V Protozoa

Protozoa are a group of microorganisms which are classified as unicellular eukaryotes. Eukaryote refers to all organisms which contain a 'true nucleus', being a structure which can usually be viewed down a light microscope which contains the organisms genetic material (DNA). Furthermore, the cytoplasm of eukaryotes contains other structures called 'organelles' such as mitochondria or chloroplasts.

Protozoa are microscopic, being unicellular, and can grow up to approximately 1 mm in size in some cases. However, they are more usually between 10 and 50 µm in size. They are heterotrophic, meaning that they obtain their energy from organic carbon sources. This can be in the form of organic matter, such as small sections of decomposed plant matter or excreted compounds such as sugars. Alternatively it can also be in the form of bacteria and other small cells such as algae and small fungal cells, up on which the protozoa 'graze'.

Currently, over 30,000 different species of protozoa are known to exist, being found in both aquatic environments and the soil. The numbers of protozoa found in soil is highly variable and depends on many different factors. A low fertility soil may contain 'just' a few thousand cells per teaspoon of soil where as a more fertile soil may contain a million or more cells per teaspoon of soil. Soil moisture is also a big determinant as to which type of protozoa are likely to be present and active in a soil. Protozoa make up four different groups depending on their morphological characteristics. These are:

Ciliates – being cells which are covered in hair-like organelles on their cellular membranes which are similar to flagella but are shorter and more numerous. As with flagella, cilia are used for locomotion. (Fig. V.I, Fig. V.II)

Amoeboids – being cells which can deform and control the shape of their cell to produce pseudopodia, being bulges of cellular cytoplasm used for locomotion. (Fig. V.III, Fig. V.IV)

Flagellates – being cells with 'whip like' organelles called flagella as external cell structures which are used for locomotion. (Fig. V.V)

Sporozoans – being spore forming cells which are exclusively parasites of animals.

Protozoa are an important part of the soil system, and are both herbivores (consumers of bacteria and other primary producers), as well as being decomposers, break down organic matter. Herbivorous protozoa function to control the microbial biomass by grazing, and thereby release other essential nutrients, into the wider soil environment. When feeding on bacteria, nitrogen in particular is released. This occurs as the grazed bacterial cells contain relatively large amounts of nitrogen, meaning that the protozoa consumes an excess of nitrogen by the time it has consumed a sufficient quantity of carbon via bacteria grazing. This nitrogen is released into the environment in the form of ammonium (NH_4^+) which can then be taken up by other bacteria and higher plants.

As well as grazing on smaller microorganisms and decomposing organic matter, protozoa are themselves a part of the food chain being fed upon by other animals which are higher up the food chain. Furthermore, they are competitors with other bacteria feeding organisms such as some species of nematode, meaning that some soils can have either high numbers of protozoa or high numbers of nematodes, but generally not both. Increased understanding of soil protozoa has possibly strong implications for the sustainability of agriculture and other managed ecosystems due to their influence on both nutrient cycling and disease suppression. For example, one group of amoeba called Vampyrellids eat fungi. They do this by 'drilling' round holes into fungal cell walls through the use of enzymes produced by the amoeba. The amoeba then sucks the cytoplasm from the fungal cell before moving on to the next cell. These amoeba attack many different types of fungi including root pathogens such as *Gaeumannomyces graminis*, the causative agent of Take-all disease in wheat.

Soil Cilliates

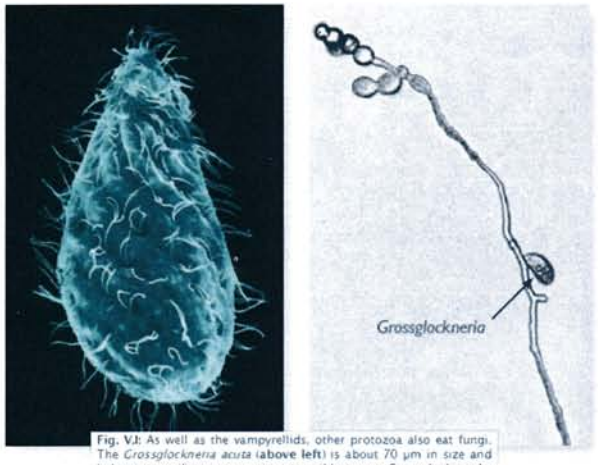

Fig. V.I: As well as the vampyrellids, other protozoa also eat fungi. The *Grossglockneria acuta* (**above left**) is about 70 µm in size and belongs to a ciliate group unique to soil known as Grossglocknerids. It has a special mouth located near the apical end and (**above right**) can be seen feeding on a fungal hyphae. (WF)

