THE SOIL IS ALIVE!

PROTECTING SOIL BIODIVERSITY ACROSS EUROPE
WHAT IS BIODIVERSITY?

BIODIVERSITY is a term that describes the variety of all living organisms (plants and animals) in all environments.

The term BIODIVERSITY was invented in 1980 by three American scientists (Lovejoy, Norse and Mc Manus) for a project commissioned by President Jimmy Carter to track marine fish stocks.

LEVELS OF BIODIVERSITY

One can talk about diversity

- Within the level of species (e.g. organs, tissues, cells, etc.)
- Among species (e.g. cats, dogs, cows, sheep, etc. – the most understood concept)
- Among ecosystems (e.g. different plant species to a forest).

HOW MANY SPECIES ARE THERE ON EARTH?

According to some researchers the number of animal and plant species on the planet ranges from 5 million to 50 million. A commonly used estimate is 12.5 million.

Currently, only about 1.5 million species have been identified! In fact, our knowledge and understanding of many of these species is limited to their name, where they live and a few vital functions.

CONCLUSIONS

It is clear that additional studies are required to identify and understand the remainder of the species that inhabit our planet.
LOSS OF BIODIVERSITY

NATURAL RATE OF EXTINCTION

If the Earth was in equilibrium, the natural extinction rate (i.e. normal evolution) would be around 1 species for every million species per year. This means that around 12 species would disappear every year. However, this does not always happen!

MASS EXTINCTIONS

Evidence of mass extinctions of species on the planet can be found through the analysis of fossils. Five distinct mass extinction episodes have been identified:

1. The Ordovician Extinction, about 435 million years ago
2. The Devonian Extinction, about 360 million years ago
3. The Permian Extinction, about 240 million years ago, end of trilobites, placoderms
4. The Triassic Extinction, about 200 million years ago, 96 % of all marine species
5. The Mesozoic Extinction, about 65 million years ago, dinosaurs, ammonites

These mass extinctions were probably caused by natural factors such as large meteors, volcanic activity, evolution of insects, etc..

6th MASS EXTINCTION

Today we are experiencing the 6th Mass Extinction.

The current loss of species is estimated at between 15,000 and 30,000 a year!

Over the last 50 years hundreds of thousands of species have been lost.

This time the causes behind drastic environmental changes are not all natural but driven by:

- Increased human population
- Destruction and fragmentation of habitats
- Farming practices
- Invasion of exotic species
- Pollution
- Climate change

CONCLUSIONS

Without some control, by 2099 we will have reduced the number of species on the planet by 50-60%! Is this the greatest risk to life on Earth as we know it?
WHAT DO WE MEAN BY SOIL BIODIVERSITY?

The range of organisms present in soil.

The variety and variability among living organisms and the ecological complexes in which they occur.

Soil is the medium for a large variety of organisms and interacts closely with the wider biosphere; the maintenance of fertile soil is one of the most vital ecological services the biological world performs as the mineral and organic contents of soil must be replenished constantly as plants consume soil elements and pass them up the food chain.
WHY IS SOIL BIODIVERSITY IMPORTANT?

Soil organisms are responsible for supplying the environment with a number of critically important ecosystem goods and services:

- Food
- Decomposition of organic matter to minerals and nutrients
- Transformations of pollutants
- Cycles of essential elements such as nitrogen and carbon

Soil organisms have a positive effect on soil fertility and plant growth. However, the effect of changes to soil biota on ecosystem processes are mostly unknown!

Soil is under threat from increased human population, poor land management and pollution. The EU Thematic Strategy for Soil Protection sets out to safeguard soil across Europe.
HOW MUCH LIFE IS THERE IN SOIL?

In a handful of arable soil (around 200g), there will be approximately 0.5 g of living matter, most of which will be too small to be seen with the naked eye (i.e. micro organisms).

This ratio works out at 5 tonnes per hectare.

This is the equivalent of 100 sheep on one hectare!

The usual stocking rates for sheep on rough pasture is around 20 per hectare!

