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Soil – the final frontier

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An adventurous biologist could once bank on finding new species by simply travelling to some part of the world little known to science. Darwin's famous voyage round the world produced many species new to science, many of which bear the scientific name Somethingorother darwinii. In this article, ***Richard Fitter*** *of York University explains that there is still much to be discovered and understood beneath our feet.*

Calceolaria darwinii *found by Darwin in Tierra del Fuego on the Beagle voyage*

Darwin's fungus Cyttaria darwinii, *found growing on Southern Beech*

New species of plants and animals are still being found all the time: we have probably described fewer than 1 in 8 of all the insects on Earth, for example, and even new birds and mammals turn up occasionally. However, the biologist who really wants to find new species in droves should become a microbiologist and delve into soil, for that is the current frontier of taxonomy, the science that deals with describing, naming and classifying the millions of species on Earth.

How many microbes?

We don't know how many species of microbes there are on Earth; we cannot even make an educated guess, because no-one has yet found a useful way of defining what a microbial species is, but however we eventually define it, the answer is likely to be millions. Bacteria and many important fungi do not reproduce sexually in the complex fashion of most plants and animals. They are largely clonal organisms although they have many curious ways of exchanging genes. They also potentially have huge populations and short generation times, so that new types can appear quickly and persist easily.

Unlike plants and animals, microbes have very few visible characteristics that allow easy classification into species, but analysis of variation in their DNA has revealed their extraordinary diversity. Bacterial diversity can be enormous: using standard assumptions about how different DNA sequences need to be for them to have come from different species, there can be 10 000 different bacterial species in a single gram of soil. There is also great diversity in fungi and many of the smaller animals which abound in soil, such as nematodes, worms and springtails.

Two small animals found in the soil – earthworms and springtails.

In some cases, the number of species found in a single place is not far off the total number of species that have been described in the whole world. Some scientists believe that is because microbes and other very small creatures are universally distributed and what you find in one place depends on what can survive there, not what can get there – a famous aphorism in microbiology is 'everything is everywhere; the environment selects'. Molecular techniques, though, suggest that is not usually true: there really is huge, undescribed diversity in these organisms.

A question of conservation

Does it matter that we know so little about these small creatures? Is there an equal moral argument for conserving microbes and soil animals as there is for conserving conspicuous and charismatic species? We put great effort into sparing tigers from extinction, but we have no idea how many species in soil are at risk of extinction. Whatever your answer to that question, the real reason why we should worry about the possible extinction of unknown species in soil is because we as a species – and the rest of the living world on land at least – depend totally on healthy soils.

Soils provide us with food, because so much of our food comes from agricultural crops. They also act as huge stores of carbon, helping to protect us from our folly in pumping greenhouse gases into the atmosphere. They store, purify and regulate supplies of water: when soils are lost, floods follow quickly. All of these essential benefits that we get from soil are now known as ecosystem services and all of them depend on the organisms within soil, cycling nutrients, creating organic matter and building soil structure.

Soil under stress, then and now – buried machinery in the 'dust bowl' of South Dakota, USA, May 1936, and salination of agricultural land, San Joaquin Valley, California, 2010

Given our dependence on soil for our survival as a species, you might expect that we would both care for it and seek to understand how the 'soil machine' works. Sadly, our record here is not encouraging. Soil is being lost at an alarming rate, globally. Only about 10% of the Earth's land surface is suited for crop cultivation and the useful depth of soil on most of that land is less than 1 metre. It seems likely that we have already lost 10 cm of soil from agricultural land, due to poor cultivation methods, and the current rate of loss is probably around 4 cm per century, though it is certainly much higher than that in some parts of the world, such as south-east Asia.

Soil does get re-created naturally, but at about a hundredth of the rate we are losing it. Add to that, the fact that we have totally lost about 7% of cultivatable land to cities and to salinity (again, thanks to poor agricultural techniques), and that human demand for food will probably double in the next 50 years, and our careless treatment of soil begins to look suicidal.

BOX Symbiosis

Symbiosis at work: root tips of a tree, covered in the white mycelium of a mycorrhizal fungus.

Symbiosis is the term used to describe close physical associations between organisms. This includes:

- **Parasitism**, where one benefits and the other suffers
- **Commensalism**, where one benefits and the other is unaffected
- **Mutualism**, where the association is beneficial to both

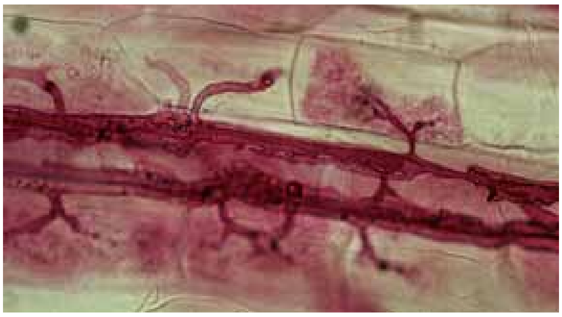
Mycorrhizal symbioses are therefore mutualistic; the fungus gets photosynthetic products from the green plant (mainly sugars), and the plant gets the increased ability to take up water and minerals from the fungus.

Fungal fertiliser

Conserving soil should be one of the most important priorities for every society, but we will also have to learn how to make use of soil in more clever ways. One example comes from the realisation that we are using up the world's stocks of phosphate rocks from which phosphate fertiliser is made. The phrase 'peak oil', describing the moment when world oil production reaches a maximum and then starts to decline, is well known; the new concern is 'peak phosphate'. All over the world there are crops being grown on soils that have insufficient phosphate, especially in Africa.

Once phosphate fertiliser becomes too rare or too expensive, what other way do we have of improving crop yields on those soils? Probably the only answer is to exploit the behaviour of mycorrhizal fungi, which are symbiotic fungi that live in plant roots and in the soil (see Box lower left). These fungi can extract phosphate from soil more efficiently than plants can, and they pass some of it to the plant in exchange for sugars. The sustainable agriculture of the future will need to make use of mycorrhizal fungi, yet we know very little about their biology, ecology or biogeography.

A root in close-up, with mycorrhizal fungus (stained blue) – the fungus is both inside and outside the root.



A close-up of an arbuscule (stained red), the site of nutrient exchange in a root cortical cell, together with the inter-cellular hyphae.

Mycorrhizal fungi are just one example of a group of soil organisms that we cannot ignore; there are many others, some of which we know to be important (nitrogen-fixing bacteria) and others that we are just beginning to learn about, such as bacteria that live in the soil around roots and can promote plant growth. Knowing more about them will not help us much, though, if we continue to destroy and damage soil at the current reckless rate.

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