



The factory of life

Why soil biodiversity is so important

soil



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Foreword

Protecting soil, a pressing challenge for 2010 and beyond

In this UN International Year of Biodiversity, 2010, there is one large but often forgotten section of global biodiversity that should be ignored no longer: soil biodiversity.

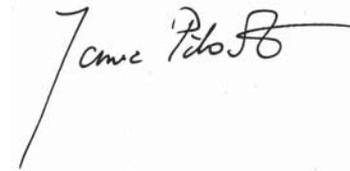
A healthy soil depends on a vibrant range of life forms living below the ground, from bacteria and fungi to tiny insects, earthworms and moles. Together, this rich biodiversity brings immeasurable benefits to life on Earth. It plays a vital role in mitigating climate change, storing and purifying water, providing antibiotics and preventing erosion. The well-being of all plants and land-based animals depends on the complex processes that take place in soil.

Biodiversity loss and climate change are two of the most pressing challenges of our time, and soil biodiversity is part of the solution to both. Yet it is under constant threat, largely from human activities that we can control. It is our responsibility, therefore, to preserve the quality of soil before it is too late, and before its resident species and their fragile habitats are lost. That is why, at the European Commission, we have put soil at the heart of our thinking.

As an integral part of its Soil Thematic Strategy, the European Commission has proposed a Soil Framework Directive in an attempt to prevent further soil degradation across the European Union, and to repair the damage that has already been done. This is a growing problem, and unless we tackle it soon and in a coordinated manner, it will cost a lot more to put right. We hope that we will soon be able to agree on the best way forward to tackle this problem, and take the opportunity of the International Year of Biodiversity to finally approve the Directive.

As we celebrate life on Earth and the value of biodiversity to our lives during 2010, let us take time to look beneath our feet, to discover and prize this unfamiliar world.

Janez Potočnik
European Commissioner for the Environment



Welcome to the factory of life

Unless we are gardeners or farmers, most of us pay little attention to soil, except to wipe it off our feet after a walk in the countryside or complain if it gets brought into the house.

But it is time to get acquainted with this precious non-renewable resource. Soil is in danger, and our lifestyle is largely to blame.

The great strength of soil comes from the life that exists within it – soil biodiversity – ranging from genes and species to communities. A single teaspoon of garden soil may contain thousands of species, millions of individuals and a hundred metres of fungal networks. Scientists estimate that at least about one-quarter of species on planet Earth live in soils.

This diverse ecosystem performs a variety of functions. It processes waste organic matter to sustain life above the ground, from plants to animals to humans; it regulates the carbon flux and the water cycle; it keeps pests at bay and decontaminates polluted land; and it provides raw materials for new pharmaceuticals to tackle infectious diseases.

Fact

Soils are home to over a quarter of all living species on earth.

This is the factory of life. Its workers are micro-organisms, small and large invertebrates, small mammals, even plant roots – their workplace is the dark or dim layers of topsoil beneath grasslands, fields, forests and green spaces in towns.