On grassland, the amount of soil biota is about 20 times greater = 2000 sheep per hectare!
A HANDFUL OF SOIL IS ALIVE!

Within soil there is a whole world of organisms, animals and plants that is mostly unknown to us. This black box is essential for life and should be preserved or protected.

Biodiversity and Soil Health

The relationship between the health of the soil and biodiversity is not completely clear. However, a medium to high level of biodiversity usually indicates a healthy soil. But how do you measure what lives in the soil? Researchers are developing new and novel methods to assess soil biodiversity.
SOIL AS A HABITAT

THE UNDERGROUND LABYRINTH

Soil is a very complex habitat in its own right.

Soil organisms need a space for living.

Most organisms are found in the top 2-3 cm of soil to coincide with the highest concentrations of organic matter.

WHO LIVES WHERE?

Earthworms and mammals are able to burrow through the soil.

Fungi can form a mat of hyphae, which can extend for metres through the soil.

Bacteria tend to accumulate inside soil aggregates because they are less likely to be eaten by predators such as protozoa and mites.

Bacteria can be carried deep into the soil by percolating water.
SOIL AS A HABITAT

THE PORE NETWORK!
While it looks solid, soil is full of space to live if you are very small.

This space can be determined by the structure and texture of the soil. Many creatures create their own spaces by burrowing.

Clay soil often has more bacteria than sandy soil because clay creates lots of small pores (spaces) which offer protection for bacteria.

THE ROOT ZONE

The rhizosphere is the part of soil that is influenced by the roots of plants.

Many soil organisms prefer to live close to the roots of plants.

Plant roots release organic compounds into the soil. These compounds, called exudates, increase the availability of nutrients in the rhizosphere and also provide a source of carbon for heterotrophic microorganisms.

Thus, the number of microorganisms in the rhizosphere is greater than in the rest of the soil.
THE SOIL IS ALIVE!

THE SPATIAL SCALE
OF SOIL BIODIVERSITY FUNCTIONS

Global level:
• Biogeochemical cycles (organic matter mineralization, nitrogen fixation, etc);
• Value of future possible but as yet unknown uses or functions associated with some aspects of soil diversity.

Regional/national level:
• Ensure short term and long term resilience of food security;
• Increases the aesthetic appeal of rural landscapes, assuming a positive relation between below- and above-ground diversity.

Farm level:
• Contributes to the productive capacity of the system by ensuring the mineralisation of nutrients from organic resources and nitrogen fixation;
• Buffers the functions of the soil and their resilience to climatic and environmental risks.

(Modified from Izac A.M.)
BACTERIA: MINUTE ENGINES OF LIFE

Bacteria are tiny, one-celled organisms – generally 1 µm wide (0.000001 mm!) and a little longer in length. Bacteria are not visible to the naked eye but they are present everywhere!

Most bacteria are decomposers that consume carbon compounds, such as fresh plant litter. By this process, bacteria convert energy in soil organic matter into forms useful to the rest of the organisms in the soil food web. Some bacteria can break down pesticides and pollutants in soil. Bacteria are especially important in immobilizing, or retaining, nutrients in their cells, thus preventing the loss of nutrients, such as nitrogen, from the rooting zone.

Some bacteria affect water movement by producing substances that help bind soil particles into small aggregates. Stable aggregates improve water infiltration and the soil’s water-holding ability.
SOIL FUNGI

Fungi are microscopic organisms that usually grow into long threads or strands within the soil. These threads which are normally only a few micrometers in diameter are called hyphae, but a single hypha can be several metres long.

Some hyphae form a mass called mycelium or thick, string-like rhizomorphs that look like roots. Mushrooms are the ‘fruit’ of fungi. Mushrooms have special gills-like structures on which spores form. A single fungus can include many mushrooms across an area as large as a football pitch.

Fungi perform important services related to water dynamics, nutrient cycling and disease. Along with bacteria, fungi are important decomposers in the soil food web. They convert hard-to-digest organic material into forms that other organisms can use. Fungal hyphae bind soil particles together to create stable aggregates that increase water infiltration and soil water holding capacity.
Protozoa are single-celled animals that feed primarily on bacteria, other protozoa, soluble organic matter and sometimes fungi.