Fig. V.II: These images show various scanning electron micrographs (with post production colour added) of soil ciliates. They range in size from <70 µm up to 600 µm, as in the case of *Bresslauides discoideus* (image a); images are not shown to scale. There are thousands of soil-specific ciliate species, showing a great diversity in morphology, feeding, ecology, and adaptation. For instance, the *mycophagous ciliates* (a) or very slender *Engelmanniella mobilis* (b). Some species, such as *Grossglockneria acuta*, are small enough to exploit the soil pores. However, large species, such as *Pattersoniella vitiphila* (c) and *Bresslauides discoideus* (a) can be found in mosses and fresh leaf litter. Some ciliates are sessile (e.g. *Paracineta lauterborn* (d), a predaceous species which lives in a neat, chitinous 'shell') although these are rare because food is quickly depleted in the soil pores. The most common soil ciliates belong to the genus Colpoda (e) and thus the soil ciliate community is called Colpodetea. The Colpoda group has greatly radiated in the soil environment, producing, *inter alia*, the mycophagous ciliates. (All images: WF)

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Naked Amoeba

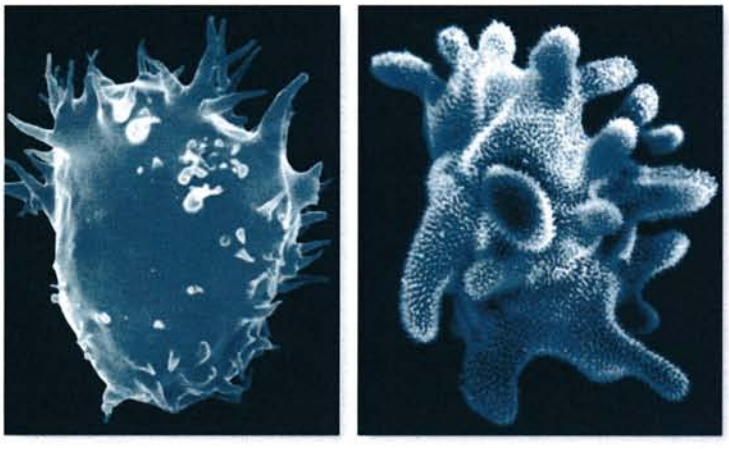

Fig. V.III: These images show various species of naked amoebae. The three above images were taken via light microscopy, with the two images to the left being taken via scanning electron microscopy, with colour added post production.

Soil naked amoebae are small, usually having a size between 10 µm and 100 µm. The cell nucleus is usually in the cell centre, being the circular structure visible in the images **above left** and **middle**.

Some amoeba have very thin and highly flexible pseudopodia, allowing them to exploit even very small soil pores (≤ 0.5 µm) and graze on the bacteria colonising the wall of the pores (**upper left** and **middle** image). However, others have thick pseudopodia, called lobopodia (**lower two images**), and feed on larger food items, such as fungal spores and ciliates. Naked amoebae are very numerous, i.e. there may be up to 40,000 individuals in 1 g of soil and, as such, they are important in soil energy flux. (WF)

All protozoa scanning electron micrographs have had colour added to them in Photoshop as a post production step by N. Frost to help highlight details. All organisms shown appear colourless in nature.

