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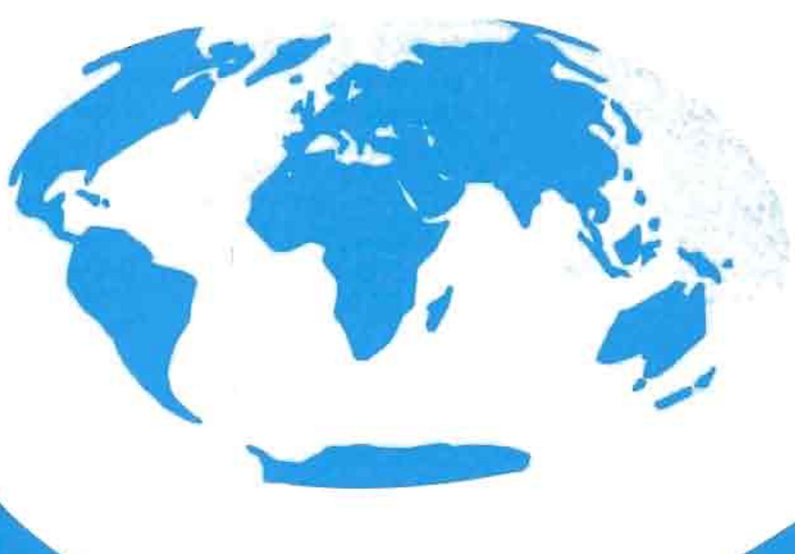

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Editorial

The Convention on Biological Diversity, DIVERSITAS, and a New Focus on Soil Biodiversity

Four years after its adoption, the Convention on Biological Diversity is proving slow to implement. Among the many constraints that limit its implementation, I wish to underline two which are apparently conflicting but actually complementary issues.

First, most nations and countries perceive biodiversity as a national resource rather than a global one. It is true that, unlike environmental pollution or global warming which do not recognize political borders, biodiversity has a geographical home-base, and the "goods" and "services" it may provide are subject to private, local, or national ownership. In other terms, biodiversity looks like a negotiable and marketable commodity.

Second, the lack of knowledge pertaining to our biological diversity. We still scarcely understand the origins, maintenance and loss of biodiversity in a quantative sense. Serious doubts and uncertainties remain concerning its role in ecological processes and response to change. There are no valid and widely accepted scientific criteria, tools and/or indicators to value and evaluate the goods and services biodiversity can provide. Without the scientific and technological base needed, policies on biodiversity conservation and management cannot be implemented. Biodiversity related science and technology represent the key for breaking the vicious circle of confrontation between the 'owners' and the 'knowers' of biodiversity.

Recognizing the vital need to bridge the knowledge gap on biodiversity, the Convention clearly stated that scientific work and training represent essential tasks for its implementation, and the responsibility for coordinating such tasks given to the Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA) which reports to the Conference of the Parties (COP). In this regard, DIVERSITAS, an international programme of collaborative research on the science of biodiversity launched in 1991 by IUBS, SCOPE and UNESCO, has a great potential to help bridge the gap of knowledge, to collaborate with the Secretariat and all Parties to the Convention on Biological Diversity and SBSTTA. Its outputs will assist nations in meeting their obligations under the Convention. This potential can be realized only through the establishment of a large partnership, as advocated by the Forum co-sponsored by IUBS/UNESCO/ICSU/France on *Biodiversity, Science and Development,* held in Paris, in September 1994 (proceedings published by CAB International, UK, 1996, 646pp.).

In harmony with the Forum's spirit, DIVERSITAS, in its second phase, expanded its partnership, and now includes the International Union of Microbiological Societies (IUMS), the International Council of Scientific Unions (ICSU), and the International Geosphere-Biosphere Programme's Global Change and Terrestrial Ecosystems (IGBP/GCTE). Also, the programme themes were refined and consist of five key elements: ecosystem functioning; origins, maintenance and change; systematics: inventorying and classification; monitoring; and conservation and restoration. These elements are supplemented by special target areas of research (STAR) that have been somewhat neglected in relation to their importance: the human dimension; marine biodiversity; soils and sediment biodiversity; and microbial biodiversity, - with a newly developing area in freshwater biodiversity.

Another important component concerns the development of national and regional networks in support of DIVERSITAS. Biodiversity activities are carried out in different countries and regions if real progress is to be made, and the establishment of DIVERSITAS national programmes and regional networks should receive the highest priority, in concert with National Biodiversity Action Plans and Strategies. This is of particular value as the DIVERSITAS Programme brings together the voluntary contributions of scientists working at national institutions, under national regulations, and supported by national sources. Such networks have so far been initiated in the West Pacific and Asia region through the International Network for DIVERSITAS Western Pacific and Asia Network (DIWPA), and the Latin-American region, through the *Programa Iberoamericano de Ciencia y Tecnologia para el Desarrollo* (CYTED-*Biodiversidad*) networks.

In the present issue of *Biology International,* five reports are published with the aim of introducing one of the STAR of the new phase of DIVERSITAS, that on soils and sediments. This topic has not received the focus it merits, especially in relation to natural ecosystems. Soils and sediments represent the most invisible and least accessible part of the ecosystems, which explains the scant attraction accorded to soil biodiversity studies. The general public's perception of *...ashes to ashes....dust to dust,* and links to death, dirt and chaos, also needs to be addressed.

The '*Diversity of Soil Fauna and Ecosystem Function*', by P. Lavelle, deals with soil biodiversity models, major functional groups, biological regulatory systems and research hypotheses. '*Soil Biodiversity and the Fertility of Tropical Soils*' by M.J. Swift, explores the research hypotheses related to the impact of agricultural intensification and diversification on soils biodiversity and resilience, and therefore the importance of tropical soils biodiversity for sustainable development. In '*Transect Approach to the Assessment of Soil Macrofauna Diversity*', B. Striganova underlines the potential of transect studies for understanding the evolution of soil animal population diversity. P.F. Cannon provides an overall perspective on the IUBS/UNESCO soils and sediments initiative and the progress made in support of DIVERSITAS. And finally, D. Freckman outlines the major goals and objectives of the SCOPE component of the DIVERSITAS STAR on *Soil and Sediment Biodiversity.*

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Diversity of Soil Fauna and Ecosystem Function

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Introduction

Soils are natural resources of utmost importance for a number of ecosystem and biosphere processes such as plant production, cycling of organic matter and nutrients, storage of C and water, and release of nitrous oxides, CO^2 and methane. Soil degradation, through various processes, is a matter of great concern, since their integrity is absolutely critical to increasing food production (FAO, 1995), and regulating atmospheric fluxes of greenhouse gases (Jenkinson, 1991; Wallace, 1994).

In this context, the present concern for the loss of biodiversity in soils is more closely linked to the possible role of species in the protection of the productive potential rather than to ethical, aesthetic, or economic considerations (Solbrig, 1991; Freckman, 1994).

Except for a few spectacular species like the 3m-long giant "gippsland" earthworm *Megascolides australis* of Southern Australia, soil fauna species do not appear on lists of endangered species that require protection. The limited knowledge (among the local farmers) of this fauna is mainly due to (Ortiz *et al.*, 1994) the small size and the difficulty in extracting and observing most species. (André *et al.*, 1994) easily explain this situation. For several decades, research mainly concentrated on a few pests, looking at efficient chemical treatments that would eliminate them. More recently however, there has been considerable development in research on the role of the whole invertebrate community in soil function. These studies consider soil fauna as a resource with potential for soil biodiversity management (Lavelle and Barois, 1988; Swift and Woomer, 1994). Attempts are being made to either biological control some of the more serious pests, or use their communities as indicators of the quality of the soil system, as most are highly sensitive to perturbations and disturbances (Bongers, 1990 for nematodes; Lavelle, 1988 and Decaens *et al*, 1995 for macroinvertebrates).

In a single square meter of soil of a European beech forest, as many as 1000 species of invertebrates may be collected (Schaefer and Schauermann, 1990). Richness differs greatly between taxa. Microarthropod communities may comprise hundreds of species with a diversity of up to 400 to 500 species of Acari and 60 to 80 species of Collembola . Under comparable conditions, nematodes may comprise up to 90 species, Protozoa, 60; Enchytraeidae, 22 ; earthworms, 15-17 ; Diplopoda, 15. In African savannas, termite communities may comprise up to 60 species. Villalobos and Lavelle (1990) collected 113 species of soil Coleoptera. Similar richness occurs in a large range of ecosystems, and a large proportion of these species have not yet been described. It is assumed for example, that the 3000 earthworm species already described only represent half of the total number of existing species. In smaller groups with high specific richness, the situation is much more critical (Hawksworth and Mound, 1991). André *et al.* (1994) explain that the selectivity of extraction methods and sampling sites, and the lack of interest for some groups of small species, has probably led to an underestimation of microarthropod species richness of 1-2 orders of magnitude. In general, much less species have been identified in tropical than in temperate areas.

During the last 10 years, great efforts have been made to understand the role of invertebrates in soil processes, and their interactions with the abiotic factors of soil function (Lavelle *et al.*, 1993, 1994; Beare *et al.*, 1995; Wardle and Lavelle, in press). Dramatic effects have been observed in the regulation of microbial activity, soil aggregation and hydraulic properties, dynamics of decomposition and soil organic matter, plant growth and pedogenesis. Although effects have often been quantified in experiments performed at the organisms scale, and less often at those which are relevant to agronomic or pedologic issues, there is clear evidence that these processes may actually operate at the ecosystem level. In addition, it was found that the functional importance of invertebrate activities is often disproportionate to their actual abundance (Anderson, 1988).

Soil invertebrate communities are deeply affected by human activities; in most agroecosystems, they tend to disappear. Little if any mention is made of possible links between the elimination of such important regulators of soil processes and the lack of sustainability of most agricultural systems (Lavelle *et al.*, 1994). On the other hand, cases exist where the replacement of a diverse native fauna by a few opportunist exotic species adapted to highly disturbed areas result in the disappearance of key functional groups. Severe degradation of the soil (by endogeic earthworms, Rose and Wood, 1980) or damages to plant crops (by termites, rhizophagous Coleoptera larvae, or parasitic nematodes) may also occur. For example, there is evidence that at least part of the degradation process that affects pastures in Central Amazonia is due to a pullulation of the earthworm species *Pontoscolex corethrurus*, at the expense of the loss of all earthworm species and the majority of arthropods from the native forest. P. corethrurus produces high amounts of compact casts at the soil surface and severe soil compaction and subsequent depressed water infiltration rapidly occur, as those species that would have normally decompacted the soil have been largely eliminated (Chauvel, Grimaldi, Desjardins, Matos, Blanchart, De Oliveira Barros and Lavelle, unpublished data).

It is therefore urgent to describe the diversity of soil invertebrate communities and evaluate their functions in order to identify management options that eventually optimise their activities. Diversity should be addressed at the population level (genetic diversity in key species), community (specific richness) and ecosystem (functional groups) levels. The need to incorporate management of soil faunal communities as part of farming systems, land remediation and other types of landuse clearly set priority on the ecosystem level. According to Elliott and Lynch (1994), a goal for soil biodiversity management should not only mean maximizing the number of species in an ecosystem. More likely it means the ability to retain the current macro-(fauna) and microflora and to emphasize certain species and processes to accomplish specific objectives. Obviously, the broad main objective is to manage biodiversity for maximum soil resilience.