Fact

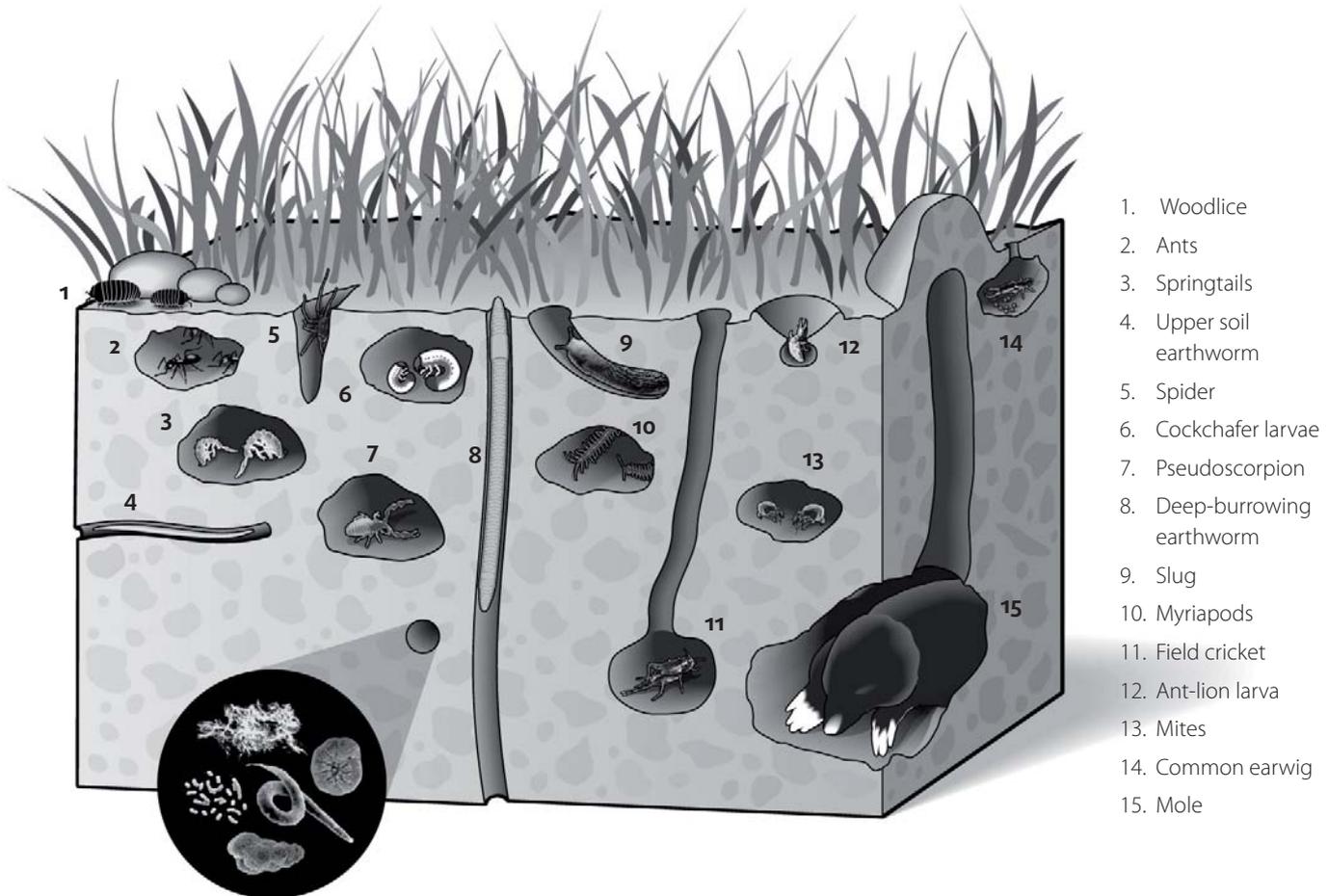
Only 1% of soil micro-organism species have been identified.

But the factory is in crisis. While other vital resources such as water and air are constantly being recycled and regenerated, soil formation can take decades, even centuries. If the factory of life breaks down, it is immensely difficult to get it up and running again.

In the following pages, we examine what takes place in this fascinating environment, the stars of its little-known community of creatures, threats to their habitat on a local and global scale, and what is being done to address the problem through legislation and scientific research. Join us on this voyage of exploration to discover the riches provided by the factory of life.



Presenting you some of the workers in the factory of life



Workers in the factory of life come under the microscope:
bacteria, nematode, fungal mycelium, protozoans.

What the factory does

Beneath our fields and our feet, an eclectic community of soil organisms toil day and night in a remarkable, coordinated effort that sustains life on Earth. These are the main services delivered by the soil factory, as we understand it so far.

The main business of the factory of life is to create and refresh soil, the most essential food source on the planet. It provides the nutrients that plants need to grow and sustain animals, including by producing our own food, textile fibres, wood and ingredients for pharmaceuticals.

Fact

In an area the size of a football field, soil organisms produce organic matter equivalent to the weight of 25 cars every year.

The soil depends on the presence of a vast community of living organisms to stay fertile. These organisms constitute soil biodiversity. When supplied with sufficient raw material, in this case dead organic matter, they get to work decomposing the waste to produce humus – complex organic matter with the nutrients necessary to sustain plants. Humus cannot be man-made. It is created by soil biodiversity.



Common terrestrial arthropods like *Entomobrya nivalis* play a role in decomposition.



The male field cricket (*Gryllus campestris*) builds a burrow up to 30cm deep.

The work of the factory may never have been more important than it is today. As the global population heads towards nine billion by mid-century, healthy soils will be critical to our future food supply – all the more so given the growing pressures on land, for urban expansion, biofuels production and natural resources extraction, as well as the ongoing land degradation due to organic matter loss, erosion, desertification and other causes.

Structuring the soil and contributing to climate regulation

Soil organisms work the sand, clay or silt, forming new structures and habitats which aerate the soil and allow water to permeate through it. Some species of fungi, for example, produce a sticky protein that binds soil particles together, thus stabilising soil aggregates, while larger creatures like termites drive tunnels through the soil.

The work done by soil organisms also enables soil to store and release carbon, helping to regulate the flux of greenhouse gases



and thus the global climate system. This has a direct impact on human health, crop productivity, water resources and food security.

Soil stores carbon mainly in the form of organic matter, and is the second largest carbon pool on Earth, after the oceans. The more organic matter there is in soil, the better a carbon sink it can be. A well-managed soil can thus be an important buffer against climate change.

