# Earth biology

## Pedobiology

Soil is the 'place' where materials essential for ecological equilibrium are formed and decompose, but it is also where our food is produced. Unfortunately, it is also the waiting room of a number of environmental problems that begin in it and terminate elsewhere.  Nevertheless, studies regarding soil biology (**pedobiology**), respect to those regarding let's say, air and water, are still rather slow: why?
The main reason is that the scientist perceives Nature in the same manner as everyone else, which is not always the correct way of understanding it. In other words, to understand Nature well, one must go beyond what one can see (or hear), and understand Nature by using simple reasoning. Let us consider for example our difficulty in imagining the many processes that take place at a microscopic or sub-microscopic level, such as those that occur in the sphere of cells; or the difficulty in adapting our way of perceiving the passing of time to the scale of biological evolution, that is measured in hundreds of millions of years. Well, these limits have represented one of the most important factors in the orientation of scientific research, in some cases with results that were rather negative for our knowledge: which is the case of soil biology.

***An environment full of life***

Even though not much is known about soil organisms, it is certain that soil is not an inert and sterile environment but, on the contrary, it is a dynamic one overflowing with life. The majority of the organisms live within the first metre in depth and, in general, the biological spaces they occupy and their biological activities are on a very small scale. The growth of cultivated plants, for example, depends on the way in which the solid particles of the soil are arranged  to allow the formation of spaces with a diameter of about 0.2 mm. Moreover, these plants depend on the activity of micro-organisms that are about 1 µm (1,000 µm = 1 mm) in size, to contribute nutrient substances such as nitrates.
Soil is a resource of great environmental value, and at the same time, it is also an ecological system that recovers with difficulty each time its health is harmed by pollution produced by Man. It carries out an extraordinary activity of preservation of ecological equilibriums and plays a crucial role in the protection of human health. A proof is its complex activity as a biological and chemical filter, capable of slowing down and limiting dangerous chemical pollutants that, penetrating from the more superficial layers towards the deeper ones, could reach the layer with the water that we drink.
As far as the inorganic chemical composition and the structure of soil are concerned the reader can refer to these topics discussed in the section 'Earth'.

## Life produces organic material

The organic part of soil comes from organisms that live over and under its surface. The variety of these organisms and the exorbitant number of substances that they synthesize, that range from simple amino-acids to large natural polymers, such as lignin, explain the great diversity of organic material present in the earth. In the soil not all the remains of vegetable and animal organisms are biodegradable in the same way. A good part of these residues remains practically unchanged for even rather long periods, accumulating in time. In addition to this, in many environments such as peat-bogs and moors of high latitudes or altitudes, the climate is dominated for most of the year by low atmospheric temperatures that slow down decomposition phenomena.
When soil's organic material remains in time, a superficial layer is formed made up of a brown-coloured matrix that is capable of staying in this phase for indefinite periods of time even though it has lost the macroscopic characteristics of the original materials from which it derives. The substance obtained is called humus.
Humus has been studied for a long time, especially from the point of view of its chemistry; nevertheless, to date, it has not been possible to describe its composition in detail. For example, it is known that part of the organic nitrogen that it contains derives from the presence of amino-acids, amino-sugars and nucleic acids, however, the nature of the remaining part is not totally clear. What can be stated, however, is that humus is fundamental in guaranteeing a reservoir of organic material that is useful for soil organisms.