This paper attempts to synthesise the existing knowledge on the perception and function of biodiversity of invertebrates in soils. New research areas and hypotheses are proposed to improve our understanding and promote the idea that fauna is a resource that needs careful management, in the same right as currently accepted physical, chemical and microbiological components of soil fertility. Part of the ideas and hypotheses presented below have been discussed at a recent TSBF/UNEP workshop held at Hyderabad (India)(Giller *et al.*, in press and Swift, in press).

First described are the functions of invertebrates in soils, followed by the current perception of soil biodiversity, and some hypotheses on the role of this diversity. Challenges that lay behind these scientific questions are also presented.

Invertebrates and the Soil System

Soil function is the result of complex interactions among physical, chemical and biological factors. A general hierarchical model has been proposed to describe the potential importance of these factors as determinants of soil processes. Inside this model, soil organisms are separated into four broad functional groups, again presented in a hierarchical order, depending on their function and on the nature of the interaction they develop with other organisms.

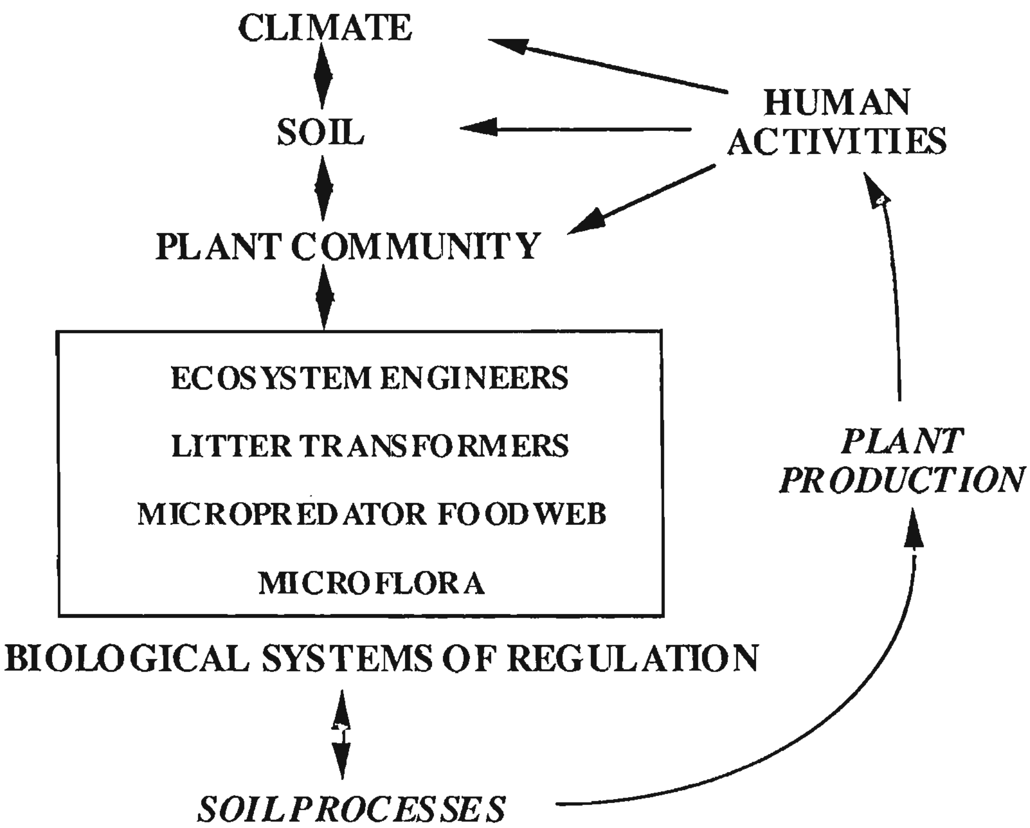
1. The hierarchical model

A hierarchical model has been proposed in which soil processes are determined by a suite of factors whose potential effect is determined by the scales of time and space at which they operate (Lavelle *et al.*, 1993). This hierarchy is a "control hierarchy" as defined by Solbrig (1991), in which factors that operate at large scales of time and space may constrain factors that operate at smaller scales. It is not, however, a rigid hierarchy since factors may affect a wide range of processes that are operating at different scales (Solbrig, 1991). The intensity of the constraint may be low, whereby factors operating at lower levels of the hierarchy then become predominant.

At the lowest level of determination, this suite of factors includes 'Biological Regulatory Systems' which comprise all soil organisms, divided into micro- and macroorganisms. According to this model, any soil process is likely to be firstly influenced by climate, then by edaphic factors (mainly clay abundance and nutrient status), followed by the quality of material produced by the plant community and brought as energy and nutrient sources, and finally biological systems of regulation, i.e., a broad mutualist association of macroorganisms (roots and invertebrates) with microorganisms (Fig.1). Evidently, human activities deeply influence the system and can be potentially one of the strongest determinants. This is, however, a potential hierarchy in which all levels interact, and in some situations when higher level factors are not particularly constraining, such as the quality of organic inputs, or the presence and activity of key invertebrate groups may be major determinants of processes. For example, this is the case for the role of termites and earthworms in tropical cropping systems, where neither the climate (in its macro- and microscales) nor soil (with little active clay minerals) or litter quality (almost homogeneous throughout the system) may significantly regulate such processes as decomposition of litter or soil physical structure.

A natural corollary to the rules which is also implicit in this model is that, depending on the intensity and relative importance of constraints operating at the upper levels of the hierarchy, the role of soil invertebrates as measured by their effect on rates of a specific ecosystem process may, or may not, be significant. In the former case, discussing their function is a relevant issue; in the latter, invertebrates may simply be used as indicators of ecosystem function since their impact is not significant to soil functioning.

Figure 1: An hierarchical model of soil function (after Lavelle *et al.*, 1993)



2. Major Functional Groups in Soils

All invertebrates in soils (and also roots) have developed interactions with microorganisms. The kind of relationship (predation or mutualism) and the nature of the microsites where developed (i.e., gut content or external structures like faecal pellets) allow the outline for a broad functional classification of soil organisms.

Microorganisms : The Sleeping Beauty Paradox

Unlike most invertebrates, microorganisms as a whole have the capacity to digest any substrate in the soil. However, their relative inability to move (which is more critical in bacteria than fungi) and the discontinuous distribution of organic resources at the scale at which they operate, cause them to be *inactive for most of the time*, i.e., in resting stages that can last from months to years. Microbial communities appear as a *huge largely dormant population, with an enormous richness of species and an ability to survive hard times* (Jenkinson and Ladd, 1981). Turnover times of microbial biomass are in the range of 6-18 months in nature, that is 1,000 to 10,000 times more than in optimal laboratory conditions. Activation of resting microbiota and redistribution of microorganisms and organic substrates is performed by invertebrates and roots that mix the soil, add water and readily assimilable substrates to the soil. This function of invertebrates and roots in the activation of dormant microflora has been referred to as the "Sleeping Beauty Paradox" (Lavelle *et al.*, 1995). The nature of the association between micro- and macroorganisms, however, varies greatly and mainly depends on the size of the invertebrates involved. The presence and nature of structures produced by the invertebrates that serve as incubators for microbial activities provide the division of invertebrates into three major functional groups: micropredators, litter transformers and ecosystem engineers.

Micropredators

The smallest invertebrates, Protozoa and Nematodes of the microfauna (average size <0.2mm) do not build any structure. Predation is the only means they have to take advantage of microbial activity. They participate in microfood webs that may include several levels, with microbial grazers and one or two levels of predators (Hendrix *et al.*, 1986; Hunt *et al.*, 1987); Moore and De Ruiter, 1991. The impact of such systems is an overall stimulation of mineralisation of organic matter (Darbyshire, 1972; Ingham *et al.*, 1985). In microcosm studies, there is evidence that increased complexity of this foodweb accelerates mineralisation (Setälä *et al.*, 1991; Couteaux *et al.*, 1991).

Litter Transformers

At the next level, litter transformers include the small Oligochaeta Enchytraeidae and arthropods of the mesofauna (<2mm) and macrofauna (>2mm). These invertebrates build holorganic structures (their faecal pellets) that serve as incubators for microbial activities; some time after deposition, they reingest these pellets to assimilate metabolites that have been released by the microflora. Cases of reingestion of pellets of a given individual or population by other individuals or populations are most likely frequent (Vannier, 1985; Lussenhop, 1992). In these pellets, mineralisation may be enhanced in short periods, but in the longer term, a relatively compact structure that limits aeration and water storage as well as the accumulation of resistant humidified molecules may result in a significant decrease of mineralisation, lasting as long as the structure's integrity is maintained (Hanlon and Anderson, 1980; Toutain *et al.*, 1982). In types of humus where H horizons are made of accumulated pellets of Enchytraeidae and Microarthropods, these structures may last for several decades and significantly affect the soil's function through the organisation of humus types (Jabiol *et al.*, 1992). At an even larger scale of time and space, leaching of organic acids released in these structures is known to alter clay minerals and thus participate in the formation of highly weathered soils (Berthelin *et al.*, 1979).

Ecosystem Engineers

A few large invertebrates (mainly earthworms) and social insects (ants and termites) are able to efficiently dig the soil and produce organo-mineral structures (casts and organo-mineral pellets that are resistant macroaggregates, mounds and nests) and a large variety of pores (galleries, chambers and voids resulting from an uncomplete backfilling of galleries). The size of these organisms allows the development of anisosymbiotic relationships with microflora in their proper gut, which is likely to be much more efficient than the external relationships in faecal pellets. Mineralisation linked to the digestive process may be high, especially in grass eating termites that may assimilate up to 93% of the ingested material (Wood, 1978). Endogeic earthworms may assimilate between 5 to 19% of the ingested organic matter depending on species and soil types, in the course of a gut transit that may last no more than 20' to 4 hours (Lavelle, 1988).

This represents a several hundred-fold increase when compared to standard *in-situ* field measurements.

The role of structures created by these organisms may be highly significant in the ecosystem function since they often are privileged sites for all basic soil processes (i.e., C and N mineralisation, denitrification or N-fixation, water and air infiltration), and one single structure, or group of structures, may affect processes that operate at very different scales of time and space. Some processes may be finely regulated within the functional domain of ecosystem's engineers when complementary, or opposite effects are observed at different scales of time and space. A simple example is represented by termites that accelerate tremendously the mineralisation of litter through their internal and external (fungus gardens) digestive processes, but then accumulate the remaining carbon and nutrients by aggregating their pellets into the highly compact structure of the termitaria where virtually no mineralisation occurs until the colony dies.