Different types of soil have different carbon storage capacities. Peatland soils, for example, cover only a fraction of Europe's land area, but store 20% of all soil carbon in Europe. Grasslands and forests accumulate carbon in their soil, while croplands often tend to release it. In Europe, the largest emissions of CO₂ from soil are due to land-use change from grasslands to arable land, and to intensive tillage without the addition of organic matter.

Soil organisms play a major role in processing the organic matter in soil. And some even incorporate it into the soil themselves. For example, dung-beetles are able to bury dead bodies of small animals in the soil, thus making their organic matter available as a food source for their own larvae as well as for other soil organisms. Earth worms can mix litter from surface layers through the soil underneath.

Storing and purifying water

A similarly vital role of the below-ground factory of life is to purify and store water. As water infiltrates the ground, contaminants

Fact

Soils without earthworms can be 90% less effective at soaking up water.

including bacteria and viruses are absorbed by soil particles, making the water both clean and safe. However, this purification capacity depends on the soil being rich in micro-organisms, which perform the work. The more biodiversity in soil, the better this function can be performed.

Fact

Land without vegetation can be eroded more than 100 times faster than land covered by vegetation.

Meanwhile, channels, nests and galleries created by earthworms, ants and termites all promote water absorption, while vegetation, with its leaf litter and root systems, helps to capture water and to structure the below-ground soil. Cutting back vegetation, for example by deforestation, does the opposite, allowing soil to be washed away. Without a vibrant soil community, the soil becomes poor in structure and water run-off increases, leading to erosion and flooding.

If the soil's ability to absorb, cleanse and store water is compromised, groundwater will be impaired, and more water treatment facilities will be required. Maintaining the soil's ability to process and cleanse water will save money and safeguard health and well-being.

Cleaning contaminated land

Few people are aware that soil organisms have the remarkable ability to clean up certain types of pollution, or at the very least dilute their impact. In a procedure called bioremediation, microbes in the soil are able to decompose some organic pollutants and convert them to non-toxic molecules.

Bioremediation is a natural process which has been frequently harnessed by humans. It is the cheapest method of soil decontamination and has proved effective in numerous cases. One famous example was the clean-up of the *Exxon Valdez* oil tanker spill in Alaska in 1989. As part of efforts to clean crude oil from 2 000 km of coastline, a mix of nutrients and fertilisers which encouraged bacterial growth was applied to the contaminated sand and sediment. The bacterial activity led to a five-fold increase in the rate of oil degradation, and an efficient site clean-up, although the oil spill caused death to many marine and shoreline animals.

Fact

Earthworms can enhance bioremediation, as they regulate the activity and distribution of microbes in the soil.

Toxins that can be removed from the soil by natural bioremediation include chemicals used in wood treatments, solvents used in dry-cleaning, agricultural pesticides and even polychlorinated biphenyls – now banned substances which were formerly used in plastics and electrical components.

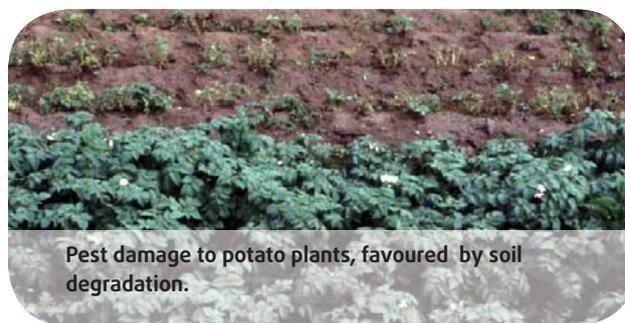
A soil rich in biodiversity is essential to obtain the best results from bioremediation. While micro-organisms work on the chemical pollutants, other organisms that control the structure and porosity of soil help it to absorb, disperse and degrade contaminants.

Natural soil decontamination does have its limits, of course. The process can take years, if not decades, since some persistent pollutants cannot be broken down and sometimes the contamination load is simply too great for the soil. In addition, heavy metals such as cadmium, lead and mercury cannot be degraded and have been found to accumulate in the food chain or to contaminate ground water. Soil may offer its services as a natural detoxifier, but we cannot expect it to work miracles.

Controlling pest outbreaks

Factories run best when the full complement of workers is occupied with the task they are skilled to do. The problems start when, due to absence or skills shortage, there are not enough hands available to do the job. Machines sit idle and production grinds to a halt. Exactly the same happens in the soil factory. Different species are able to replace each other to a certain extent, standing in for one another if one is made redundant or falls sick, for example. But if half the workforce falls ill, output will suffer seriously. Keeping a broad cross-section of staff healthy is important for the benefit of each of them, as well as for the overall functioning of the factory.