## Earth biology

In the soil, the main biological role, in purely quantitative terms, is played by micro-organisms and in fact, researches have been concentrated mainly on fungi and bacteria. However, if it is true that micro-organisms represent the living creatures that are most ‘present’ in the hypogeal environment, it is also true that they alone cannot explain all the ecological phenomena that take place in the soil. For example, knowledge regarding the relations that concern the higher levels of the soil food chains is still rather poor. The consequence of this delay is a still incomplete and inadequate knowledge of biopedological dynamics. Many phenomena that are, for example, connected to the nutrient cycle, in fact concern organisms that occupy very different positions in the ecological networks of the soil and are still not well known to date. In spite of the difficulties, some studies have clarified the identity of single species that normally live in the soil and this has lead to the possibility of formulating some hypotheses on their ecological functions.
Today, the role of particular biological groups can be studied in different ways and allow the elaboration of a sort of organizational chart of hypogeal ecology. A principle often used when classifying these biological groups takes their dimensions into account. As a result, five fundamental categories of hypogeal organisms have been identified:

- microflora: bacteria and fungi;
- microfauna: protozoa and nematodes;
- mesofauna: springtails, mites, enchytraeids (potworms) and others;
- macrofauna: isopods, molluscs, miriapods, earthworms and others;
- megafauna: amphibians, reptiles and mammals.

## Many factors

A mature soil, from the point of view of pedogenesis, can be defined as a layer of sedimentary rock that is inhabited by living organisms. For pedogenesis (a process that is truly never ending because all soils are slowly and continually changing) purposes, the soil is transformed into a tank, with a practically unlimited capacity, containing organisms. The consequent biodiversity has a very high ecologic value that is also very useful for Man.
The characteristics of the biodiversity of the microhabitats in the soil are defined directly by a number of factors, but mainly by the variations in the availability of water and air and the temperature.

***Water***

The spaces (pores) that form between the solid particles play a decisive role as far as the presence of water in the soil is concerned, and consequently the presence of organisms. The water content is subdivided into the various chemical/physical forms that water can be found in: vapour, gravitational water, capillary water, hygroscopic water, crystallization water.
Gravitational water accumulates in the larger cavities and tends to precipitate to the deeper layers due to the simple effect of weight. It is probably the most immediate source of water supply for the hypogeal biological community.
Capillary water collects in microscopic cavities and spaces where it is held with a certain energy. Hygroscopic water binds to the various substances that are present in the soil with an even greater energy, thus its biological availability is even more limited. Crystallization water is not available for the organisms.
Therefore water is held by the soil with a certain energy that varies depending on its particular form. Water tends to move in the soil following this principle, obviously interfering with the capacity of plants and other organisms to reach and maintain the right moisture level. All this is of primary importance because it not only conditions the presence/absence of hypogeal organisms, but also their seasonal or circadian (daily) migrations.

***Air***

In principle, observation of hypogeal atmosphere shows a “qualitative” composition that is very similar to the epigeal atmosphere, with some significant “quantitative” differences, i.e. with regard to the dosage of the single gases. For

example in the soil, $CO_2$ is present in a quantity that is about ten times greater than in the air of the epigeal atmosphere, while $O_2$ is present in minor quantities. Furthermore, the hypogeal atmosphere is often saturated with water vapour.
The lack of oxygen in the ground can support the breathing requirements of the resident biological communities for no more than a few days. However in normal conditions, it is very improbable that $O_2$ should represent a limiting factor, because sufficient air is stored in the pores to guarantee an abundant supply (bearing in mind that in air, the diffusion of $O_2$ is 300,000 times greater than in water).

***Temperature***

The temperature in the microhabitats in the ground is directly proportional to the atmospheric temperature and the solar radiation that reaches the surface layers. Furthermore, it is in turn influenced by biological factors, such as the presence of vegetation. Temperature range follows circadian and seasonal rhythms, and on the surface, the recorded temperatures range from a few degrees below zero to +60°C (depending on the latitude and altitude).
However at deeper and deeper levels, the temperature range becomes much less substantial. The high temperatures of the ground are often accompanied by arid conditions that interact in a rather complex manner with the hypogeal organisms, usually with negative results specially on their breathing systems. However, in relation to the thermal conditions in which underground life takes place, the most important factor that has been established is that rapid and very extensive excursions provoke effects that are much more harmful than extreme conditions characterized by a constant trend.