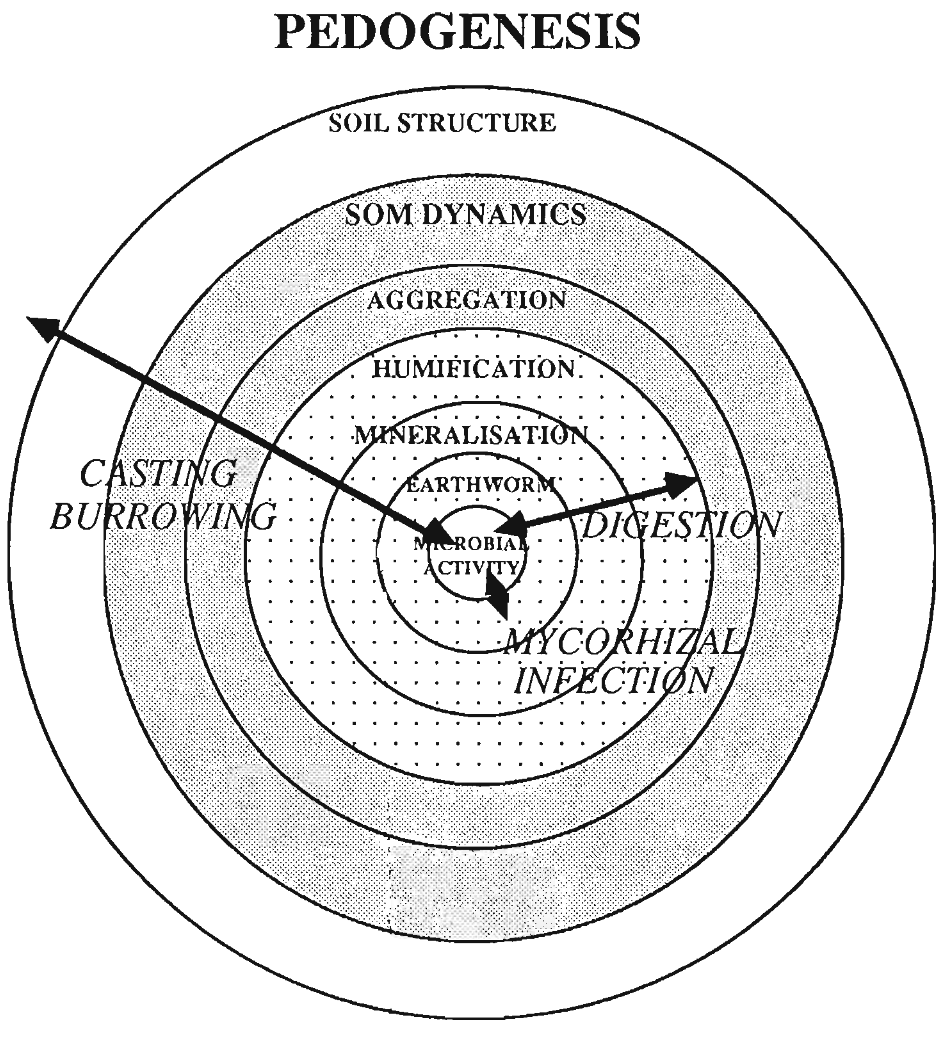
3. The Main Biological Systems of Regulation (BSR)

The functioning of biological systems of regulation largely depends on the nature and biological characteristics of all three major components i.e., characteristics of the energy source, microbial communities and invertebrates . It is therefore possible to separately consider (i) the litter systems, which comprise leaf litter as a food supply, surface lateral roots, epigeic invertebrates (mainly arthropods) and microbial communities dominated by fungi; (ii) the drilospheres, which include earthworms, soil organic matter as a food source, and free-living soil microflora dominated by bacteria; and (iii) the termitospheres, i.e., the whole volume of soil and organic resources that termites affect through their activities, in association with obligate or optional mutualist microorganisms. The rhizospheres, i.e., living subterranean roots and the soil and microflora that they influence are another important biological system of regulation that has an analogous functioning to that of the above mentioned systems.

4. Processes Affected by Invertebrate Activities

Invertebrate activities have significant effects on soil organic matter dynamics, the organisation and structure of soil, and plant growth . One common characteristic is that a single process like ingesting and digesting a mixture of soil and litter may have effects on a large range of processes, at different scales of time and space, i.e., short-term enhancement of mineralisation during gut transit, and delayed effects in fresh and ageing structures produced by these organisms (Fig. 2). The selective ingestion of organic and mineral particles, mixing of soil and organic matter, and excavation of galleries and chambers accumulated over time may have dramatic impact on the morphology and function of soil (Fig.3). An important attribute of soils such as aggregation, i.e., the organisation of particles in micro- to centimetre aggregates is largely dependent on the activities of invertebrates that produce aggregates (as organomineral faecal pellets), or other species that split them into smaller units when they excavate , or feed on these large structures. This is the consequence of huge ingestion rates by earthworms and termites that range from several hundred to more than one thousand t ha-1 dry soil in soils with intense macrofauna activities.

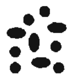
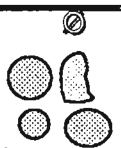
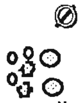
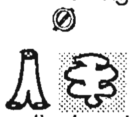
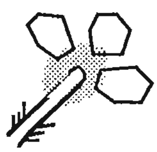
Figure 2: Consequences of the activities of an Ecosystem Engineer (an earthworm in that example) on soil processes operating at different scales (Lavelle *et al.*, in press)



The Function of Biodiversity in Soils

Soil zoologists have long asked themselves why so many species inhabited soils (Ghilarov, 1977; Anderson, 1977; Vannier, 1985). A currently admitted reason is the large diversity of resources and microhabitats that soils offer, a mixture of highly microdivided aerial and aquatic phases. It has also been argued that the extended occurence of mutualistic relationships between macro- and microorganisms increase the niche space and hence the possibility of having increased numbers of species (Lavelle, 1986; Lavelle *et al.*, 1995).

Figure 3: Relationship among structures created by major functional groups of invertebrates and roots, the structures they produce in soil, biodiversity of smaller organisms affected by these structures and major soil processes

	STRUCTURES	EFFECTS ON BIODIVERSITY	EFFECTS ON FUNCTION
MICRO-PREDATORS	none	- selection of microflora?	- enhanced mineralisation
LITTER TRANSFORMERS	 Organic fecal pellets	- selection of microflora - microhabitats for smaller invertebrates - food for other invertebrates	-Enhanced mineralisation + -sequestration of organic matter (depending on time scale)
ECOSYSTEM ENGINEERS	 Large compact structures  smaller aggregates  galleries, burrows, chambers	-selection on litter transformers -associated microfauna - selection on microflora - effects on root development	- Bioturbation - Dissemination of spores (mycorhizae, fungi) - Regulation of structural porosity - Water storage capacity - Infiltration rates - Aeration - SOM dynamics at different scales of time - Nutrient cycling (synchrony) - Surface structures (runoff, infiltration..)
ROOTS	 Rhizosphere structures	- production of polysaccharides - selection on microflora - associated food-webs - root + root litter feeders	- Aggregation - Plant production - Overall biodiversity (through energy supply and diersity of primary food resources)

Classifications of soil invertebrates based on the consequences that their activities have on soil processes (also referred to as their "function") are required. Such classifications also imply a better knowledge of the interactions existing among organisms to focus on species, or groups of species, that determine the diversity of other ones, and establish the bases of a classification based on the functions that are actually performed.

1- Species Redundancy and Functional Groups

The idea that many species are redundant (di Castri and Younès, 1990) in soil has been long implicitly accepted by those scientists who proposed diverse functional classifications for most zoological groups (Gisin, 1943 for Collembola; Grassé, 1984 for termites; Lee, 1958 and Bouché, 1977 for earthworms). However, there is almost immediate feedback between the effect an organism has on its environment and the consequences for its future conditions of life. Therefore, if we can admit in a first instance Andren's (1995) remark that *organisms have evolved through selection to maximize their contribution to future generations ....not to serve functions in the ecosystem*, we have to add that the effect of a dominant species on soil processes is likely to affect their resource base in the future. Selection may have operated on the long term consequences of function of a species on its life condition.

On the other hand, the idea that a few keystone species (Paine, 1966) or functional groups, that possibly comprise related taxa or mixed phyla, may determine the abundance and diversity of smaller species, is receiving growing acceptance (Wardle and Lavelle, 1996). The model presented in Fig.1 clearly points out the importance of ecosystem engineers as possible regulators and determinants of communities of smaller invertebrates. As a result, there is a need for functional classifications that 1) group redundant species; 2) are based on well identified functions in soils, 3) give prominent status to species or groups with key functions, but 4) recognise that some groups that do not significantly affect the rates of any ecosystem process may serve as indicators of on-going processes.

2- The Present Status of Functional Classifications

Zoologists have attempted to reduce the huge species richness of many soil invertebrate groups into a smaller number of functional groups; these would implicitly group redundant species regarding their function in soils, be easy to recognise on the basis of morphological features, and have homogeneous impacts on soil processes. Several classifications have been proposed since, sometimes more than one for a same taxonomic group. Classifications grouping several large taxonomic groups with similar ecological niches have rarely been proposed (Table 1).

These classifications are clearly centered on biological and ecological features that describe some aspects of adaptive strategies. They have proved to be useful to describe foodwebs comprised of microorganisms, micro- and mesofauna (Hunt *et al.*, 1987; Ingham *et al.*, 1986; De Ruiter *et al.*, 1993). They are certainly insufficient in the case of larger invertebrates whose function exceeds simple trophic processes by far. Improvements are still required, and should radicate in a clear view of the roles that invertebrates play in soils, at the scale of the whole soil system, and in their respective functional domains also called biological systems of regulation. Research is needed to provide a clear framework for the definition of such groups.

3-The Structure and Functional Significance of Biodiversity in Soils: Research Hypotheses

Biological systems of regulation characterise large functional domains that have general features in common that differenciate them from other large domains. An example is the drilosphere, *viz.* earthworms, the sum of structures (macropores, galleries, aggregates) that they have built and the smaller organisms (microflora, fauna) that ~~inhabit~~ these structures. Inside these entities, different species will have differing impacts and therefore different functions in the soil. To properly assess the role of biodiversity in soils, and the conditions for its maintenance, it is essential to 1) clearly identify the links existing among species, especially in the functional domain of a given BSR, to test to which extent the presence of a given organism may influence the occurence of other ones, as the hierarchical structure proposed in Fig 1 would suggest; 2) try to group key species (ecosystem engineers, or litter transformers) that may have similar impacts in the environment, on the basis of their real effect irrespective of their taxonomic affinities, and morphology, when these criteria will prove to be irrelevant ; and 3) consider biodiversity in the context of energy fluxes, a very important issue in managed systems in which the drastic reduction in carbon fluxes may indirectly affect biodiversity. Research hypotheses that address these topics may be formulated as follows:

Table 1 : Functional classifications proposed for a few major groups of soil invertebrates

Taxonomic Group	Author	Main criteria	Categories Proposed
Nematodes		Feeding regime	Saprophages Bacterial feeders Fungivorous Omnivorous
Collembola	Gisin, 1943	Size & morphology as related to location in the soil profile	Hyperedaphic Epiedaphic Hemiedaphic Euryedaphic
Earthworms	Lee, 1958 Bouché, 1977 Lavelle, 1981	Feeding regime, Habitat, Characters of burrows, Size, Morphology, pigmentation, Demographic profil, anatomy, diapause	Epigeic Anecic Oligo-, meso-, or poly-humic endogeic
Termites	Grassé, 1984	Feeding regime, associated micro-organisms	Xylophagous Fungus growers Harvesters Humivorous

Hypothesis 1. Nested biodiversities

Diversity in plant communities determines below-ground diversity in the following order : plant diversity --> ecosystems engineers --> litter transformers --> microfauna --> microflora.