One consequence of breakdown in the factory of life is pest outbreak, which can mean crop destruction on a massive scale, a potential disaster for human communities. For example, it is estimated that the value of potato crops in the UK at risk from the Colorado beetle is of the order of around €322 million.



Pest damage to potato plants, favoured by soil degradation.

A soil rich in biodiversity is better able to control pests, since it contains both a range of predator species and a varied supply of nutrients. While some nutrients may support the pest species, others will be detrimental to it. In general, a more diverse ecosystem has a better balance of species and a greater capacity to impede pest development.

Pest outbreaks are common in cultivated fields of monocultures, where soil functioning is modified. In contrast, diverse vegetation supports natural communities and reduces the impact of pests.

Harnessing this natural pest-control service can also replace the need for broad-spectrum pesticides which, as well as harming beneficial insects, can have many other unintended – and costly – consequences.

Providing life-saving medicines

In 1928, the Scottish biologist Alexander Fleming noticed that a soil fungus growing in his laboratory was inhibiting the growth of a nearby culture of staphylococcus bacteria. He deduced that something in the fungus must have been killing the infectious bacteria, and shortly afterwards isolated penicillin. Antibiotics containing penicillin were the first drugs capable of treating many serious diseases and are still used today.

The soil is like a great medicine cabinet for the future, where micro-organisms such as bacteria and fungi are constantly producing genetic compounds to fight other microbes. Scientists are permanently on the lookout for previously unknown soil species, as the unique survival strategies of any one of them may offer the potential to create a new life-saving pharmaceutical.

This is particularly important work since, due to their nature, bacteria divide very quickly and are able to evolve and mutate to



Soil and its micro-organisms are an important part of humanity's medicine cabinet.

survive. This brings its own problems, as many bacteria are now resistant to penicillin: at least 90 000 deaths a year in the US alone are attributed to bacterial infections, more than half of which are resistant to at least one common antibiotic.

What's a worm worth?

Various methods have been used to estimate the economic value of soil biodiversity; all of them have concluded that the cost of protecting soil biodiversity is money well spent.



Earthworms help to aerate soil and allow water to penetrate.

One way to calculate value is to consider the price of final articles (food, fibres, raw materials) that soil organisms help to produce; another is to look at their utility, by asking people about their willingness to pay for services provided. A further option is to identify the cost of an alternative product that fulfils the same function – for example, the cost of fertilisers and pesticides to replace the services provided by soil organisms; the cost of repairing damage caused in the absence of a healthy ecosystem, such as erosion or flooding; or the costs of preventing negative impacts in the first place.

A US study in 1997 calculated the worldwide economic value of soil biodiversity at around \$1.5 trillion per year. Calculations made at a national level include an Irish study which estimated the value of soil fertility and nutrient cycling in the country at €1 billion annually; while in France, the carbon stock in grassland soils is thought to be worth €320 per hectare per year.

Who works in the factory?

The factory of life is a hive of below-ground activity, home to an incredible number and variety of organisms. It rarely stops: workers consume and process waste organic matter – and each other – to create a renewed and refreshed soil that is packed with minerals and nutrients essential for plant growth.

Although many soil organisms have yet to be identified, our understanding of their role and importance is increasing as we discover how they interact with each other and their surroundings in a complex and interdependent system.

Soil organisms can be classified into three main groups which describe the principal function they perform in the soil: chemical engineers, biological regulators and ecosystem engineers.

In our factory of life, chemical engineers are like workers on the factory floor, the smallest organisms in soil. They decompose organic matter, like leaf and plant litter, and transform residues into nutrients, such as nitrogen, phosphorus and sulphur.

Biological regulators can be likened to factory supervisors. They regulate the abundance and activity of chemical engineers, mainly through feeding, which enhances or reduces the productivity of the system.



The ant-lion larva digs a pit in the earth to trap its prey.

Ecosystem engineers are the factory's architects and builders. They design the structure of soil that enables the other groups to thrive, building passages, tunnels and pore networks and transporting particles around the bustling subterranean community.

Fact

One gram of soil can contain around 1 million individual fungi, while some species can reach lengths of several hundred metres.

The workers

The 'chemical engineers' in soil include all organisms that decompose organic matter. They are able to break down and transform carbon and nitrogen molecules into carbon dioxide and the nutrients plants need. Their activity sustains the growth of all living organisms, from plants to the animals (including humans) that feed on them.

But they depend on particular conditions for their survival and growth, including moisture, air and pore spaces between particles of sand, clay or silt. They are most prevalent where there are significant quantities of organic matter or animal manure, and around roots.

The smallest soil organisms, bacteria and fungi, make up the largest population of this group, which also includes algae and viruses.



Bacteria can double their numbers in minutes.

