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The relevance of the Rio-Convention on biodiversity to conserving the biodiversity of soils

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Abstract

Nowhere in nature are species so densely packed as in soil communities. A large number of animal phyla and a diverse microflora are represented and these comprise a considerable part of any country's biodiversity. There are three main reasons for protecting soil biodiversity, (i) Ecological reasons: Decomposition and soil formation are key processes in nature and represent 'ecological services' for the rest of the ecosystem. Soil organisms also represent the base for several above-ground food chains and the majority of terrestrial insects are soil dwellers for at least some stage in their life cycle, (ii) Utilitarian reasons: Soil biodiversity form the basis of agriculture, some medicines, and research in ecology and other disciplines and (iii) Ethical reasons: All life forms can be said to have an inherent value. Many groups of soil organisms are very old in evolutionary terms. Soil biodiversity must be included in the national strategies for long-term preservation of biodiversity to be developed following the Rio-Convention on Biodiversity. This implies both pure conservation measures and sustainable use of soils. Conservation measures must include identification and protection of sites with unique, endemic or threatened soil communities. Other targets could be rare soil types or intact soil profiles. Soil biodiversity is generally high in forests which may represent 'hot spots' in agricultural landscapes. Measures for sustainable use must aim at keeping the biodiversity of agricultural and forest soils as high as possible. Chemicals and other treatments, which reduce soil biodiversity, should preferably be avoided. Conservation of soil biodiversity is a new and challenging field, for soil biologists, conservation biology, and local, national and international authorities. There is a great need for strengthening both basic and applied soil biology, including taxonomy and soil biologists should start the process by publicising the role, great complexity and threats to soil communities. © 1998 Elsevier Science B.V.

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1. Introduction

The Rio-Convention on biodiversity focused on 'the forgotten environmental problem' – the global loss of biodiversity which, if allowed to proceed unchecked, could well lead to the elimination of between one quarter and one half of all the Earth's species (Myers, 1993). The term biodiversity (Wilson, 1988, 1992) has proven to be very useful in discussing strategies to stop this wave of extinction. The Rio-Convention defines three levels of biodiversity: The multitude of nature types or ecosystems, the number of species, and the genetic variation within each species.

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The convention, which came into effect in January 1994, urges each signatory country to develop a national strategy for long-term preservation of biodiversity. This includes both purely conservation measures and a sustainable use of biodiversity. By June 1996, more than 130 countries had ratified the convention which indicates that a great part of the world has accepted the challenge to do what they can to avoid Myers (1993) extinction estimate becoming a reality.

Traditionally, the global focus of biodiversity has been the tropical forest canopy. Erwin (1983) concluded that most tropical arthropod species live in the canopy and extrapolated that there might be as many as 30 million tropical arthropod species in this first biotic frontier. Later, Grassle (1989), Grassle and Maciolek (1992) discovered a huge unknown diversity of deep-sea benthic invertebrates and indicated that deep sea areas may contain tens of millions of animal species representing a second biotic frontier. Still more recently, soil zoologists and soil microbiologists have made discoveries and estimates indicating that soils also contain much more species than anticipated. There are, therefore, good reasons to acknowledge soils as the third biotic frontier (c.f. André et al., 1994; Lawton et al., 1996).

The aim of this paper is to challenge soil biologists, governments and environmental bodies to include the soil biota in the national strategies for conservation and sustainable use of biodiversity. As stressed by Giller (1996), virtually no attention appears to have been paid to conservation activities for soil communities, even though, as early as 1979, Usher et al. (1979) described soil communities as 'the poor man's tropical rainforest'.

However, soil biodiversity has come sharply into focus during the last few years with discussions of topics such as how many species there are, how it is possible to pack species so densely, why so many animal phyla can be found in soil, how organisms interact, and what soil communities contribute to the running of the whole ecosystem. Recent overviews have been published by Collins et al. (1995) and a special number of Biodiversity and Conservation (vol. 5, No. 2, February 1996). Knowledge is increasing rapidly and the time has come to ask how this knowledge can be used in advising practical conservation work.