This hypothesis is a soil analogous of Hypothesis B1 developped by Solbrig (Ed., 1991) stating that *'keystone' species are essential for maintaining species richness in communities*...(Terborgh, 1989; Gautier-Hion and Michaloud, 1989). This hypothesis first considers the existing links between diversity of plant and below-ground invertebrate communities, and the effect of "ecosystem engineers" (*sensu* Stork and Eggleton, 1992; Lavelle, 1994) on community structure of smaller invertebrates and microorganisms. It is hypothesised that structures created by these organisms considerably modify the habitat and trophic resource base of organisms that are smaller and less mobile. To test this hypothesis, communities of macro- and microarthropods, enchytraeidae, nematodes, and microorganisms will be sampled at three different spatial scales:

- by comparing diversity and abundance of small organisms in sites with contrasting abundances and diversities of ecosystem engineers;
- at a smaller intra-site scale, communities may also be compared in patches with high densities of the key species considered, and patches where they are not found (when populations of plants and ecosystem engineers have aggregated distributions);
- at a microsite level, investigations will compare communities found in structures produced (e.g., termite or ant mounds and nests, earthworm casts) to 'bulk soil' that was not recently modeled by faunal activities.

Hypothesis 2. The role of structures as intermediates between diversity and function

Diversity of soil invertebrates results in the production of structures whose abundance and diversity are critical to the conservation and dynamics of soil organic matter, nutrient release and maintenance of physical properties that are essential ~~for~~ a sustained primary production (Fig. 2).

This hypothesis, rather specific to the soil environment, points at the importance of metabiotic processes in soils: structures created by keystone species influence the location and evolution of organic resources that are commonly used by large part of the soil community. Special emphasis is set on the role of the characters of structures, their composition, shape, location, abundance etc., as specific microsites for the activities of microorganisms, and hence determinants of soil organic matter and nutrient dynamics; as specific components of the overall soil structure (macropores, aggregates, mounds, ant cemeteries) biological structures also influence hydraulic properties of soils and their resistance to erosion. Testing this hypothesis is another way of identifying invertebrate functions in terms of their impact on soil properties, and the activity of smaller organisms, irrespective of the taxonomic unit they belong to.

Hypothesis 3. The energetic bottle neck

In a soil with depleted organic resources, foodwebs tend to have a reduced number of trophic levels, and less components at each level. This hypothesis is a simple application of the well known productivity hypothesis to explain species richness (Giller, 1984) concerning soils. It can be casts of a given species of earthworm or organo-ineral faecal pellets of large Diplopoda that could serve as a food resource to a diverse microflora and fauna of populations of micro- and mesofauna. When the invertebrates feed on an impoverished soil, the energetic value of casts is lower and they will not sustain invertebrate and microbial populations that would normally have developped in these structures. These structures with lower organic contents are also likely to have a lower structural stability (Blanchart *et al.*, 1993).

At the scale of an ecosystem, it may be important to determine thresholds of organic resources of a given quality beyond which critical levels of key faunal activities are observed. In the African savannas of Lamto (Côte d'Ivoire) for example, the annual cost of having an active earthworm community has been evaluated at 1.2t ha-1yr-1 organic matter from relatively young pools, irrespective of particle-size (Lavelle, 1978; Martin *et al.*, 1991). Similar data for other groups and situations are stll very scarce. If maintenance of soil invertebrate communities at a significant level were to be considered as part of sustainable management practices, this kind of information would be extremely useful.

Perspectives for the Management of Soil Biodiversity

At present, there is a critical need to: (1) clearly understand the roles that invertebrates play in soils, especially representatives of key functional groups; and (2) assess the value of diversity to design management practices that optimize the conservation of species, in accordance with well identified objectives. In some cases, the objective may be conservation, in other situations, a sustainable use of soils. In the first case, the objective will probably be to maintain a minimum diversity of plants that provide the diversity and abundance of resources necessary to sustain a complex community. In the case of agroecosystems and soils submitted to rehabilitation techniques, the objective is to maintain key functional groups. It is essential to know if key species really exist and what they are, and how many are necessary to sustain soil processes and plant production at given rates. Other species that do not have the status of 'key species' may be useful indicators of the state of the system to monitor changes occuring in the function. They may be species that reflect specific structural or trophic characteristics of the soil.

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Transect Approach to the Assessment of Soil Macrofauna Diversity

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Introduction

Soil-dwelling invertebrates are known to be important contributors to the soil profile formation. Together with soil microorganisms they participate in the decomposition of organic matter and maintenance of soil fertility. High soil productivity usually indicates high biological activity and abundant and diverse animal population.

Current knowledge of these global functions of invertebrate pedobionts has been based upon a few groups only, such as earthworms and termites (Hawksworth & Ritchie, 1993). Earthworms are the most numerous and active soil-formers in temperate latitudes, and termites in tropical and subtropical soils.

At the same time, soil animal diversity on the Earth includes more than 30 0000 species, accounting for about one-third of all known species of invertebrates (Striganova, *in press*). The bulk of taxonomic richness relates to larval and adult stages of insects and arthropods, belonging to the macrofauna group. But the bulk of a zoomass and population density of pedobionts is made up of smaller animals (micro- and mesofauna): protozoans, nematodes and microarthropods.

Inventory studies of soil animal communities meet a number of problems, due to the insufficient taxonomic knowledge of some systematic groups, and the complexity of the spatial structure of the soil animal population. This complexity is determined by different environmental factors, such as climatic conditions. Within different climatic zones, soil cover diversity is determined by the parent rocks, territory's age and relief patterns. Within the habitats, the patchiness of a soil cover is determined by differences in the plant cover's structure. All these continental, regional, local, and habitat factors create a complex mosaic of animal communities fluctuating in time and modified by anthropogenic impacts.

At the same time a number of keystone groups of macrofauna are characterized by comparatively restricted areas with clearly expressed limits, pronounced topic preferences inside their areas and low migratory capacity. It facilitates the assessment of animal population biodiversity and the development of unified methods of inventorying and monitoring.

One methodological approach to assess β-diversity of biotic communities is to study their differences along a gradient of any environmental factor (Pianka, 1966; Whittaker, 1970; Wilson & Mohler, 1983). This includes different levels of spatial scales from an intra-habitat mosaic diversity level to biodiversity in a geographic region level (Whittaker, 1960, 1970).

The present report considers the potential of using a multi-scale transect method to assess the differential diversity of soil animal communities. Changes of species composition and structural characteristics of soil macrofauna along ecological gradients are also taken into consideration.

Latitudinal gradient

Soil animal communities were investigated along a polyzonal transect crossed West-Siberian Plain from the south tundra to forest-steppe (Tjumen region). Quantitative soil-zoological samples on watersheds or on upper parts of watershed slopes were made to compare soil communities of typical zonal landscapes. The latitude gradient of the territory under study ranged between 68 and 55 North. Along this transect, the above-zero temperature period increased from 75 to 130 days. Perennial mean July temperatures increased from 14 to 18°, and those of January from -25 to -17°.

The transect crossed the border of the permafrost dispersion, which disappeared to the south of 62 latitude, between the middle and southern taiga subzones. The soil type series along the transect was represented by podzol-grey, podzol, podzol-turf and degraded chernozem soils.

Soil animal communities under *Abies* and *Betula* stands were studied. The former being typical of this region's zonal forest communities, while the latter are widely distributed in secondary forests, occupying extensive areas in the West-Siberian taiga zone. Integral characteristics (population density, number of species of the macrofauna, diversity and eveness indices) are represented in Table 1.

Island Abietum are present in the forest-tundra, forming elfin woodland communities. Abieta predominate throughout the taiga zone. The southern border of the southern taiga coincides with the Abies distribution in this region.

Table 1. Zonal trends of changes of soil animal communities (macrofauna) in forest soils of the West-Siberian Plain

Natural zones	forest-tundra	northern taiga	middle taiga	southern taiga	forest--steppe
	1	2	3	4	5
Abies forest					
N	115.2	76.0	100.0	233.4	
S	21	15	17	37	
H'	1.52	2.16	1.82	1.97	
E	0.34	0.55	0.44	0.38	
Betula forest					
N*	113.6	54.4	101.6	71.2	128.0
S**	29	24	35	31	26
H'***	2.55	2.31	1.89	2.90	2.36
E ****	0.45	0.50	0.37	0.58	0.50

*N - population density (individuals m^2); **S - number of species; *** H' - Shannon Index; ****E - Eveness Pielou Index

Population density of soil invertebrates reached its maximum in the southern taiga, was comparatively low in the central sub-zones, and increased near the northern limit of the *Abies* distribution. The same latitude dynamics were characteristic for animal communities in soils under birch stands. This supports the hypthesis concerning the concentration of biotic activity in ecotones (in this case, transmissions to tundra and open steppe landscapes).

In Abieta these border subzones were characterized by a higher species richness. In the forest-tundra and southern taiga, 38% and 35% of species, respectively, were found only under Abieta. This edificatory tree species creates its peculiar phytogenic field even in isolated stands on its northern borders by maintaining specific communities of soil animals. In the south-taiga soils, there was a high abundance and diversity of species, which can be explained by the disappearance of the permafrost. Population density increased two-fold. At the same time, some forms characteristic of coniferous forests of the northern taiga for example, soil *Coccinea* inhabiting wet acidic soils, were noted to be absent.

Values of the β-diversity of soil animal communities in the northern and southern taiga averaged 0.5, which means that half of the species is replaced. The value of Shannon index was the lowest in the forest-tundra, indicating the super-domination of two species, their weight averaging 74.3% of the total density. Table 2 shows the composition of predominant species in coniferous forest soils. Only two species are present throughout all subzones, while others were found in one or two subzones.

Table 2. Predominating species of the soil macrofauna in *Abies* forests of the West-Siberian Plain

Species	% of total population density			
	forest tundra	northern taiga	middle taiga	southern taiga
(Aranea)				
(*Lycosa* sp.	9.7	13.7	19.8	(*)
(Myriapoda,Lithobiidae)				
Monotarsobius curtipes	50.7	11.6	12.6	28.4
(Homoptera, Coccinea)				
Arctorthezia sp.	23.6	9.4		
Newsteadia sp.			6.3	
(Oligochaeta,Lumbricidae)		5.2		(*)
Lumbricus rubellus				
Eisenia nordenskioldi		27.3		
(Coleoptera, Carabidae)				
Pterostichus oblongopunctatus				5.8
(Coleoptera, Staphylinidae)				
Stenus sibiricus				7.8

(*) presence of single specimens

On the transect under study the middle taiga represented the pessimal zone with comparatively low biodiversity and evenness indices. In the West-Siberian taiga ranges of separate soil-dwelling species are strictly localized, which is why the biocenotic similarity between animal communities of *Abies* stands in different subzones seems to be low.