Bacteria live in the water-filled pores in soil. They reproduce rapidly and can double their population in minutes. But they can also enter a dormant stage and come back to life after a period of years. Their Prince Charming may come in the guise of a plant root, pushing them into a fertile new environment, or an earthworm, whose gut provides the ideal conditions to reawaken them. **Fungi** comprise an eclectic group that vary from single-celled yeasts to complex structures visible to the naked eye, as in the case of mould on fruit. They inhabit the spaces around soil particles, roots and rocks. Some species recycle dead or decaying organic matter, while others break up sugars, starches and cellulose in wood.

The supervisors

The group of soil organisms known as ‘biological regulators’ are a diverse bunch which control the activities of the lower order of factory workers, the chemical engineers, and form a crucial link in the food web. Some act as plant pests and parasites, while others activate microflora. At the same time, their movement around the soil helps to fragment organic material, creating more surface area and thus boosting the nutrients available to microbes.

Protists are the smallest in this group. They live in the water layer around soil particles and control bacteria populations through feeding. They can propel themselves by means of tiny oar- or

flipper-like body parts and can be transported by wind as well as water while in a dormant phase.

Nematodes are tiny worm-like creatures, most of them measuring up to 1mm long. They are highly adaptable and found in all types of soil, including extreme environments in Antarctica and the deep ocean. Their prey varies from algae, bacteria and fungi to plant roots, other nematodes and protists.

Fact

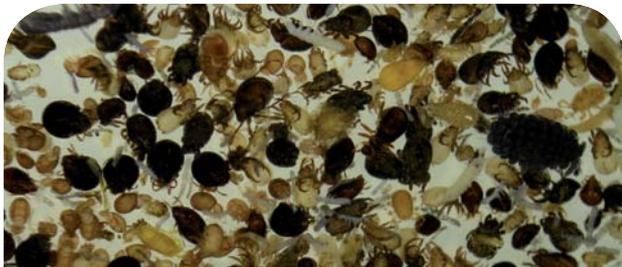
Bacteria are thought to be the most species-rich group of organisms on Earth, and the vast majority of them live in the soil.

Microarthropods are small invertebrates (animals without a backbone) which mainly inhabit topsoil, feeding on decaying vegetation, bacteria and fungi, as well as their fellow ‘supervisors’. They vary in size from microscopic (certain mites) to several millimetres in length (springtails, for example, which hop around using their tail as a spring).

Just as for chemical engineers, the presence of biological regulators in the soil depends on soil type, water availability and cultivation practices. Their ability to grow and reproduce fluctuates with



Nematodes are found in all soils.



Many species of microarthropods live in topsoil.

the season and available resources. Protists and nematodes that feed on bacteria, flourish in the few weeks after organic matter is added to the soil, for example. They can then enter a period of rest or dormancy.

Fact

Termites have air-conditioning in their nests.

The architects

The builders in our factory of life – the ecosystem engineers – spend their lives restructuring the factory's various departments, mixing and moving soil as they graze, and creating habitable spaces and conditions for other soil organisms. Their indirect contribution to nutrient cycling plays a key role in improving soil fertility and plant production.

Earthworms, termites, ants, isopods (such as woodlice) and plant roots all fall into this group, as do millipedes, centipedes, beetles, caterpillars and scorpions. Part-time soil residents such as voles,

snakes, lizards, mice and rabbits are also ecosystem engineers, moving the soil as they dig for food and shelter.

Earthworm casts and tunnels, termite mounds and ant heaps help aerate the soil and increase its porosity. This allows water to filter down, increasing the available habitat for other organisms. Earthworm casts also enhance the nutritional supply. Moisture and higher in nutrients than the surrounding soil, they are a favoured incubator for organisms in the chemical engineers group.



Moles

Moles are found everywhere in Europe except Ireland and in all types of soil deep enough for tunnelling, barring the compacted, semi-arid soil in coniferous forests. Moles can eat up to 100% of their body weight every day. They catch their prey – earthworms and other invertebrates – in networks of tunnels and traps created using broad forefeet perfectly adapted for burrowing.

Unlike moles, other burrowing mammals are just part-time soil residents, but still perform a valuable function in maintaining soil biodiversity. When shrews, voles and badgers tunnel for shelter, nesting or to avoid predators, they help to fertilise the soil by mixing faeces, plant litter and seeds into the topsoil. At the same time, their burrowing creates airways and passages through which water can enter the soil rather than run off.

Major threats to the factory's future

Healthy soil needs a healthy environment. Given the best raw materials and working conditions, the soil will function at full capacity, delivering a streamlined service and sustaining life above ground. But if it is deprived of what it needs – often as a result of human behaviour – soil biodiversity will be impaired, and its ability to work will falter. This chapter describes the causes and features of degraded soil.

