An Australian coral fungus, *Ramaria versatilis*, one of many fungi contributing to nutrient cycling, and soil and plant health, in eucalypt forests.

hearts of darkness

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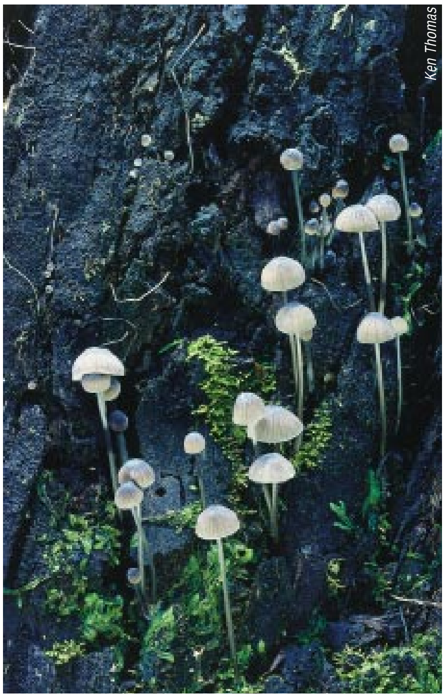


***Mycena* sp., a decomposer fungus of eucalypts.**

***Macrolepiota* sp., a toadstool that lives on decaying grasses.**

***Hypholoma* sp. draws its energy from decaying wood, in turn increasing nutrient availability.**

The role of fungi in Australian ecosystems is vastly underestimated. Alastair Sarre sheds light on the forgotten kingdom.

When British mycologist Mordecai Cooke published the first handbook of Australian fungi in 1892, he remarked that the 2000 species presented therein were not 'by any means exhaustive of the Fungi of the Australian Colonies'.

It was a masterpiece of understatement. In fact, his collection represented less than 1% of the 250 000 or more species of mushroom, toadstool, mould, slime, mildew, smut and truffle now estimated to inhabit the continent. Even today we have named only about 13 000 of these, or 5% of the total. The neglect of this dark, damp and fascinating kingdom is one of the great shames of Australian science.

Part of the reason is that fungi have a bad name. Athletes with tinea between their toes, farmers whose wheat crops go rusty, adventurous cooks poisoned by some kind of wild mushroom – all have cause to loathe fungi.

The folklore we imported from Britain only adds to our sinister view of the kingdom. In fairy tales, elves and other mythical creatures invariably sit on toadstools or shelter beneath them, and witches' brews always seem to feature a few mycological ingredients. The common names we've given to some local fungi do nothing to dispel the mystique: 'death cap', 'ghoul', 'ghost' and 'dead men's fingers', to mention a few.

In the scientific world, it wasn't long ago that fungi were regarded simply as plants without chlorophyll, a curious evolutionary diversion of little consequence. In fact, unable to manufacture their own energy, fungi are more akin to animals than plants.

This has been confirmed by genetic techniques that trace the origin of species. Perhaps a billion years ago – before even elves were around – there was a splitting of the evolutionary tree. Plants went one way and the progenitors of fungi and animals went another. It wasn't until some time later that the fungal and animal kingdoms diverged from each other.

Nevertheless, grouping fungi with plants was an understandable mistake. Fungi commonly grow in the ground, developing a mass of root-like threads called hyphae. Many produce plant-like fruiting bodies – the mushrooms, toadstools, corals and brackets – that use the wind to disperse their spores, in the same manner that many plants scatter their seeds.

But fungi play quite different ecological roles to those of plants, due in large measure to the absence of chlorophyll. Without it, fungi must obtain their carbohydrates – their energy – from other organisms.

They do it in several ways. Some are parasitic, draining resources from another living thing. A leaf-spotting fungus, for example, is tapping into the energy supply of its plant host and giving it nothing but a blighted spot in return. Some are saprotrophic, which means they suck out energy from dead things. The mould in the compost heap is doing just that. And others are symbiotic, which means that while extracting energy from another living organism, they repay their debt by providing the host with valuable products and services.

According to Neale Bougher, a mycologist with CSIRO Forestry and Forest Products, we vastly underestimate the role of fungi in ecosystems.

'Why do almost all terrestrial ecosystems have fungi in abundance?' he asks. 'Because

About 250 000 species of fungi are thought to occur in Australia, with only 5-10% of them named. Many species are unique, as they have co-evolved with native plants and animals.