Birch stands occur in all subzones including the forest-steppe. The Shannon index tends to decrease in the Nord-South direction, and species richness increasing. As in primary forests, the pessimum zone is characteristic of the middle taiga in spite of the maximum species richness. Birch forests of the middle taiga accumulate species, which in southern subzones occur only in coniferous stands, and to the north located in intrazonal habitats with a high heath only.

Animal communities of the forest-steppe birch stands are characterized by the presence of some steppe species. But the bulk of soil animal population was composed of forms distributed along the whole transect. The lowest similarity values were characteristic of soil communities of both the northern and southern taiga subzone.

Thus along the latitude transect the animal population showed clearly pronounced faunistic and structural differences related to climatic factors. Two high diversity areas were found in the northern and southern taiga subzones. The β-diversity value between these communities approximated at 0.5 suggesting that half of the species composition was replaced. These centres concentrated on northern and southern faunistic elements respectively, their ranges being determined by the permafrost border.

Meso-relief gradient

Effect of a meso-relief on the soil animal population diversity was studied in the forest-steppe zone of Central Russia (Voronezh region). The transect crossed a watershed slope from the highest point (130 m abs. height) to the upper flood plain border (70 m abs. height). This altitude overfall was transversed by the catena of different habitat types: eluvial areas on watershed elevations replaced by accumulative ones on low slope positions. The mesophytization of soil conditions grows downwards. Diversity of the soil cover was represented by turf podzolised soil in watershed habitats, forest brown soil on the transit position and by the grey forest soil on the low slope position bordered with the river flood plain. The latter representing the zonal soil type, characteristic of the northern forest-steppe of Central Russia.

Soil animal population was studied in three positions of this forest-steppe catena in primary and secondary forest communities. Primary forests on the two upper positions were represented by different types of Pineta, and on the low position by an oak stand. Secondary forests were represented by a dry oak forest on the watershed elevation, a complex pine stand with broad-leaved species on the transit position and aspen forest in the low position of the meso-relief. Characteristics of the animal communities are presented in Table 3.

Table 3- Diversity of soil animal communities on the meso-relief transect in the forest-steppe of Central Russia

Mesorelief positions:	watershed		transit		accumulative	
Study areas (No)*	1	2	3	4	5	6
N**	93.1	136.4	84.9	185.4	742.1	248.1
S	36	57	18	62	75	56
H'	2.29	3.86	2.64	3.19	2.46	2.54
E	0.44	0.66	0.63	0.53	0.39	0.43

* 1 -*Pinetum hylocomioso-herbosum*, 2 - *Quercetum cytisidoso- herbosum*, 3 -*Pinetum tilioso-caricetosum*, 4 - *Pinetum tremuleto-caricetosum*, 5 -*Quercetum caricetoso-aegopodiosum*, 6 - *Tremuletum aegopodioso-caricetosum*.

*N - population density (individuals m^2); **S - number of species; *** H' - Shannon Index; ****E - Eveness Pielou Index

Abundance of soil invertebrates increased downwards, and was related to the humidity factor. In primary communities a 7-fold increase was recorded on the lower end of the transect in comparison with the upper one. A maximum of both abundance and species richness were observed in the zonal grey-forest soil type.

Soil animal population on the transect was characterized by the presence of typical forest-steppe (or south-forest) species. A number of taiga elements connected with podzol-turf soil plots were also found.

Faunistic differences between animal communities on separate transect positions averaged 0.7 in primary forest habitats. Such value of the β-diversity seems to be highly sufficient, what means that more than a half of the species were localized on separate profile positions. Inventory (α) diversity was the highest in the middle of the transect, supporting the idea that the typological catena centre in temperate climatic conditions disposes of its transit positions.

The structure of the soil animal population in marginal points of the catena differed significantly, characterized by the lowest values of the diversity index. Secondary stands had, as a rule, a higher taxonomic richness and diversity indices. β-diversity between secondary habitats did not exceed 0.4. On the transect, the structure of soil animal communities reflects the peculiarities of local soil formation processes related to relief positions. Podzolized soil plots on watershed dry elevations represent azonal formations in the forest-steppe zone, isolated from the main area of the turf-podzol soil concentrating a number of taiga faunistic elements. The macrofauna of the low position was typical of forest-steppe oak stands on grey forest soil with the super-domination of earthworms. The population of the middle position reflected to a lesser degree local soil forming processes and manifested faunogenetic features, characteristic of the forest-steppe zone as a whole. Both species with wide polyzonal areas and forest-steppe forms were found there.

Microclimatic gradient

Intra-habitat diversity of the soil animal population determined by both micro-relief, patchiness of soil cover and structure of a plant stratum, was investigated along a micro- transect crossing a series of microsites under a tree canopy and between trees. Samples were collected in the Pistacia open woodland in Central Asia (Southern Turkmenistan). Pistacia stands are distributed there in semi-desert landscapes, which are characterized a warm arid climate and water deficiency in soil landscape. Soil cover is represented by typical grey desert soils.

Shadowing of a soil surface by plants creates pronounced micro-climatic differences between shadowed and open plots. The diameter of undercrown areas under old Pistacia trees reached 5-6 m. Specific shadow-grass cover developed under crowns reinforces the differences of the hydrothermic *regime* under and between crowns. Together with the leaf fall, grasses form the stable litter horizon, stabilizing hydrothermic conditions on soil surface. Undercrown animal communities show some features particular to temperate forest communities. Three spatial microzones were separated in undercrown plots- stem zone (attached to tree stems), central zone and marginal mound (on the border of shadowed area). The latter represents the ecotone zone, combining forest and semi-desert forms of the soil fauna. These transects were 2.5-3.5 m long.

Table 4 shows characteristics of soil invertebrate communities of 3 undercrown plots and open area attached to the crown border. Undercrown moulds were characterized by both maximum abundance, species richness and diversity values. But the eveness index was comparatively low because of the concentration of diplopods *Cylindroiulus cushkensis*, averaging 39% of the total abundance. The lowest diversity was recorded on open plots for account of a low species richness and superdomination of Curculuonidae larvae, feeding on herb roots, consisting of 81% of the total density.

The highest similarities were found between animal communities of the central zone and undercrown mounds, and the lowest between the stem zone and other undercrown microsites. Differences in the animal population are correlated with the soil diversity: soil characteristics in stem plots corresponded to those of dark grey desert soils, indicating the activity of specific zoo-microbial communities.

Table 4. Diversity of soil animal communities on the gradient of micro-climatic conditions of the undercrown area

MICROSITES	UNDERCROWN AREA			OPEN PLOT
	stem zone	**central zone**	**undercrown mound**	
N*	160.0	148.0	377.3	181.1
S	8	9	21	8
H'	1.44	1.53	1.88	0.52
E	0.55	0.54	0.45	0.20

*N - population density (individuals m^2); **S - number of species; *** H' - Shannon Index; ****E - Eveness Pielou Index

Investigated also was the structure and spatial dispersion of animal communities under Pistacia trees in dry and humid years. The spatial discretion in the zonation of animal communities was invariable, but territorial borders between separate communities pulsated. In humid years undercrown communities expanded on open plots, and in dry years inhabitants of semi-desert herb formations (Carabidae, Histeridae beetles) migrated under crowns.

These materials demonstrated a clearly pronounced structural discretion of the animal population at transects of different scale levels. Spatial diversity of invertebrate communities in soil reflects both latitudinal and altitudinal regional changes of climatic and edaphic factors, soil typology in the landscape boundaries and soil anisotropy on the limits of habitat.

This suggests that the transect methods and gradient analysis can be successfully used in soil-zoological studies related to biodiversity inventorying and monitoring. They allow the assessment of the differential biodiversity of soil animal population; help to reveal ecotone zones; and analyse the phenomenon of discretion and continuity in the spatial distribution.

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Soil Biodiversity and the Fertility of Tropical Soils

The TSBF Soil Biodiversity Network

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Introduction

Agenda 21 calls for the conservation of biodiversity as well as actions to ensure sustainable development in the agricultural and other sectors. A major feature of global change in the tropical regions is that of land-use associated with agricultural intensification.

Soil is the habitat of a diverse array of soil organisms -bacteria, fungi, protozoa and invertebrate animals - the activities of which contribute to the maintenance and productivity of agroecosystems by their influence on soil fertility (Swift & Anderson, 1993). Global food supply depends on intensive agriculture. As intensification occurs, the biological regulation of soil processes is altered, and often substituted by the use of chemical fertilisers and increasingly mechanised tillage. The assumption is often made that the consequent reduction in the diversity of the soil community (Lavelle & Pashanasi, 1989), and eventual extinction of species, may cause a catastrophic loss in function and reduce the ability of agricultural systems to withstand unexpected periods of stress. The causal relationships between (i) the composition, diversity and abundance of soil organisms and (ii) sustained soil fertility remain however to be quantified. Furthermore large numbers of farmers in the tropical regions have limited access to inputs but are nonetheless forced by circumstances to intensify production. The maintenance and enhancement of soil biodiversity may be particularly critical to the increase and maintenance of production to in such conditions of 'intermediate' or 'emergent' intensification (Swift *et al.*, 1996).

Formation of a Network

At a workshop of 44 scientists from 15 countries held in Hyderabad, India in January 1995 and funded by UNEP, agreement was reached to form a Soil Biodiversity Network to implement a programme of research to investigate the relationships between agricultural intensification, soil biodiversity and the sustainability and productivity of agricultural lands. These questions will be addressed with a particular focus on farmers at the most vulnerable, intermediate stages of intensification, in the tropical regions.

The research in the network will address the following objectives:

1. To measure the impact of agricultural practices on soil biodiversity.

2. To determine the effects on agroecosystem productivity and sustainability of soil biodiversity loss.

3. To identify management practices that improve the productivity and sustainability of agricultural systems through manipulation of key functional groups of soil biota.

4. To assess policy options for optimising management of soil biodiversity for sustainable agricultural production.

It is expected that the work conducted within the network will result in: an inventory of the diversity of key taxonomic and functional groups of soil biota across gradients of agricultural intensification in a range of tropical environments; improved experimental evidence of the impact of loss of diversity in selected groups of soil organisms on ecosystem function and agricultural productivity; improved methods for management of soil biodiversity in tropical agricultural systems; evaluation of the benefits of enhanced soil biodiversity for agricultural productivity and sustainability and formulation of potential policy options for optimising management of soil biodiversity; enhanced capacity for interdisciplinary biodiversity research in a number of tropical countries.

Hypotheses and Research Questions

The Hyderabad Workshop agreed on a number of Hypotheses and Questions to guide research. Papers from the Workshop will be published in a special volume of Applied Soil Ecology later this year. The full report of the workshop proceedings is available from TSBF.

***Global Hypothesis 1**: Agricultural intensification results in a reduction in soil biodiversity leading to a loss of function detrimental to resilience and sustained productivity*

Justification

Global food supply depends on intensive agriculture and the assumption is often made that biodiversity declines as a result of intensification. It is further assumed that such a decline in biodiversity, and eventual extinction of species, may cause a catastrophic loss in function and reduce the ability of agricultural systems to withstand unexpected periods of stress. Despite widespread acceptance of this view, a direct causal link in this chain has yet to be proven.