They are several times larger than bacteria – ranging from 5 to 500 µm in diameter.

As they eat bacteria, protozoa release excess nitrogen that can then be used by plants and other members of the food web.

Amoebae are a type of large protozoa.

Nematodes are small cylindrical worms that are very numerous in the top layers of soil.

Nematodes are by far the most numerous invertebrates to be found in soil, both in terms of the number of individuals and for the huge range of species.

They are able to adapt to almost all habitats.

Nematodes can cause substantial economic losses in agriculture not only as a result of a decrease in the yield of crops but also in the cost of fumigants to sterilize the soil.
ARTHROPODS

Arthropods are invertebrates (i.e. they have a hard external covering called an exoskeleton instead of a backbone). They get their name from their jointed (arthros) legs (podos).

Arthropods range in size from microscopic to several inches in length. They include insects such as springtails, beetles, and ants; arachnids such as spiders and mites; myriapods such as centipedes and millipedes; and scorpions. Crabs and other crustaceans are also arthropods.

Based on their functions in soil, arthropods can be grouped as shredders, predators herbivores or fungal-feeders (see mites, left). Most soil-dwelling arthropods eat fungi, worms or other arthropods.

This springtail (Collembola), below-right, is a fungal-feeding arthropod that lives in the surface layer of natural and agricultural soil throughout the world while millipedes, below-left, are shredders, chewing up dead plant matter.

As they feed, arthropods aerate and mix the soil, regulate the population size of other soil organisms and shred organic material.

Karl Ritz
Joseph Calev
Steve Hopkin
David Walter
EARTHWORMS

Earthworms are soft, thin invertebrates (no backbone) and are probably the most well known of the creatures that live in the soil. They are major decomposers of dead and decomposing organic matter and derive their nutrition from the bacteria and fungi. They fragment organic matter and make major contributions to recycling the nutrients.

Earthworms occur in most temperate and many tropical soil type.

There are more than 7,000 recorded species.

They range in length from 1 – 40 cm and are found at all depths in the soil.

In terms of biomass and overall activity, earthworms dominate the world of soil invertebrates, including arthropods.

Earthworms perform several beneficial functions to soil. They dramatically improve soil structure, water movement, nutrient dynamics and plant growth. Their presence is usually an indicator of a healthy system.
SOIL FOOD WEB – ENERGY IN THE SOIL

The soil food web is the community of organisms living in the soil. The food web diagram below shows the series of conversions of energy and nutrients (represented by arrows) as one organism eats another!

Primary producers (e.g. plants, lichens, moss, bacteria, …) use the sun’s energy to fix carbon dioxide from the atmosphere. Most other soil organisms get energy and carbon by consuming organic compounds found in plants, other organisms, and ‘waste’ products.

Soil organic matter is a storehouse for the energy and nutrients used by plants and other organisms. Bacteria, fungi, and other soil dwellers transform and release nutrients from organic matter.

Soil organisms play a role in the conversion of soil organic matter to humus, a relatively stable form of carbon that can be sequestered in soil for decades.
### THE ECONOMIC VALUE OF SOIL BIODIVERSITY