Erosion strips the roof off the soil factory, damaging the complex organisation beneath. It occurs when the surface is scraped off the soil by wind and water, and affects many European soils, the result of farming practices, deforestation, overgrazing, forest fires and construction work. It is expected to worsen with climate change.

Fact

Each year, across the world, 75 billion tonnes of soil are stripped from the land by wind and water erosion, most of it from agricultural fields. This environmental damage can result in human disaster, as people are forced to leave their homes in search of fertile cropland.

Depleting the level of **organic matter** in soil amounts to starving all the below-ground workers. Converting a natural ecosystem such as a forest to farmland, for example, cuts the soil carbon pool by 50-75%, while inappropriate irrigation or removing biomass from fields (such as straw) strips nutrients from the soil and prevents the recycling and replenishing of

organic material that keeps soil organisms working. In nearly half of Europe's soil, organic matter accounts for below 2%, seen by some as critically low.

Salinisation, the accumulation of water-soluble salts in soil, is like a form of poisoning. The result of inappropriate irrigation or the excessive extraction of groundwater in coastal areas, it can push bacterial species into a dormant phase, and kill other soil organisms. The result is a decrease in plant growth and crop productivity, and an increased risk of desertification.



Only certain salt-tolerant plants can survive in these conditions.



Soil **compaction** crushes the factory of life. It is caused by both natural and human activities, particularly the use of heavy machinery in farming on wet soils. It causes air to be squeezed out of the soil, preventing water infiltration and destroying networks of tunnels and pores used by soil architects such as earthworms. This threatens all underground habitats and restricts the availability of nutrients.

Sealing, a term that describes any impermeable layer between the above-ground and below-ground environment, effectively suffocates the soil. The result of urbanisation and the widespread use of asphalt and concrete, it causes the death of most soil organisms. It can also damage areas beyond the local environment, as displaced water runs off to other areas where it may cause erosion and flooding.

As cities often flourish near land with high soil fertility, urban sprawl can eat into some of the most productive land available. Retaining semi-natural areas in urban zones and green roofing are two solutions that can combat the worst effects of sealing.

Land-use change

Just as a factory designed to make flowerpots cannot be transformed overnight into a carpet factory, so a forest soil packed with organisms that love to munch leaf and woody waste will take time to adjust to becoming pasture.

Different types of soil contain varying levels of biodiversity, some much higher than others. Grasslands support more biodiversity than other soils, followed by forests, croplands and urban land. The challenge is to manage each type in the most sustainable way to allow soil to thrive.



One-way ticket to desertification

When the damage to soil is irreversible, the result is **desertification**, a particular risk for soils with low levels of **organic matter**. It usually results from **excessive wind or water erosion or saltiness, or both**, and can be caused by **climatic conditions or human activities**. **Stripping away vegetation aggravates the erosion of topsoil and undermines the soil's ability to support plant growth.**

Desertification happens in stages. The damage to topsoil, plant and animal species happens first, then, as topsoil erodes, the possibility of restoring productivity is undermined. This downward spiral leads to greater desertification and ultimately leaves barren landscapes that will be out of production for generations.

- Grasslands represent 16% of EU territory and favour a high density of nematodes, microarthropods and diverse and abundant earthworm communities.
- Forests cover 35% of Europe's land, and have soil characterised by extensive root networks and layers of leaf litter, tending to host highly diverse soil communities.
- Croplands, which cover over a quarter of EU territory, are less favourable to soil organisms. Regular deep tillage and ploughing, the use of chemical fertilisers and pesticides, the removal of crop residues and the insufficient recycling of organic material,

such as manure and compost application, deprives the factory, of food and good working conditions and the soil of stabilising and fertilising source material.

- Urban areas cover about 5% of Europe and are expanding faster than the population. As well as problems of soil sealing and compaction, local biodiversity also has to contend with air pollution, heavy metal pollution and higher temperatures. In gardens and parks, the use of chemicals and the limited layer of organic waste on the soil surface add to the challenges for soil biodiversity.

Trends in land-use in Europe show a mixed picture for soil biodiversity, with elements both good and bad. Although rural areas are expected to decline over the coming decades, and urban areas to grow by 1% by 2020, forest area is expected to increase by 5% between 2000 and 2020 (although this does include monoculture plantations of lower ecological value), and organic farming, which places less strain on cropland biodiversity, is growing slowly but steadily.



Climate change

Climate change is expected to impact on soil organisms directly, by altering their habitat and food web, or indirectly, through increased erosion, droughts, wildfires and so on.

- Carbon storage and climate control: higher temperatures can promote the faster breakdown of organic material in soil, and



thus an accelerated release of carbon dioxide into the atmosphere. This will lead to further rises in temperature in a positive feedback cycle.