2. Soil: A biotic frontier

Soil contains all major groups of micro-organisms and fungi, green and blue–green algae and a great number of animal phyla (Lee, 1994). One square metre of forest soil may contain over 200 arthropod species (Usher and Parr, 1977) and up to 1000 species of soil animals altogether (Anderson, 1975). According to Behan-Pelletier and Bisset (1992), mature forest soils appear to have a phylogenetic diversity greater than any habitat, with the possible exception of coral reefs. This is perhaps not so surprising since evolution has 'worked' for several hundred million years in soil communities.

Recent studies have indicated that we have only peered into the keyhole concerning soil biodiversity and the estimates of species numbers in soil are expanding constantly. Using a new flotation method to extract microarthropods from coastal sand dunes, André et al. (1994) were astonished to find a dominance of undescribed species smaller than 0.2 mm, mainly Actinedida mites. They suggested that large numbers of microarthropod species and other small animal groups have been overlooked even in forest soils, and hypothesised that perhaps ten million small, edaphic soil animal species remained to be discovered. The authors considered that 'the canopy may be viewed as the upper biotic frontier of the terrestrial biota while the soil, especially the deepest horizons and the rhizosphere, forms the lower frontier. In the light of our results, it seems that the latter constitutes a huge reservoir for biodiversity, probably much more important than the former'.

In a Cameroon near-primary forest, Lawton et al. (1996) found 204 nematode species in five soil samples with a total area of 14.2 cm^2. They anticipated finding more than 1000 species, virtually all of them new to science. In this forest, 115 species of termites were also recorded, including 33 new species and three new genera. Wilson (1992) recorded 275 species of ants on 8 ha of Peruvian rain forest. Evidently, when specialists take time to study single plots intensively, great numbers of new soil animal species are almost inevitably revealed.

The situation is still more dramatic with soil microflora. While the taxonomy of fungi and bacteria has been based to a large extent on culturing, Torsvik et al. (1990a) have estimated that the proportion of unculturable microorganisms in the soil is 90–99% and as many as 4000 different microbial genomes have been found per gram of soil (Torsvik et al., 1990b) The species concept is difficult among fungi and bacteria, and microbial biodiversity is comprised of three interrelated elements: genetic, functional and taxonomic (Solbrig, 1991; Pankhurst et al., 1996; Zak and Visser, 1996). Much remains to be done before each of these elements can be quantified and little is understood about the linkages between these different ways of characterising microbial diversity.

In terms of soil animals, several authors have tried to explain why there are so many coexisting species (e.g., Anderson, 1975, 1978; Siepel, 1994; Lee, 1994; Giller, 1996). The ongoing discussion indicates that our current niche concept may not be useful in soil, and that ecological theory might provide new inputs and perspectives through studies of soil communities. We are still not ready to answer the questions posed by Usher (1985) as to what extent the general theories of ecology are applicable to the soil ecosystem, and what the study of soil communities might contribute more widely to ecology?

3. Conservation of soil biodiversity cannot wait

While waiting for increased understanding of the function of soil communities, for new estimates of soil biodiversity, and for huge numbers of species to be described, we can do one thing – we can start to try to preserve this amazing diversity for the future. Explanations and descriptions of species can to a certain degree wait, but an extinct species is lost forever. Starting conservation measures is perhaps the most important and challenging task for soil biologists in our time, and both knowledge and courage is needed. However, if successful, a global focus on soil biodiversity conservation might stimulate the whole field of soil biology.

The intentions of the Rio-Convention will not be fulfilled until soil biodiversity is included into practical conservation work. Even with limited knowledge, we can point to some general starting points and combined with skilled ecological guessing, a strategy can be built up. First, however, we shall briefly discuss why soil biodiversity should be preserved.

4. Why preserve soil biodiversity?

The general arguments for preserving biodiversity can be grouped into three main categories: Ecological, utilitarian and ethical (Hågvar, 1994). This framework can also be used for soil biodiversity.