Testate Amoeba

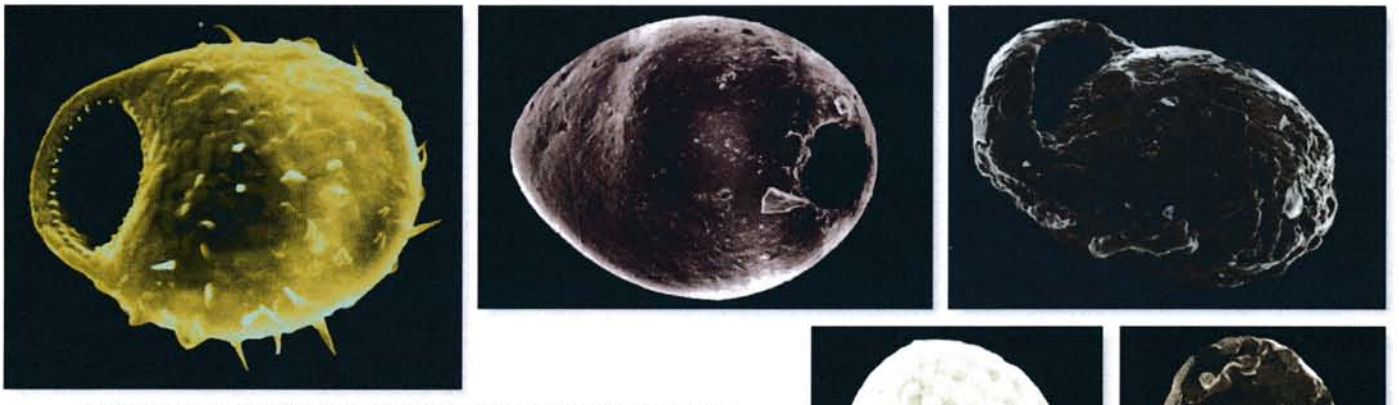

Fig. V.IV: These images show scanning electron micrographs (with post production colour added) of various testate amoebae. Their size ranges between 30 µm and 100 µm. There are usually up to 20,000 individual testate amoeba in just 1 g of soil. Testate amoebae play an important role in the energy flux of the soil and are excellent indicators of soil quality. The testate amoebae are basically similar to the naked amoebae, except of having a shell with a small opening called pseudostome. The shell is either made of siliceous platelets produced by the amoeba, as in *Corythion asperulum* (**top left**) and *Euglypha* (**bottom left**), or of mineralic particles taken from the soil environment, as in *Pseudawerintzewia orbistoma* (**top middle**), *Difflugia lucida* (**bottom right**), and *Centropxsis cryptostoma* (**top right**). The pseudostome of soil testate amoebae is often smaller than that of lake and river dwelling species to minimise loss of water. Accordingly, many of the species occurring in soil are specialised and restricted to the soil environment. (WF)

Soil Flagellates

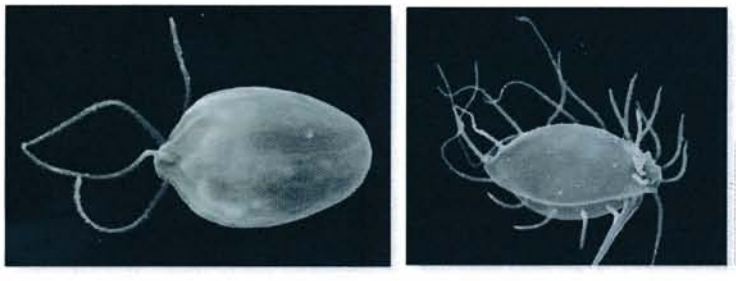

Fig. V.V: The images to the left show electron micrographs (with post production colour added) of two different species of soil flagellates, named for the long tentacle like protrusions called flagella which are used for locomotion. *Polytomella* sp. (**left**) has four flagella and is very common in soil globally. They are usually about 20 µm in size.

Hemimastix amphikineta, a 20 µm-sized flagellate with two rows of flagella, occurs only in soils in central and south America as well as Australia soils, likely being a palaeoendemic, that is it probably used to exist over a much greater range which has become reduced in size over time. The fine structure of this organism is so peculiar that it has been classified in a distinct phylum, the "Hemimastigophora". (WF)