Hypotheses

1.1 The diversity and abundance of structures created by soil organisms is essential to the conservation and dynamics of soil organic matter turnover, nutrient release and soil physical properties essential for sustained productivity.
(a) Does reduced biodiversity result in loss of function?
(b) Are key functional processes independent of structural diversity?

1.2 Redundancy protects key functional groups of organisms from reduction to crucial thresholds below which agroecosystem function is impaired.
(a) What are key functional groups the loss of which is detrimental to system resilience and productivity?
(b) Can changes in soil biodiversity be detected before loss in function? (early warning signals)
(c) Can the appearance or extinction of key functional groups or individuals within a group be an indicator of degradation?

1.3 Intensification triggers a spatial and temporal decoupling of organisms which alters the regulation of soil structure development and nutrient cycling.
(a) Does loss of biodiversity disrupt the cascade of organic transformations necessary for effective and timely decomposition?
(b) Can an external input reduce the role of one key functional group whilst boosting another and thereby enhance net productivity?
(c) Can relationships between key functional groups be used to increase soil biodiversity?

Global Hypothesis 2: *Agricultural diversification enhances ecosystem resilience and sustained productivity by increasing soil biodiversity*

Justification

Diversity in cropping systems and management practices is widely accepted to buffer farmers against short-term risk. Agricultural diversification at both the scales of field and landscape may also have long-term benefits through the enhancement of functional and taxonomic diversity, particularly in degraded lands. This enhanced biodiversity contributes to the re-establishment and multiplicity of organisms able to carry out essential biological functions; factors that buffer agroecosystems against risk which increase resilience and sustained productivity.

Hypotheses

2.1 Above- and below-ground biodiversity are interdependent across scales of resolution from the pedon to the landscape.
(a) Are above- and below-ground diversities interdependent?
(b) Are roots, through differences in the amount and quality of inputs and in architecture, a primary mediator of diversity and function in soils?

2.2 Increases in the spatial and temporal diversity in biological resources, refuges and habitats (and hence biodiversity) buffers against impairment of agroecosystem function.

a) Does bioturbation result in improved dispersal of favourable organisms and a reduction in pests?
b) Can synergistic interactions, both above and below-ground, be used to enhance function in degraded soils?

2.3 Functional redundancy is more easily enriched through management than key specific functions are re-established through reintroduction.

(a) Does enhanced soil biodiversity confer greater functional resilience?
(b) Is reintroduction a feasible management tool?

2.4 Resource-limited farmers have the most to gain in the short-term from enhancement of soil biodiversity, although all will benefit in the long-term.

(a) Is biodiversity a prerequisite for ecosystem resilience and long-term productivity but not for short-term production?
(b) Does soil biodiversity buffer farmers against risk?
(c) Are the most resource-limited farmers the most reliant on soil biodiversity?
(d) Does intensification differentially influence soil functional groups?
(e) Are different functional groups equally important regardless of the productivity?
(f) Does a shift in the dominance of key functional groups lead to a change in ecosystem function?

Implementation

The network membership consists of scientists from Universities and Research Institutions from ten countries across all three tropical continents. The Network will be coordinated by the Tropical Soil Biology and Fertility Programme (TSBF) from Nairobi.

TSBF was initiated in 1984 under the patronage of the IUBS-UNESCO programme the Decade of the Tropics. The Programme was founded with the aim of promoting soil biology as a research discipline in the tropical regions on the premise that the biological management of soil fertility is an essential component of sustainable agricultural development. Biological management of soil fertility is a holistic approach integrating the biological, chemical and physical processes that determine the natural fertility of soil with all appropriate management practices (Woomer & Swift, 1994). It is distinct from organic farming in that it recognises the need under many circumstances for inputs of inorganic fertiliser and is wider than the integrated plant nutrition concept in that it embraces the physical as well as the chemical aspects of fertility. The research approach advocated by TSBF includes both process-level and system-level study of agroecosystems. Process level research is focused on understanding the biophysical regulation of soil fertility by such mechanisms as decomposition, soil organic matter dynamics and soil fauna activity. At the system level research is concerned with assessing the ways in which soil fertility is regulated by the farmer and by both the socio-economic and biophysical environment in which soil management is practised.

One of the major research themes of TSBF is that of the Soil Biota the objective of which is to develop a better understanding of the functional role of key groups of soil biota and thence explore the means of managing them to improve soil fertility (Woomer and Swift, 1994). Work in this area has until recently largely concentrated on two functional groups, the Earthworms, through strong links with the EC-funded Macrofauna Network *(see paper by Lavelle in this journal)*; and N-fixing bacteria through the Rhizobium Ecology Network for Eastern and Southern Africa (RENEASA), funded by UNESCO and the Rockefeller Foundation. The Soil Biodiversity Network will extend the taxonomic range to other key functional groups including termites, nematodes and mycorrhizal fungi as well as the decomposer microorganisms.

Relationships with other International Programmes

The TSBF Soil Biodiversity Network has grown out of the experience gained by the Macrofauna Network described by Patrick Lavelle in an accompanying paper.

The network forms part of the TSBF Programme and is affiliated with DIVERSITAS and GCTE. The aims of the network research are in particular consistent with the DIVERSITAS theme on the relationships between diversity and ecosystem function. The research is also integral to the GCTE activities on Complex Agroecosystems (Activity 3.4) and Soil Biology (Activity 3.3.3).

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The Array of Available Strategies for Soil and Sediment Biodiversity Analysis, and the Potential for Amalgamation of Protocols

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Introduction

The average cubic metre of terrestrial soil or aquatic sediment in temperate regions probably contains thousands of species, and the level of organismal biodiversity in similar tropical ecosystems is even higher. A whole range of biotic activities in soils are essential for continuing life on Earth, including nutrient and mineral cycling, and the maintenance of soil structure and fertility. Even so, the variety, frequency and individual functions of organisms in soils and sediments remain almost unknown, in contrast to the relatively well-understood realms of above-ground biodiversity.

As a first step following recognition of the lamentable state of our knowledge of the soil biota, IUBS and UNESCO undertook the task of examining the range of existing study methods of soil organisms, in support of the DIVERSITAS programme. This has resulted in the preparation of a book containing protocols for examining the diversity of all groups of soil and sediment organisms, which is about to be published by CAB INTERNATIONAL (Hall, 1996). The chapters are contributed by a panel of 32 international experts, and include information on the importance of the various organismal groups in ecosystem processes, sampling and extraction techniques and their limitations, suggested methods to refine existing protocols, and a bibliography.

The groups include:

1. Heterotrophic bacteria (J. T. Staley, Seattle)
2. Chemolithotrophic bacteria (S. K. Haack, US Geological Survey)
3. Actinomycetes (E. M. H. Wellington and I. K. Toth, Warwick)
4. Cyanobacteria (B. A. Whitton, Durham, UK)
5. Non-culturable bacteria (J. M. Tiedje and Ji-zhong Zhou, Michigan)
6. Algae (J. D. Dodge, Egham and L. E. Shubert, Natural History Museum, UK)
7. Protozoa (J. F. Darbyshire, Aberdeen, O. R. Anderson, New York and A. Rogerson, Millport)
8. Dictyostelids and myxomycetes (S. L. Stephenson, West Virginia and J. C. Cavender, Ohio)
9. Yeasts (J. W. Fell, Florida and C. P. Kurtzman, Illinois)
10. Zoosporic 'fungi' (G. S. Hall, IMI)
11. Filamentous fungi (P. F. Cannon, IMI)
12. Arbuscular mycorrhizal fungi (J. P. Clapp, A. H. Fitter and J. W. Merryweather, York)
13. Micro- and macroarthropods (J. E. Bater, Rothamsted)
14. Mites (D. A. Griffiths, Ash, Surrey)
15. Meiofauna in marine and freshwater sediments (M. Vincx, Gent)

16. Rotifers (P. A. Rublee, North Carolina)
17. Turbellarians (E. R. Schockaert, Limburg)
18. Nematodes (D. J. Hunt and P. De Ley, IIP)
19. Molluscs and crustaceans (M. B. Seddon and P. G. Oliver, Cardiff)
20. Earthworms (S. W. James, Iowa)
21. Burrowing mega- and macrofauna from marine sediments (J. D. Mackenzie, Argyll).

Analysis of Protocols

Extracting and identifying the complete range of organisms in a soil or sediment sample is a task not to be undertaken lightly. A primary aim of the exercise was therefore the identification of sampling protocols which could be applied over a wide range of organisms and their amalgamation into a single volume, thus allowing simultaneous study of a series of major taxa. Some organism groups require individual treatment, with protocols which cannot easily be adapted for other taxa. Nevertheless, the methods advocated fall into three major categories; direct observation, culture and molecular analysis. Within these broad groupings some significant overlaps occur. Protocols include both direct sampling and a wide selection of baiting techniques. The numbers in square brackets refer to the chapter numbers cited above.

Direct Observation

Organisms which exhibit the structures with which they are normally characterized in raw samples can be studied directly without further treatment, especially when they occur on soil or sediment surfaces. For others, samples have to be processed in various ways in order that species may be detected and identified. For organisms within the soil or sediment structure, samples usually have to be suspended in water to allow separation of the various physical and organismal components. This is particularly important for motile taxa such as dinoflagellates, ciliate protozoa, and zoosporic 'fungi' [6, 7, 10], whose movement makes observation much easier. In contrast, some surveyors of rotifer diversity anaesthetize their target organisms, which encourages separation of rotifers from soil particles [16], and similar techniques are used by workers studying various of the larger soft-bodied organisms [19, 21] to relax specimens to allow easier observation. Sieving, often following suspension in water, is a standard technique for many groups, including meso- and meiofauna [13, 15, 16, 18, 19, 20], the larger protozoa [7] and arbuscular mycorrhizas [12]. Such protocols used in isolation will not necessarily sample all stages of the life cycle of large organisms. Sieving followed by culturing has recently become popular in fungal diversity analysis [11]. Density gradient centrifugation has also been used in place of sieving [7, 12, 15, 18], and flotation methods trapping organisms at the interface between two immiscible liquids with differing densities have been employed for arthropods and mites [13, 14], although current safety regulations preclude the use of some such protocols unmodified.

For many mesofaunal groups, techniques using physical and/or chemical gradients are popular. Heat sources create temperature and humidity gradients within soil samples which drive the target organisms into collecting vials [13, 14]. They are also used for nematodes [18], although the heat source may select for active animals and increase the risk of target death through poor oxygenation. In marine sediments, techniques using osmotic gradients created through the melting of sea-water ice have been successfully used to capture organisms such as rotifers and turbellarians [16, 17], and oxygen gradients are used also to sample the latter group. Chemical gradients involving the surface application of compounds such as formaldehyde are used for earthworm collection [20].