- Nutrient cycling and fertility: changes in CO₂ concentration, temperature and rainfall will impact on the availability of nutrients in soil. Warming can increase the nitrogen available to plants, while a combination of warming and higher rainfall has been shown to reduce the number of certain soil bacteria.
- Water control: fluctuations in temperature and rainfall are also likely to affect soil structure and acidity. This, in turn, will alter its ability to absorb and store water and sustain soil-dwelling organisms. Many species of soil organism are extremely sensitive to water availability: bacteria, which live in the water-filled pores of soil, as well as earthworms.
- Pest control: the more diverse the soil community, the better the pest control. If interdependent species are similarly sensitive to changes in the climate, the balance will be maintained; if they are not, the balance will be disturbed. Changes to the climate system will likely impact certain species more than others, which could compromise the soil community's ability to control pest outbreaks. Pests may be bacteria, fungi, nematodes, insects or invasive exotic plants, microbes and invertebrate animals; warmer temperatures generally favour insect pest populations.



Farming for soil biodiversity

Farmers, as custodians of much of the land, can play a crucial role in protecting soil biodiversity, since their choice of tools and techniques has an enormous influence on the factory of life.

Mulching, or covering soil, for example with crop residues or compost, helps retain heat, preserve moisture and prevent erosion. Organic mulches can be broken down by soil organisms and help to structure the pores and architecture of the underground factory, as well as sustain micro-organisms.

Applying well-rotted organic residues (manure or compost) to the soil provides food for soil organisms and a good structure for ecosystem engineers like earthworms.

The use of chemicals in farming, such as pesticides and fertilisers, can upset the delicate balance in the soil, supporting

one type of organism over another, and disrupting its varied functions, such as the ability to store carbon or water.

Crop choice is also significant. Legumes (peas and beans) act as natural fertilisers as they help fix nitrogen in soil. Other crops only take resources out of the soil, and if planted in succession may impair soil structure and deplete organic matter. Rotating the type of crops planted can help prevent the build-up of pathogens and pests, and preserve nutrients in the soil.

Meanwhile, field margins and boundaries can be managed to encourage biodiversity and bring it closer to crops. Hedgerows and grassy strips around fields provide stable habitats and food sources for organisms whose work in structuring the soil can help it combat pest outbreaks.

Other threats

Chemicals can affect soil organisms directly, with toxic effects on their reproductive ability and survival, or indirectly, by contaminating their food supply or habitat. Their effects may be short-lived or long-term, and impact some or all soil organisms.

As they affect different species in different ways, they can disturb the interactions within and among the classes of soil organisms.

Microbial organisms, the workers in this factory of life, reproduce very rapidly, and may develop resistance to a toxin, via natural selection, or even be able to transform chemicals into less-toxic compounds.

Biological regulators, meanwhile, have been found to suffer from exposure to industrial chemicals such as heavy metals and petroleum. Ecosystem engineers such as earthworms are very sensitive to pollution, whereas ants and termites are more resilient. This may be because worms swallow large quantities of soil and their skin is highly permeable to water. Cadmium, a metal found in certain types of fertilisers, can be extremely poisonous to earthworms and even fatal at very low levels.

Genetically Modified Organisms (GMOs) may impact on soil biodiversity and promote genetic resistance in the pest species they are designed to target. They can interfere with the structure and efficiency of bacteria in soil, and affect the soil's ability to decompose organic matter.



Invasive species disrupt soil processes and are an expensive nuisance: it costs billions of euros each year to control invasive species in Europe.

In the soil, invasive plants may be more resilient than natives to root herbivores and soil pathogens, and this will simply boost their invasiveness.

But soil biodiversity can also help tackle invasive species. The more abundant and varied the biodiversity, the more resilient it will be to invasion.

Helping to protect soil biodiversity

A broken-down factory of life means poor soils, a one-way ticket to poverty for the whole community, and no chance of rebuilding the complex organisation.

Yet while evidence of soil degeneration has been apparent for some time, we are still standing by, watching the soil factory fail



GMOs could disrupt the beneficial activity of bacteria.

as its structures fall into disrepair, fewer workers show up to clock in each day, and output falls.

In Europe, Member States have not been able to agree on how to preserve this source of our well-being, development and chances of future prosperity. Even efforts to combat biodiversity loss have largely overlooked the below-ground environment until now.

One recent initiative could be crucial to soil protection. Proposed by the European Commission in 2006, the **Soil Framework Directive** aims to establish Europe-wide legislation for the protection and sustainable use of soil, while leaving Member States the freedom to implement it as they see fit. Although this proposed Directive does not directly tackle soil biodiversity, it is expected to play a decisive role in its protection by addressing the main causes of soil degradation: erosion, sealing, contamination and the decline of organic matter. But European ministers have yet to achieve the agreement that would allow it to enter into force.