4.1. Ecological arguments

The important ecosystem processes of energy flow, nutrient cycling, water infiltration and storage in soil are mediated by the soil biota, i.e., soil biota contribute to the maintenance of ecosystem integrity (Whitford, 1996). The key role of decomposition represents an ‘ecological service’ for the whole ecosystem, as 60–90% of terrestrial primary production is decomposed in the soil (Giller, 1996). If soils suddenly became sterile, all terrestrial ecosystems would collapse rapidly. Furthermore, soil represents a necessary substrate for a large part of the globe’s biodiversity. Even the majority of terrestrial insects are soil dwellers for at least some stage in their life cycle (Ghilarov, 1977; Behan-Pelletier, 1993). In this way, soil contributes indirectly to pollination for example, and directly or indirectly, the biodiversity of soils feeds a number of above-ground food chains. Also within the soil itself, many species and groups have clear functions as important links in food chains. Symbiotic microorganisms make digestion possible in earthworms and termites, and mutualism is generally important for soil biodiversity (Lavelle et al., 1995). Mycorrhizal fungi on tree roots make forest ecosystems possible at high latitudes, and more than 1000 ectomycorrhizal species may occur in northern coniferous forests (Allen et al., 1995).

During the past few years there has been a focus on the possibility that many species may be ‘redundant’ and can be lost without any consequences to the system (e.g., Walker, 1992). From such a point of view, there is perhaps no great danger in losing a lot of species, as long as the ‘keystone species’ are maintained. In my opinion, this a dangerous attitude in nature conservation, for several reasons: (i) we know too little about the role of single species; (ii) the precaution principle in the Rio-Convention stresses that all doubt shall be in the favour of biodiversity; (iii) during temporary or permanent ecosystem stress, certain species may become important to retain ecosystem processes; (iv) in the long-term species which seem redundant or which are very rare today may achieve important ecological functions or represent valuable genetic material for future evolution. Fortunately, some authors in the redundancy discussion have pointed to these arguments, especially point three (e.g., Andrén et al., 1995; Bamforth, 1995; Lawton et al., 1996). Beare et al. (1995) stress that both the 'redundancy' and the 'keystone species' viewpoint tend to ignore the importance of biodiversity in maintaining the numerous and complex interactions among organisms in soils and their contributions to biogeochemical cycling.

4.2. Utilitarian arguments

The ecological arguments can to a certain degree be considered as utilitarian, since mankind requires the general function of nature. In agriculture, we rely upon many of the processes mentioned above. Marshall et al. (1982) described soil as our most precious non-renewable resource. Certain species may even serve as bioindicators for classification of soils and detection of disturbances and pollution (Giller, 1996). Besides feeding the human population, soils contain organisms which are useful in pharmaceutical production: penicillin and cyclosporin are two well-known fungal products. The search for medicines from soil organisms is only beginning. Soil organisms also detoxify many of the waste products of human society, allowing use of the soil as a recipient as long as we do not simplify or stress the community too much.

In many fields of research and eduction, the great biodiversity of soils offers possibilities. Our ecological insight is still very fragmentary, since we know so little about soil ecology. For instance, there appears to be virtually no information on the effects of predators on soil biodiversity (Giller, 1996). And how can so many species with apparently overlapping niches occur together? Our basic wish to understand nature cannot be fulfilled until the soil biota are understood. This system of densely pack diversity may contain the answers of some basic questions about evolution and life itself, which man is eager to solve.

Also, soil biodiversity fascinates man through the beauty of many organisms. Many persons have become soil biologists because they were attracted by the beauty and uniqueness of certain species or groups, including many highly specialised ways of life.

4.3. Ethical arguments

The ethical element is an important aspect in conservation biology, focusing on the intrinsic value of life, and the respect for other life forms, or even ecosystems (e.g., Naess, 1986; Johnson, 1991; Hågvar, 1994). The ethical value is independent on whether or not the biodiversity or system has a direct advantage to man. The concept that an ecosystem has a right to exist independently, rather in terms of human perception or for anthropomorphic reasons, avoids the requirement to comprehensively document faunas and distributions before they can be afforded protection (Greenslade and New, 1991).

5. Threats to soil biodiversity, conservation possibilities, and some cases

It is unlikely that soil organisms will be unaffected by the global extinction wave which Myers (1993) and other have foreseen. In a literature review, Giller (1996) concluded that man's activities more often than not lead to a reduced biodiversity of soil communities. Examples are removal of forests, and various land management practices including burning, tillage, manure or pesticide application, and pollution. There is a clear need for more sustainable agricultural practices, which includes the preservation of soil biodiversity. Another important focus is to preserve forest habitats in general, and especially sites which are little influenced by man. Forest soils tend to be very species-rich and represent stable and often very old environments. Siepel (1996) found a decline in microarthropod diversity in a sequence from old forest stands to low-input grasslands, and high-input grasslands. Today, abandoned fields in central and northern Europe are slowly changing into forests. In order to preserve a high diversity of soil invertebrates, Scheu and Schulz (1996) recommend preserving all successional stages to mature forest in a wide range of habitats. They found maximum diversity of oribatid mites in beechwood forest.