A wide variety of preparative and observational techniques for microscopy has been employed. Differential staining has wide applications, making observation of particular groups easier [e.g. 11], and methods borrowed from palynology dissolve detritus and mineral matter leaving highly resistant cysts and spores [6]. Fluorescence microscopy is used in many studies, for example highlighting chlorophyll in living algal cells [6]. Antigenic techniques such as the immunofluorescence protocols advocated for actinomycetes [3] can be applied to a wide range of soil organisms, although they are more suited to detecting individual taxa in a known universe than initial diversity sampling of unknown samples. Direct SEM examination of soil samples is labour-intensive, and inability to use differential staining techniques is a further limiting factor. However, such protocols have been used with some success (both with and without culturing) in studying morphologically distinctive groups of actinomycetes [3] and fungi [11]. It is also of considerable value in observing the smaller arthropods, nematodes etc.

Cultural Techniques

Culturing is used for a wide range of organisms. Methods have first to be selective, so that the organismal group being studied is preferentially grown. The most effective methods include incubation in conditions where only the simple chemical components necessary for metabolism are available, as in the case of protocols for chemolithotrophic bacteria [2]. Methods which inhibit the growth of other organisms are widely employed, such as the use of antibacterial agents in fungal cultures [11], and the fungal and eukaryotic alga inhibitor cycloheximide in cyanobacterial analysis [4]. Submerging soil particles below agar surfaces encourages fungal growth at the expense of bacterial colony development [11]. The choice of culture media and incubation conditions may also have a profound effect; for example yeasts [10] are separated from filamentous fungi using media with high nutrient content and shaking rather than static incubation, and cyanobacteria may be separated into nitrogen-fixing and non-nitrogen-fixing taxa using N-free media. Once the initial culture has grown, it can either be examined directly using light or SEM techniques, or individual colonies can be removed and grown in subculture. This second method is necessary for most organismal groups to avoid overwhelming of slow-growing species by the more 'weedy' taxa. For some groups, overgrowth is a serious problem [e.g. 11], and is dealt with using various protocols including minimal media, cool incubation temperatures and growth inhibitors such as cyclosporin. Once single-species cultures have been obtained, they can be characterized by direct microscopy, or subjected to enzymatic, biochemical, fatty acid (FAME), or molecular analysis.

For some biotrophic taxa such as the marine Labyrinthulomycetes, dual culture in conjunction with the yeasts on which they feed is necessary. Multiple culture is currently the only reliable method for preservation of arbuscular mycorrhizal fungi, in pots along with their plant associates. Many other organisms can only be preserved in a living state in conjunction with their supporting taxa, and the whole research area of cultural techniques involving multiple organisms needs particular attention.

Baiting Techniques

Most baiting techniques involve the provision of nutrient sources, and are incorporated into cultural protocols. Soil and sediment protozoa and dictyostelids may be captured using minimal media with a bacterial bait [7, 8]. Different groups of fungi [11] may be encouraged using a diverse range of baits, including cellulose, keratin, dung and other organisms such as nematodes and rotifers, and zoosporic 'fungi' [10] are frequently sampled using baits such as hemp seed, pollen, algae, cellulose and snake skin. Mesofauna such as micro- and macroarthropods may be sampled using baits such as bran or beer, or various cellulosic substrata. The bait can be placed in pitfall traps, or in mesh bags at or below the soil surface as appropriate.

Protocols involving light (i.e. photo-) baiting are used for some groups. Microscope slides are embedded vertically in soil or sediment samples, attracting motile photosynthetic organisms such as dinoflagellate algae [6]. These methods are applicable primarily to surface samples. Glass slides and microcapillaries are also used to sample a variety of thigmotactic species, including several groups of protozoa; many of these cannot be cultured using standard methods. Light baiting is also used for some arthropod groups [13]. Immunomagnetic capture has been applied in study of various bacterial groups [3] and is of particular value in sampling genetically modified organisms (GMOs).

Molecular Methods

Nucleic acid analysis may potentially be used for in situ detection and identification of any soil or sediment organism. Its use has been developed most extensively in bacterial and actinomycete sampling [1-3, 5], the small size of these organisms making traditional methods difficult or impossible to apply. Morphological characterization can be only very rudimentary in these circumstances, and evidence gathered since the early 1980s has shown that traditional cultural protocols sample only a small proportion of the total organismal diversity for these groups. Molecular methods are particularly suited to groups such as the chemolithotrophic bacteria [2] which are typically found in extreme environments, and there is a wide range of bacterial groups which apparently cannot be cultured at all [5].

Small sub-unit ribosomal RNA (rRNA) or DNA coding for rRNA (rDNA) is analyzed with these protocols. There is a wide variety of techniques, but they all involve a similar series of steps, including total RNA or DNA extraction and purification, PCR amplification and gene cloning. Sequencing is commonly carried out, although gel electrophoresis band patterns can be used to provide an overall estimate of diversity.

As with cultural techniques, it is desirable in many circumstances to separate samples into groups of organisms before further analysis. This is most commonly carried out by hybridization with universal primers for the group concerned, but in some cases other methods may be effective. These include differential centrifugation to separate bacterial (prokaryote) DNA from that of other (eukaryote) organisms, although such methods may recover less than 50% of the total cell numbers present. Soils and sediments are particularly difficult environments from which to perform nucleic acid analysis, due to problems in cell lysis, DNA shearing, and humic acid contamination [5]. Differential recovery of taxa using molecular methods is a potential barrier to accurate biodiversity analysis, but recent refinement of methods has lessened the extent of this problem.

Further Developments

If comprehensive surveys of species in single samples are ever to be achieved, either as a component of ecological process research or inventory programmes, a carefully planned synthesis of protocols is essential. Such an approach has benefits not only for individual site survey, as a well-designed and widely implemented suite of common methods would greatly facilitate intersite comparisons. The value of the enormous volume of data available on biodiversity and ecosystem components at all levels is currently greatly diminished due to the difficulties of comparing results from different study areas.

At first sight, the plethora of techniques for examination of organismal diversity is bewildering. Fortunately, on closer analysis it can be seen that there is considerable scope for combination and modification of protocols, in order that several groups of organisms may be sampled in one operation. It will clearly still be necessary to separate the sampled organisms into major groups to facilitate identification, but in many cases the preliminary stages of sample analysis can be merged and carried out by trained non-specialists. This does not mean that the overall analysis can be dramatically reduced in scale; for acceptable study even of a single organism group several protocols are necessary which will inevitably partially overlap. Training will be necessary to achieve reliable separation of samples into systematic groups by non-specialists, and custom-designed manuals would be desirable. Further training on species concepts for the taxa concerned would allow non-specialists to separate the organism groups obtained into morphospecies, which would dramatically reduce the time necessary for specialist identification. Samples could also be sent to the specialist, rather than the specialist coming to the samples.

There are particular advantages in merging protocols for meso- and meiofauna, whose constituent groups are almost all sampled by direct observation following sieving or differential centrifugation. Cultural work could also benefit from merged protocols, although the large number of necessary techniques would limit the savings in time and effort. For some of the microorganisms, research is necessary to minimize the sampling overlap produced from different cultural protocols, although the large systematic diversity within microorganism groups compared with some of the meso- and meiofaunal taxa may demand a greater range of sampling methods.

The greatest reduction in overall effort is potentially in molecular diversity analysis. Protocols are largely similar for the groups which have so far been studied, and the availability of universal primers for at least most of the organism groups means that separation into major taxa is simple. Potential drawbacks include the number of organism groups for which the techniques are untried, and the cost and technical skills needed for carrying out the protocols. There are also major problems in species identification. Available sequence libraries contain information on only a tiny proportion of the known taxa likely to occur in soil or sediment samples, so in order to provide a complete and fully identified diversity analysis of even a well-known soil ecosystem an extensive period of sequencing known taxa would be required. Molecular diversity analysis of environmental samples need not necessarily involve species identification; knowledge of individual sample identities is not needed for testing a range of scientific hypotheses relevant to analysis of change in biodiversity or ecological processes. The comparison of band patterns may allow acceptable results if a wide enough variety of amplification primers is used.

The most important component of any biodiversity analysis should be the design of strict protocols, making the results both repeatable and comparable. If this principle is properly adhered to, then combined protocols for biodiversity analysis are both achievable and desirable. A complete analysis of organismal diversity of a soil or sediment sample will still be a major undertaking, but the value in terms of investigation of an unknown world will be considerable. IUBS and UNESCO, in collaboration also with the SCOPE Soil Biodiversity and Ecosystem Function Programme, are now developing proposals to refine and synthesize further these protocols with the aim of testing them in the field.

Acknowledgements

The project reported on here was conceived jointly by Professors D. L. Hawksworth (President, IUBS) and P. Lasserre (Head, Division of Ecological Sciences, UNESCO), and carried out under contract from UNESCO under the management of Dr G. S. Hall (IMI, CAB INTERNATIONAL).

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Soil and Sediment Biodiversity and Ecosystem Function

A New SCOPE Programme Element in DIVERSITAS

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A new SCOPE project "Soil and Sediment Biodiversity and Ecosystem Functioning" has been developed as part of the second phase of the DIVERSITAS Programme. This programme element will focus on studies of biodiversity in soils and sediments, knowledge of the ecological role of taxa at different scales of resolution (genetic to landscape), and results from ecosystem experiments and models, to provide a basis for developing common principles relating biodiversity and ecosystem function in and across terrestrial, marine and freshwater environments. Also, the programme aims at evaluating and assessing the current state of knowledge of the relationships of soil and sediment organisms to critical ecosystem processes and to publish a synthesis and priority area of needed research.

Soils and sediments are basic media for maintenance of life processes, and their organisms are the major component of biodiversity of many ecosystems, yet, they are, for the most part, unknown because they are small, numerous and less described. Field experiments have historically studied processes by assigning organisms to major functional categories based on size, biomass, and trophic group. Nevertheless, even this limited knowledge of the importance of soil biodiversity has had immense economic significance for agriculture and forestry, and we may expect a similar importance to fisheries and aquaculture in marine and freshwater systems. A need in biodiversity research common to both soils and sediments is to identify the diversity of microbes in order to bridge the gap between the taxonomic/physiologic information and the role of the organisms in the soils and sediments. Such research could have large impacts in identifying microbes useful for biological control of plant and health pests.

Presently, microbial taxonomy is primarily based upon physiology with identifications carried out in laboratories. However, only a small percentage of microbes found in field studies can be identified in this way.

Recent advances in molecular biology offer promise for experiments relating a broad range of taxa, not just microbes, to their functional role. Is soil and sediment biotic succession related to ecosystem functioning and processes? Are only a few key taxa responsible for ecosystem functioning of soils and sediments? Can we assess our state of the knowledge if we, the few scientists examining soils and sediments, continue isolated studies of biodiversity and ecosystem functioning? These questions and assessments are a focus of the three year SCOPE Committee synthesis, and are particularly relevant as humans impact soils and sediments globally.

Soils are linked to freshwater and marine sediments by hydrologic processes and sediment transport in streams and estuaries. Run off from watersheds and movements of ground water are especially important in freshwater and coastal environments. The organisms of soils and freshwater sediments play a critical role in filtering and decontaminating ground water. These soil and sediment functions are necessary for the maintenance of aquifers used for irrigation and drinking water. The linkage between land and aquatic environment through soils and sediments is also important in maintaining fisheries and aquatic environments suitable for recreational use.