Above: *Piptoporus australiensis*, the 'punk fungus' which causes a rot of trees.

Above centre: *Laccaria lateritia*, a common mycorrhizal fungus in Australian forests and woodlands, is now also introduced in many eucalypt plantations throughout the world.

Above right: *Aseroe arachnoidea* has a foul odour to attract insects, which disperse its spores after landing in a sticky spore-mass.

Below: Many fungi have been introduced to Australia with exotic trees. An example is the truffle-like fungus Rhizopogon, pictured here with pine trees.

The pines rely on mycorrhizal fungi to help them extract nutrients from the soil. Pines in Australia grew poorly early this century before the fungi were introduced to help them thrive. Australian native mycorrhizal fungi do not partner pine trees because they have specific co-evolved relationships with eucalypts and other Australian plants.

Below centre: This jelly fungus, *Heterotexus peziziformis*, is another species that lives on decaying wood.

Below right: The Earth star (*Geastrum* sp.).

they play major roles in driving the nutrient turnover systems that perpetuate an ecosystem. If we didn't have fungal decomposition of leaf litter and dung we would be up to our necks in the stuff.'

His colleague Inez Tommerup agrees.

'All the measurements in wild systems show that fungi are by far the dominant component of the microbial network that picks up and recycles nutrients,' she says.

Tom May, a mycological taxonomist at the Royal Botanic Gardens in Melbourne, says Australian ecologists have paid insufficient heed to fungi.

'An entire kingdom of the biota is almost totally absent from ecological work,' he says. 'For example, only recently have we realised that fungi are an important food source for many marsupials.'

May teamed with Andrew Claridge, an ecologist with the New South Wales National Parks and Wildlife Service, to review the evidence of mycophagy – consumption of fungi – and found that 37 species of native Australian mammals have been known to dine on fungal matter. Some, including the rare and endangered long-footed potoroo, rely heavily upon fungi as an all-year-round resource.

Gilbert's potoroo, which was presumed extinct until rediscovered in 1994 at Two People's Bay in the country's south-west, may be another example. In a study funded by Edith Cowan University and the WA Department of Conservation and Land Management, Bougher found that more than 90% of scats from the Gilbert's potoroo were composed of fungal material.

Most available evidence suggests that mycophagous mammals predominantly eat truffle-like fungi. These fungi, which resemble the European truffles so popular amongst gourmets, produce fruiting bodies that remain buried in the ground until unearthed by an animal. Because of this, scientists believe that the mammal-fungus relationship is one of mutual benefit: the animal has a food source and the fungus has an effective means of dispersing its spores.

But what happens when the dispersing agent – the potoroo, bettong, woylie or marsupial mouse – goes extinct from a region? No one knows.

'We've discovered that there are a number of truffle-like fungi in remnant vegetation patches in the West Australian wheatbelt,' Bougher says. 'But now that the woylies and the bettongs and other animals have disappeared, we wonder how these fungi will be dispersed.

'Even if the spores are viable as they sit buried underground, they're not going to be spread around if the animals disappear and the fungi aren't being dug up,' May says. 'And it may be that the spores need to pass through the gut of an animal or be deposited in certain places to allow the best germination. It's unclear what happens to the fungi when animals stop digging them up, but you would think it would have a significant effect, at least on the genetic structure of the fungal population.'

This could be a problem should we want to reintroduce such animals to their former ranges. If their food sources are gone, they may not be able to survive.

But there's another reason for concern. And this is that the truffle-like fungi are often involved in symbiotic relationships with tree and shrub species.

In these relationships the fungi surround or invade the plant's roots, forming structures known as mycorrhizas; in effect, the hyphae of the fungus act as an extension of the plant's root system,

delving into soil pores too small for the comparatively clumsy roots to penetrate. They capture vital resources such as phosphorus, trace elements and water and channel them back to the plant.

Scientists also suspect that mycorrhizas help protect plants from fungal diseases, partly by occupying the space that a pathogen might otherwise exploit, partly by enhancing plant fitness through increased nutrient uptake, and partly by responding antagonistically to the arrival of such organisms. In return, the fungus helps itself to the carbohydrates circulating through the root tissue.