## Hypogeal animals

An initial concept that must be understood before undertaking a digression on the fauna of the soil is that present day knowledge is not sufficient to list with certainty all the types of animals that inhabit this important natural environment. In fact, the data available nowadays regard animals that have already been studied in most of the ecosystems of the planet. But no one can certify that this data is actually complete with all the hypogeal species, because still today many areas of the planet have not been thoroughly explored as far as the biological component resident in the soil is concerned.

***An incredible variety of animals***

As we have seen in the previous special report dedicated to soil biology, a frequently used criterion to sort out the fauna that lives in the uppermost layers of soil is that of classifying it according to the dimensions of the various taxonomic groups.
This criterion however is considered arbitrary and unsatisfactory because it is unable to offer information that is useful in understanding the relationships existent between one animal species and other cohabiting species. A much more useful way of proceeding would be that of considering not just the body dimensions but also the dietary habits and the role of each individual species in the hypogeal ecological network. A thorough knowledge of these aspects in fact would be very important in order to understand how the soil works where the word soil is intended as a natural system provided with its own specific ecological identity.
Generally speaking, the soil fauna belongs to the taxonomic groups of the Protozoa, Nematodes, Annelids, Molluscs, Arthropods and Vertebrates. Naturally this information reflects only a part of the biological knowledge that is necessary to be able to explain the ecological complexity of soil. To have a clearer picture other information is necessary, such as that regarding the abundance of a single species, the different distribution (in space and time) and the nature of the ecological relationships.
In this special report we will try to offer the basic knowledge regarding zoological groups in the soil, knowing well, however, that among the many species that live just a few centimetres below the surface of the soil, a network of relationships is established of which there is still a lot to discover.

## Protozoa and Nematodes

***Protozoa***

Protozoa can be considered unicellular animals (formed by a single cell) that have dimensions ranging between 2 and several hundred µm (remember that 1000 µm = 1 mm ). They are extremely abundant and well distributed in the entire thickness of the first centimetres of soil and their geographical distribution covers climates that extend from the warm and dry areas typical of deserts to cold and damp ones typical of the tundra. **Flagellates** and **amoeboids**represent the majority of soil protozoa, specially with respect to those very particular biological communities that form close to the roots of plants (**rhizosphere**). Protozoa are particularly important in the global ecology of the soil and their role is basically that of keeping a check on the bacteria population that they feed on.

***Nematodes***

Nematodes – that are, as can be remembered, small cylindrical worm-shaped pseudocelomates, i.e. without a real coelom – have dimensions that vary from a few tens of ?m to about 2 mm. They carry out a fundamental function in soil ecology because, depending on the species, they have different life styles: in fact, they can be predators or parasites of plants and animals. However, briefly it can be stated that, in the soil, the role of the nematodes is mainly that of keeping the abundance of other organisms in check and to demolish organic substances. Moreover, nematodes, as has been stated also for protozoa, are very efficient predators of bacteria.

## Annelids and molluscs

***Annelids***

It is important to reflect on the fact that, unlike nematodes, annelids are worms with a real coelom and that phylogenetically they occupy a very different position respect to the former. The main representatives of this particular component of soil fauna are the oligochaetes, i.e. common earthworms with a circular cross-section, characterised by very accentuated body metamerism (the repetition of identical anatomical segments along the body's principal axis) and by a length that often exceeds 10 mm. Respect to the taxonomic groups discussed so far, oligochaetes are animals characterized by a minor dependence on the amount of water present underground. Contrary to what one might think, annelids, and oligochaetes in particular, are animals that have been studied a lot by biologists in the past, starting from*Charles Darwin* who took particular interest in them. In fact, their importance in the ecological equilibrium of the soil is undisputed since they participate in all the mixing processes of organic substances and mineral components present in soil particles, increasing their fertility.