<table>
<thead>
<tr>
<th>Activity</th>
<th>Soil biodiversity involved in such activity</th>
<th>World economic benefits of biodiversity (x $10^9 / year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste recycling</td>
<td>Various saprophytic and litter feeding invertebrates (detritivores), fungi, bacteria, actinomycetes and other microorganisms</td>
<td>760</td>
</tr>
<tr>
<td>Soil formation</td>
<td>Diverse soil biota facilitate soil formation, e.g. earthworms, termites, fungi, etc</td>
<td>25</td>
</tr>
<tr>
<td>Nitrogen fixation</td>
<td>Biological nitrogen fixation by diazotroph bacteria</td>
<td>90</td>
</tr>
<tr>
<td>Bioremediation of chemicals</td>
<td>Maintaining biodiversity in soils and water is imperative to the continued and improved effectiveness of bioremediation and biotreatment.</td>
<td>121</td>
</tr>
<tr>
<td>Biotechnology</td>
<td>Nearly half of the current economic benefit of biotechnology related to agriculture involving nitrogen fixing bacteria, pharmaceutical industry, etc</td>
<td>6</td>
</tr>
<tr>
<td>Biocontrol of pests</td>
<td>Soil provide microhabitats for natural enemies of pest, soil biota (e.g. mycorrhizas) contribute to host plant resistance and plant pathogens control.</td>
<td>160</td>
</tr>
<tr>
<td>Pollination</td>
<td>Many pollinators may have edaphic phase in their life-cycle</td>
<td>200</td>
</tr>
<tr>
<td>Other wild food</td>
<td>For example mushrooms, earthworms, small arthropods, etc</td>
<td>180</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1,542</strong></td>
</tr>
</tbody>
</table>

*Total estimated economic benefits of biodiversity with special attention to the services that soil biota activities provide worldwide* (modified from Pimentel et al., 1997)
Crops are threatened by soil-borne disease, that can cause severe yield decrease and economic damage.

Soil has the potential to limit the effect of soil-borne diseases. This suppressiveness is a major component of soil health.

Suppressive soils can be defined as soils in which the severity of a disease or incidence remains low, in spite of the presence of a pathogen, a susceptible host plant and climatic conditions favourable for disease development.

There is some evidence to suggests that soil biodiversity confers disease suppressiveness.
SOIL BIODIVERSITY AND MEDICINES

While many people recognize the important duties that soil performs in our everyday lives, most do not realize that soil has also served as an important source of commonly used antibiotics.

Soil is indeed almost a perfect laboratory for the creation of natural medicines.

Actinomycin, neomycin and streptomycin are common antibiotics derived from soil actinomycetes.

Many scientist are looking at soil biodiversity, especially in remote areas, in an attempt to find the most promising medicines for the future.
FINDING OUT ABOUT SOIL BIODIVERSITY IN YOUR GARDEN

Moles are members of the mammal family *Talpidae*. An 80g mole needs 50g of earthworms per day. Moles can be beneficial to people by preying on harmful insect larvae while tunnels help drain and aerate heavy soil. Molehills are a sign of a healthy soil.

Count earthworms by pouring a solution of mustard and water on the soil allowing it to percolate down. The mustard solution irritates the skin of earthworms and they come to the surface to avoid it. Then they can be collected and identified.

Cut a plastic bottle in half. Insert the neck of the bottle into the base as a funnel and seal the join with tape. Bury the bottle in the ground with the opening flush with the surface. Leave overnight. In the morning, see who has dropped in!

Arwyn Jones
Erika Micheli
Marcin Pawinski
THE SOIL IS ALIVE!

The BIO-BIO Project: Assessing the health of soil through biodiversity and bio-indicators

The JRC’s unique BIO-BIO project, attempted to assess soil health by using an innovative approach that involved an assessment of biodiversity and the use of bioindicators in close combination with chemical and physical analysis of soil in relation to the use of the soil.

An experiment was set up in northern Italy to study the effects of three different land uses on the biodiversity of a single soil type.

- Soil treated with sewage sludge and cultivated with corn
- Soil treated with manure and cultivated as pasture (mixed grass)
- Soil treatment with farmyard compost (biodynamic) with crop rotation

Key soil properties (e.g. pH, water content, etc.), heavy metals, trace elements, pollutants, bacteria, protozoa, nematodes, arthropods, earthworms and clover (plants may have changes in DNA induced by pollutants in the soil) were measured four times a year at three layers (0-5 cm, 5-15 cm, 15-30 cm).

CONCLUSIONS

The study showed that biodiversity levels remained constant for the plots treated with manure and farmyard compost.

A reduction in biodiversity was observed in the plots treated with sewage sludge together with a slight increase in the concentration of heavy metals and dioxins.

The relationship between soil health, soil biodiversity, climate, soil type, land use and the levels of contaminants can only addressed through a multi-disciplinary approach.