In addition to their role in decomposition and regenerative processes, soils and sediments are essential for decontamination of toxic chemicals that tend to accumulate in these environments. The most polluted environments known are soils and sediments. Because of the direct relationship to human health, environmental management tends to focus more on air and water quality, yet soils and sediments are often the most severely impacted components of the ecosystem. The loss of known taxa in soils and sediments is one of the most sensitive indicators of anthropogenic changes in ecosystem function, however the linkage of individual components to normal functioning is not well understood. In the long term, ecosystems cannot be maintained if soils and sediments continue to accumulate pollutants.

Remediation and restoration of these environments are among the major challenges faced by environmental managers. The design of economically viable processes for decontamination of soils and sediments are essential for both human health and normal ecosystem function. The augmentation of natural regenerative processes is likely to become an essential feature of successful ecosystem management.

There are many questions that need to be addressed across the three domains and with each domain, and these include:

- Are a few taxa responsible for key ecosystem processes in soils and sediments? Can we identify key taxa in functional groups that have a disproportionate effect on ecosystem processes?
- What are the patterns of biodiversity for soil and sediment dwelling biota across habitats from landscape to global scale?
- Can we identify the ecological determinants for soil and sediment biodiversity and relate them to ecosystem functioning?
- How is diversity within soil functional groups involved in maintenance of plant productivity?
- How important is the diversity of soil and sediment organisms in conferring resilience and stability to ecosystems?

The *Scientific Advisory Committee* (SAC) of this project is chaired by Diana W. Freckman (Colorado, USA) and has three domain groups (soil, freshwater sediments, and marine sediments), each with a chair. Members of the SAC are: Fred Grassle, (USA), David Hawksworth (UK), Patricia Hutchings (Australia), Timo Kairesalo, (Finland), Isao Koike (Japan), Josef Rusek (Czech Republic), and Osvaldo Sala, (Argentina). Domain Chairs are: Margaret Palmer (USA) for Freshwater Sediments, Lijbert Brussard (Netherlands) for Soils, and Henry Blackburn (Denmark) for Marine Sediments domains.

Transect Studies on Global Change and Biodiversity in the West Pacific and Asian Region

Beijing, China, 6-8 May 1996

An International Symposium on Transect Studies on Global Change and Biodiversity was held on 6-8 May 1996 at the Institute of Botany, in Beijing, China. Co-sponsors were the National Natural Resource Science Foundation of China, the Chinese Academy of Science (CAS), the DIVERSITAS West Pacific Asia (DIWPA) network, the Chinese National Committee of the International Geosphere-Biosphere Programme (CNC/IGBP), and the Biodiversity Committee of CAS. The objectives of the symposium were to exchange information related to global change and biodiversity research in the region, and to promote the cooperation among scientists involved in transect studies. This also signified an important regional contribution to both the IGBP and DIVERSITAS programmes.

The key questions addressed by the participants were (1) how global change will affect biodiversity and (2) how biodiversity is linked to biogeochemical processes and other ecosystem functions, using the ecological transect as an effective approach in resolving these issues.

During the 3-day meeting, one plenary and four specific sessions were held:
(1) Ecosystem Physiology and Global Change; (2) Ecosystem Structure and Global Change; (3) Biodiversity and Ecosystem Functions under Global Change; and (4) General Topics of Transect Research. Fifty-nine scientists from 10 countries and areas (mostly Asian) participated. Four papers were presented in the plenary session. Seventy-five papers (36 oral and 39 poster) were listed on the curriculum, but not all presented.

Among the contributions, Tamiji Inoue (Japan) and Abang Abdul Hamid (Malaysia) dealt with an approach for understanding and conservation of biodiversity of tropical rainforests. Studies undertaken within the framework of the North East China Transect (NECT) Research Programme were presented by Zhang Xinshi, China. The issue of environmental gradients controlling ecosystem dynamics in temperate ecosystems of Asia and North America was addressed by Dennis Ojima (USA) and Chuluun Togtohyn (Mongolia).

Many papers dealt with terrestrial vegetation and relatively few were devoted to animal sciences and the interaction between organisms. We hope to have another opportunity to learn more of the research activities in these areas, since interactions are believed to be a mechanism to enrich biodiversity and the complex function of the ecosystem.

The meeting highlighted the need to build a more effective network among the researchers and research sites in this area. It was pointed out that although each research project may produce excellent results, only the integration of these studies on a global scale could provide the solutions to problems concerning global change and biological diversity. We hope that this symposium, and other activities within the IGBP and DIVERSITAS will work in promoting cooperation in the network of researchers and research projects.

by Tohru Nakashizuka
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and
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CYTED Ibero-American Workshop on Biodiversity Inventorying and Monitoring

Viña del Mar, Chile, 22-25 April 1996

In his search for gratifiers, man tends to simplify the natural processes, and the excessive use of some species has lead many to extinction. Until the middle of this century a rich diversity of organisms was maintained - perhaps the greatest that has ever existed on Earth. In the last 50 years, accelerated demographic expansion, the growing requirements for raw materials, contamination, as well as poverty are provoking an accelerated loss of biological diversity. This was the central theme of the UNCED in Rio in 1992, and continues to be a growing concern in the international scientific community and in numerous civic groups.

In order to know what we are losing or what we could lose, it is necessary to realize the magnitude of this biodiversity. We must be able to measure it and be able to establish monitoring programmes. This is a very complex and difficult matter due to the enormous variety and number of living species.

Out of the three main inventory projects underway in the world, two are in Latin America. The inventories of the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) of Mexico are designed to coordinate information on species and supra-specific levels on a geo-referential basis (and quite similar to the ERIN projects being developed in Australia). The inventory which is being done in Costa Rica by the Instituto Nacional de Biodiversidad (INBio), emphasizes the species level and intra-specific variations. One use for this information obtained is to detect new substances helpful to man.

The objective of the *Taller Iberamericano sobre Diversidad Biológica* was to review CONABIO's and INBio's inventories concerning the Iberic fauna and Iberic flora (this last one already with a CD-Rom version) projects, and to evaluate strategies for measuring biodiversity, i.e., using parameter groups alternate (approximation developed by the Instituto de Ecología, México) or non-parametric analysis.

The Workshop took place in Viña del Mar, Chile, with 39 participants from 13 countries, and organized by Sub-programa XII of the Diversidad Biológica for the Programa Iberoamericano de Ciencia y Tecnologia para el Desarrollo (CYTED). The Consejo Nacional de Investigaciones Cientificas y Técnicas (CONICYT) of Chile coordinated the Chilean participation and local organization. The meeting was also co-sponsored by the International Union of Biological Sciences (IUBS), the Oficiná Regional de Ciencia y Tecnología para América Latina y el Caribe (ORCYT) of UNESCO, and the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). The proceedings of this workshop will be published in both Spanish and English. Considering its success and the scientific interest awakened, a similar workshop is being envisaged for 1997 in Spain.

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IUBS Financial Statement for the Year 1995

STATEMENT 1: Balance sheet at December 31, 1995 (Expressed in US$)

ASSETS:	
cash and banks	
Crédit Lyonnais, Paris	
in US$	170 763
in FF	102 880
in US$ (Deposit Account)	100 000
Merrill Lynch, New York (in US$)	502 366
Other Receivables	41 344
	917 353
LESS: LIABILITIES	
Sundry Creditors	(30 616)
EXCESS OF ASSETS OVER LIABILITIES	**886 737**
Represented by	
General Fund	246 737
Mandatory Reserve	640 000

STATEMENT 2: Income and Expenditure for the year ended December 31, 1995 (Expressed in US$)

1. INCOME	
ICSU Subventions	27 800
Special Subventions from International Organisations	57 374
Contributions from National Members	365 432
Sales of publications	1 568
Interests and Dividends	42 308
Other Income	13 080
TOTAL INCOME	**507562**
2. EXPENDITURE	
Business Meetings	
General Assembly, Executive Committee & Officers Meetings	28 421
Publications	18 591
Scientific Programmes and Activities	
Scientific Meetings; Symposia Colloquia	10 556
Grants to IUBS Scientific Programmes	106 153
Representations at scientific meetings	6 924
Contribution to other organisations	7 405
Scientific Activities of IUBS Scientific Members	25 000
Secretariat	
Salaries & Related charges	227 814
General Office expenses	47 479
Office equipment and supplies	7 027
Bank charges & Loss over Exchange	2 520
Audit fees	5 723
TOTAL EXPENDITURE	**493 613**
EXCESS OF INCOME OVER EXPENDITURE	**13 949**

PUBLICATIONS REVIEW

CONSERVATION AND MANAGEMENT OF TROPICAL RAINFORESTS
An integrated approach to sustainability

By E.F. Bruenig, published by CAB International. (1996) 352 pages.

The richness and diversity of tropical rainforests species have been acknowledged for centuries, and measures to protect endangered species within this ecosystem were thought necessary since the mid-19th century.

Since the 1920s commercial greed, political misdemeanour and the relentless increase in the human population have all posed increasing threats to the future of rainforests. This book describes the principles of integrated conservation and management that lead to sustainability. It identifies the unifying phenomena that regulate the processes within the rainforest and are fundamental to ecosystem viability. Many practical examples and field studies from Amazonia and South East Asia particularly Sarawak, are included.

ENVIRONMENTAL MANAGEMENT
Issues and Solutions

Edited by Michael Atchia and Shawna Tropp, published on behalf of UNEP by Wiley. (1995) 250 pages.

This volume has grown from a series of seminars on environmental management organized by the UNEP Environmental Education and Training Unit with contributions by over 50 specialist authors from 25 developing countries from various regions. Looking at the foundations and policies of sustainable development, the book describes the principles and processes of ecosystems and the basic environmental management tools, including funding possibilities that are required for environmental management.

ECOSYSTEM REHABILITATION

Edited by Mohan K. Wali, published by SPB Academic Publishing by The Hague, Netherlands. (1992) Vol. I, 230 pages and Vol. II, 388 pages.

"Ecosystem Rehabilitation: Preamble to Sustainable Development" represents an essential and comprehensive contribution to help meet the challenges posed to the world by sustainable development. Two volumes deal with (1) policy issues and (2) ecosystem analysis and synthesis. Both are very useful and necessary tools to help universities, research institutes, government agencies, consulting firms and industries, etc., that are associated with the environment and development sector.

PROTECTION OF THE HUMAN GENOME AND SCIENTIFIC RESPONSIBILITY

Edited by Michio Okamoto, Norio Fujiki and Darryl R. J. Macer, published in English and Japanese by Eubios Ethics Institute. (1996) 205 pages.

The Proceedings of the 1995 MURS-Japan/ UNESCO IBC Seminars held 15-21 October 1995, in Tokyo, Nagoya, Fukui and Kyoto, Japan. The first part includes a presentation of the UNESCO's approach to issues on Bioethics by Mrs. N. Lenoir. Summary reports include the Tokyo Panel discussion "Progress in Medicine and Medical Ethics", and Nagoya and Fukui sessions on Medical Geneticist's Responsibility, and perspectives on the Human Genome Project, Biotechnology and Ethics.