***Molluscs***

Molluscs, whose dimensions vary from few mm to a few tens of mm, have been neglected for a long time in soil biology studies for the simple fact that historically they have been considered more as generically epigeal animals rather than real hypogeal ones. The latter idea, however, albeit incorrect, had a logical explanation since, in numerical terms, molluscs rarely appear among the animals that dominate life in the soil. Currently, however, recently updated information on the biology and ecology of molluscs indicates that these animals are part of many trophic relations in food webs characteristic of the hypogeal environment. From this viewpoint, the main taxonomic group is that of the Gasteropoda pulmonata (with or without shell) whose ecological function must be prevalently related to the demolition of organic material present in the topmost layers of the soil. Often, however, the specimens of this subclass have herbivorous feeding habits since the main food of many species includes leaves and other decaying vegetation

## Arthropods

Numerically, arthropods certainly represent the major taxonomic group of hypogeal fauna. Moreover, as far as the range of their dimensions is concerned, arthropods that live in the soil detain a relevant record that is supported by the fact that their length extends from a few tens of µm of the most microscopic ticks to several tens of mm of the longer miriapods. Generally speaking, the most relevant group of arthropods can be identified in the above-mentioned ticks, in collembola (wingless insects in the subclass *Apterygota*), in miriapods and in araneids. Considering the characteristics of the environments that are being studied, however, even other groups of arthropods can be significantly represented, such as pseudoscorpions, isopods (guinea pigs) and several winged insects such as coleopters, dipters and hymenopters.
On the premise that the arthropods resident in the soil cover a wide range, it is impossible to identify a dominant trophic characteristic that allows us to place them in a single ecological role. In other words, the arthropod fauna of the soil is so rich in both taxonomic and morphologic terms that the life styles and feeding habits of the different species practically

cover the entire spectrum of the ecological niches that this environment offers. For example, among the arachnids, scorpions, opiliones and pseudoscorpions are all predators; however, many ticks and mites (also belonging to the class *Aracnida*) feed on decaying organic matter as isopods (crustaceans) do too. Among the miriapods there are numerous herbivores such as symphylans while the majority of chilopods and diplopods are respectively predators and eaters of detritus. If one goes on to investigate insects, the possibilities are almost infinite with groups such as the orthopterans
that are totally herbivorous and groups such as the diplurans that are mainly predators instead. Moreover, in between these two extremes, there is an intermediate group that comprises a vast series of arthropods whose diet is very variable. Suffice it to give the example of coleopters, to prove what a great diversity of feeding habits can exist within the same zoological group. The same can be said about hymenopters, hemipterans and dipterans.

## Vertebrates

In soil biology studies, vertebrates have received the importance they deserve only in recent years. The fact that these animals have on average a much greater mobility respect to invertebrates has probably made some of their adaptations to life underground be overshadowed, but nowadays their importance is being rediscovered. In the course of time, biologists realized that even though they were endowed with great ecological flexibility, many vertebrates had very strong connections with the soil environment.

It must be said that even the vertebrate soil fauna, at times called megafauna by soil biologists, shows significant variations in its dimensions, that vary from a few cm of the insectivores (such as the shrewmouse) and of the small amphibians, to the much greater dimensions of the cusk-eels and of the bigger rodents.

As can be imagined, vertebrates that have adapted to an underground existence include all the groups that are comprised in the entire series of tetrapods. Many of the latter, for example, spend a part of their life-cycle in natural cavities or in shelters dug in the ground for this purpose because of the advantages that this type of life style offers both in terms of protection from predators and in terms of a better regulation of some physiological functions (for example thermoregulation and water saving). Contrary to what one might expect after what has been stated with regard to ecological flexibility, vertebrates include some animals that can, or rather, must live in very limited ecological conditions such as those typical of some hypogeal habitats of tropical ecosystems. Amphibians with a worm-shaped body bear witness to this – the adaptations to life in the soil of the so-called caecilians have reached a formidable level of specialization. These animals, besides having eliminated their limbs completely, are often characterized by a regression of their eyes and a reduction of their skin pigments. Hence, their life style is very similar to that of many invertebrates which they resemble due to ‘adaptive convergence’.