Further work is required to establish European standards to measure soil biodiversity.

For more information on the Bio-Bio Project, please contact roberto.cenci@jrc.it
REDUCING THREATS TO SOIL BIODIVERSITY

The EU Thematic Strategy for Soil Protection encourages the sustainable use of soil.

To minimize threats to soil biodiversity, the Strategy proposes:

**Increased organic matter content:** Regular additions of organic matter improves soil structure, enhances water and nutrient holding capacity, protects soil from erosion and compaction and support a healthy community of soil organisms. Practices such as leaving crop residues in the field, crop rotations that include high residue plants, applying compost and low or no tillage systems increase organic matter content.

**Reduce tillage:** Less ploughing reduces the loss of organic matter and protects the soil surface with plant cover. Tillage breaks up soil structure, destroys the habitat of soil organisms while increasing decomposition rates, the loss of organic matter and the threat of erosion.

**Limit agro-chemicals:** Pesticides and chemical fertilizers have valuable benefits but can harm soil organisms. Even nutrients from organic sources can pollute when mis- or over-applied. Non-chemical approaches to pest and nutrient management are increasingly used.

**Prevent soil compaction:** Compaction of the soil by repeated traffic, heavy machinery, or travelling on wet soil reduces the amount of air, water, and space available to roots and soil organisms. As remediation is difficult or impossible, prevention is essential.

**Minimise the risk of erosion:** Bare soil is susceptible to wind and water erosion, drying and crusting. Vegetation protects soil, provides habitats for soil organisms and can improve water availability. The soil can be protected by leaving crop residue on the surface or by planting cover crops. In addition to ground cover, living cover crops provide additional organic matter, and continuous cover and food for soil organisms.
THE SOIL IS ALIVE!

For further information on what you have seen here, please contact:

Luca Marmo  
European Commission  
Environment Directorate-General  
Brussels, Belgium  
Tel.: +32 2 299 63 61  
Fax.: +32 2 298 88 41  
E-mail: luca.marmo@ec.europa.eu

Claudia Olazabal  
European Commission  
Environment Directorate-General  
Brussels, Belgium  
Tel.: +32 2 299 04 41  
Fax.: +32 2 298 88 41  
E-mail: luca.marmo@ec.europa.eu

Arwyn Jones  
European Commission  
Joint Research Centre  
Ispra, Italy  
Tel.: +39 0332 78 9162  
Fax.: +39 0332 78 6394  
E-mail: arwyn.jones@jrc.it

Roberto Cenci  
European Commission  
Joint Research Centre  
Ispra, Italy  
Tel.: +39 0332 78 9771  
Fax.: +39 0332 78 6394  
E-mail: roberto.cenci@jrc.it

Ciro Gardi  
European Commission  
Joint Research Centre  
Ispra, Italy  
Tel.: +39 0332 78 5015  
Fax.: +39 0332 78 6394  
E-mail: ciro.gardi@jrc.it

Professor Karl Ritz  
Cranfield University  
Cranfield  
United Kingdom  
Tel.: +44 1234 759064  
E-mail: k.ritz@cranfield.ac.uk

Professor Gabriele Broll  
University of Vechta  
Vechta  
Germany  
Tel.: +49 4441 15 334  
E-mail: gbroll@ispa.uni-vechta.de

Dr Ulfert Graefe  
Institut für Angewandte Bodenbiologie  
Hamburg  
Germany  
Tel.: +49 40 593308  
E-mail: ulfert.graefe@ifab-hamburg.de

Dr Paul Stegmann  
University of Applied Sciences  
Osnabrück  
Germany  
E-mail: p.stegmann@fh-osnabrueck.de

Mr Reinhard Gierse  
European Land and Soil Alliance  
City of Wuppertal  
Germany  
E-mail: reinhard.gierse@stadt.wuppertal.de

European Commission: Environment  
http://ec.europa.eu/environment/index_en.htm

European Commission: JRC – SOIL  
http://eusoils.jrc.ec.europa.eu