperate forests (Heneghan et al., 1999). Reduction of the microarthropod community had no drastic effects on litter C and N mineralisation at any site, but at

one tropical site a slightly lower N concentration was recorded in naphthalene-treated litter.

## 2.4. Sorting out the can of worms

In conclusion, recent advances in methodology have revealed a high diversity even at very small scales. The organisms modify the environment, and organismal activity matters. However, the overwhelming diversity of organisms found makes a Linnean interpretation (every species counts and is necessary for the ecosystem) more and more illogical.

It may seem as though we have opened a can of worms, but there is no need to despair. Instead, we are rapidly learning more: the explosion of known species due to the new molecular techniques will continue; the factors that control biodiversity levels will progressively be revealed, and understanding the connection between essential ecosystem functions and biodiversity is within our reach. This understanding is necessary if we not only want to preserve biodiversity, but also to maintain a sustainable use of soils and, more generally, manage our environment the way it deserves.

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