Loss of original forest may also be due to plantations. Deharveng (1996) found that the change of seminatural beech forest to conifer plantation in the Pyrenees resulted in a loss of Collembola species. An endemic component suffered a particularly severe loss of species richness and abundance. The author stressed a general need for a systematic inventory and protection of forests with endemic soil biota.

Greenslade (1994) presented a 'heritage list' of invertebrate sites in southeastern Australia. This pioneer work pointed to several important sites for endemic faunal elements, including the Giant Gippsland Earthworm, *Megascolides australis*. Greenslade and Rusek (1996), and Rodgers and Greenslade (1996) showed the necessity to protect certain localities to preserve the highly endemic Collembola fauna of Australia and Tasmania. Many species are now restricted to small fragments of what were originally much larger areas of native vegetation. Other species which have specific habitat requirements have had their populations drastically reduced. Some examples are species restricted to well rotted logs which are no longer abundant because of forestry management practices. In the southern USA, Hendrix (1996) has argued for the preservation of whole forest ecosystems, especially sites with a lot of dead wood on the forest floor, in order to preserve the nearctic earthworm fauna.

Unique environments tend to have a specialised soil fauna. These may be for instance very dry and adverse sites, as shown from rangelands in Australia (Greenslade, 1995). Sea shore habitats tend to have a unique and highly specialised microarthropod fauna (Fjellberg, pers. comm.; André et al., 1994). This may be due to the long history and continuity of shore habitats, together with a requirement to adapt both to a steep gradient, to harsh environments, and special habitats as sand dunes or the tidal zone (Fjellberg, pers. comm.). Knowing that coastal habitats are strongly disturbed all over the world, such habitats could be the aim of systematic soil community studies and conservation measures.

Transport of species also represents a threat to soil biodiversity. The earthworm-feeding flatworm *Artioposthia triangulata* was introduced to Ireland from New Zealand in the early 1960s, probably in the root balls of horticultural plants. Now it is distributed in Northern Ireland, Scotland, the Faroe Islands and Iceland. The flatworm has shown itself capable of eliminating earthworm populations from pastures and gardens, resulting in changes in soil structure and a reduced rate of removal of plant material from the soil surface (Royal Commission on Environmental Pollution, 1996).

6. Recommendations

In light of the Rio-Convention, the preservation of the biodiversity of soils represents a great challenge. The situation calls for a co-operation between a number of participants, from taxonomists to international bodies. The following recommendations are given.

6.1. International bodies

A specialist group for soil biodiversity could be established within the Species Survival Commission of IUCN. Soil biodiversity also represents a challenge for the scientific committee of the Rio-Convention, which gives advise to the signatory countries. The International Society of Soil Science could, for example, focus on conservation of soils and soil communities by arranging special workshops.

6.2. National strategies

Each signatory country of the Rio-Convention should include soil communities in their national strategies to preserve biodiversity.

6.3. Legislation

The need for international and national legislation to prevent harmful introduction of soil organisms should be considered, including quarantine controls. Besides unintended transport of organisms, controls may be important in connection with intended import of biological control agents or genetically modified organisms.

6.4. Agriculture and forestry

A more sustainable practice in agriculture and forestry must include the best possible preservation of soil biodiversity.

6.5. Landscape planning

Land planners should be aware of preserving a variety of soil and vegetation types, including little-influenced systems. In agricultural landscapes, the conservation of forest patches (the older the better) would be very valuable for soil biodiversity. Local authorities responsible for long-term area planning probably represent key bodies for preservation of soil biodiversity.

6.6. Research

Systematic research should be performed to map site of unique, endemic or threatened soil communities. This demands increased economical resources, increased motivation among soil biologists, and increased number of taxonomists.

6.7. Information and attitudes

The inclusion of soil biodiversity in ordinary conservation work will demand both information and change in attitudes. Soil biologists have a responsibility to publicise the role, great complexity, and threats to soil communities. In practical conservation work, soil biodiversity will often be combined with other conservation motives. However, one should be able to establish nature reserves on the basis of soil biodiversity alone.

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