Other EU policies and initiatives may also help protect soil, although this is not necessarily their primary focus. Among the most relevant are:

- The Natura 2000 network of protected areas, created under the Habitats Directive and designed to preserve habitats and vulnerable species. Soil biodiversity tends to be higher in areas of conservation.
- The EU's LIFE funding instrument, which supports nature conservation projects. A small number of projects address soil biodiversity.

- A Directive on the use of pesticides, the Nitrates Directive and the Sewage Sludge Directive, each of which targets potentially harmful farm products and practices.
- The common agricultural policy (CAP), which now requires farmers receiving subsidies to incorporate environmental protection measures in their land management.
- The EU Forest Action Plan, which is intended to prevent land degradation resulting from land-use change, erosion, forest fires and landslides.
- The Water Framework Directive, in its efforts to reduce and prevent pollution and protect the aquatic environment.
- The Waste Framework and Landfill Directives, which require Member States to reduce the impact of waste on human health and the environment.
- The Regulation on organic production, which sets a framework for organic farming with greater focus on biodiversity and environmental protection.



'Out of sight, out of mind'

Soil organisms represent around a quarter of all biodiversity on Earth, yet are widely neglected in conservation efforts. Worldwide, only eight soil species are protected under CITES, the international rules on trade in endangered species: three scorpions, four tarantulas and one beetle. This is not because soil species are not endangered: it is simply because they are so little known and because their habitat and functioning are complex.

Quite simply, soil species are out of sight and out of mind. But taking steps to protect them may be doubly useful: while measures to protect above-ground species do not necessarily help below-ground biodiversity, efforts to protect soil communities are very likely to help conserve endangered plants and animals that are better-known. Policies that target soil biodiversity directly or indirectly by protecting their environment could therefore have a much greater impact than anticipated.

What else can be done to protect soil biodiversity?

Looking to the future, what can we do to save the factory of life from the worst impacts of our activities?

The complexity of soil biodiversity and the threats it faces suggest that we need to tackle the challenges on three main fronts. We need to overcome the widespread lack of understanding about what goes on beneath our feet; there needs to be support for further research; and we need policies aimed at protecting soil and soil biodiversity in particular.

Knowledge about soil life can be improved among policy-makers, conservationists and the general public alike. Wiped off our feet as a nuisance, soil is most often thought of for its physical and chemical characteristics, not for its biological features, the home and workplace for a massive community of life forms. In this International Year for Biodiversity and beyond, a great opportunity exists to highlight the pivotal role that soil biodiversity plays in sustaining all life on earth.

At the same time, we need to learn more about how the soil functions. At present, just 1% of bacterial and fungal species have been identified, compared to over 80% of plants. Fewer than 2% of nematode species are known to us, and just 4% of mites. Without knowing what actually lives down there, how can we possibly understand their role in keeping soil healthy? The more we know, the better we can predict trends and take remedial action. Despite all the research to date, there is no standardised system to allow comparison between different sites and plots, as well as over time. This could provide the basis for long-term monitoring, just as the quality of water and air is assessed. Some progress is being made: a research programme called ENVASSO

(Environmental Assessment of Soil for Monitoring) has proposed the building blocks for the first comprehensive, harmonised soil information system in Europe.

As for policy, the adoption of the proposed Soil Framework Directive would improve soil conditions across the EU, including for life below ground. And the EU Habitats Directive could be reinforced to better deal with soil biodiversity. In other policy areas, integration between different policy sectors could be enhanced, for example between agriculture and environment.

One thing is certain: a greater focus on incorporating below-ground habitats into rules and research can only help increase awareness of the factory of life. This may be the best chance we have of preserving it for the future.



Further reading on soil biodiversity

European Commission Directorate-General for Environment

http://ec.europa.eu/environment/soil/index_en.htm

European Commission Directorate-General Joint Research Centre

<http://eusoils.jrc.ec.europa.eu>

Report 'Soil biodiversity: functions, threats and tools for policy makers'

<http://ec.europa.eu/environment/soil/biodiversity.htm>

European Atlas of Soil Biodiversity

http://eusoils.jrc.ec.europa.eu/library/maps/biodiversity_atlas

Soil Atlas of Europe

http://eusoils.jrc.ec.europa.eu/projects/soil_atlas/index.html

Convention on Biological Diversity

<http://www.cbd.int>

FAO Soil Biodiversity Portal

<http://www.fao.org/nr/land/sustainable-land-management/soil-biodiversity/en>

World Soil Information Centre

<http://www.isric.org>

Global Soil Map

<http://globalsoilmap.net>

European Commission

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pseudoscorpion (*Chelifer cancrivorus*) - Christian Fischer;

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