Mycorrhizal research has been expanding rapidly, although until recently almost exclusively in agriculture and plantation forestry. Megan Ryan, a post-doctoral fellow at CSIRO Plant Industry, says the response of agricultural crops to the presence of mycorrhizal fungi varies.

'If you grow different plants in a glasshouse with and without the fungi, some of them will grow a lot better with the fungi and maybe won't even grow at all without them,' she says. 'But other plants grow equally well with or without.'

Despite a spate of research, mycorrhizas remain enigmatic.

'It's a huge area of research. Hundreds of papers come out every year devoted to mycorrhizal fungi,' Ryan says. 'But the big problem is knowing what these fungi actually do in real soils, not just in glasshouse pot mixes.'

To know this you need to create non-mycorrhizal plants to compare against plants colonised by mycorrhizal fungi. This can only be achieved by sterilising the soil, which immediately changes the soil chemistry and eliminates diseases and other micro-organisms.

'You get a result,' she says. 'But who knows how relevant it is to a field situation?'

Nevertheless, some progress is being made in sorting out what happens in the real world. In field experiments at CSIRO Forestry and Forest Products, some plantation trees inoculated with mycorrhizal fungi have increased growth with certain fungi, but not with others. One key may be to select the right fungus to suit particular soils or climates.

Working out what's going on in native ecosystems is even more difficult.

'In the bush you've got dozens and dozens of different plant species interacting with hundreds and hundreds of different fungi,' May says. 'A single tree might form mycorrhizal partnerships with a number of different individual fungi and many different species of fungi. In addition, the relationship changes in time and space and is influenced by the fauna as well. So it's actually quite a challenge to devise ways of studying such a complex system.'

Bougher believes that understanding the basic interactions between fungi, vegetation and animals could prove essential to landcare. He and Tommerup have observed that remnant patches of woodland in the Western Australian wheatbelt have a surprisingly high diversity of fungi, both saprotrophic and mycorrhizal.

'But when we look across the road to a patch of revegetation, we see a much reduced number of fungi – maybe as few as one hundredth the number of species found in the native woodland,' he says. 'So we think to restore the nutrient cycling system in revegetation, to kick-start the system, we should be trying to re-establish some spectrum of fungal diversity.'

Tommerup says that besides assisting the vegetation, such fungi will also support the return of other essential soil micro-organisms.

'You can almost think of them as being the key ecosystem engineers,' she says. 'By

Fungi are key organisms for management, conservation and sustainability of ecosystems because of their abilities to decompose litter and to capture soil nutrients and feed them to plants.

Above left: *Russula clelandii*, a mycorrhizal fungus in eucalypt forests

Above centre: *Peziza whitei*, an Australian truffle-like fungus.

Above: *Morchella elata,* a deliciously edible 'morel' which occurs throughout Australia.

Below left: Each individual fungus contributes to maintaining the vital functions of the forest or other ecosystem in which it lives, including highly specialist jobs for some of them. For example, the 'ghoul fungus', *Hebeloma aminophilum*, is always found close to carcases of kangaroos and other large animals. It is a so-called 'ammonia fungi', group of fungi with greatly enhanced activity in the presence of ammonium nitrogen compounds.

Experiments by CSIRO Forestry and Forest Products have induced a succession of various ammonia fungi to appear in eucalypt forests by applying ammonium nitrogen in the form of urea.

Below and below centre: This fly (below) and caterpillar (centre) each are covered with an unidentified entomopathenogenic fungus.

Torrendia grandis, **a fungus recently discovered and named as a new species by Neale Bougher. The fungus was found in remnant salmon gum and wandoo woodlands near Kellerberrin in the WA wheatbelt. Like many woodland fungi,** ***T. grandis*** **produces fruit bodies which occur below the soil surface.**

transporting carbon fixed from the tree into the soil, way beyond the fine roots, they are supporting the whole functioning of the decomposer system by providing food for things like bacteria and microfauna.'

The complexity of the love triangle between fauna, flora and fungi is daunting enough. But May says it is the lack of basic taxonomy – the identification, naming and grouping of species – that is retarding the advance of mycology in Australia.

'The first thing we need is an inventory of all our biota,' he says. 'It underpins all scientific research. You can't work on any group of organisms without knowing what's out there and being able to identify them.'

To illustrate the point, Bougher talks about fungi as food. The Chinese, for example, eat more than 200 species of fungi, yet Australians regularly consume only a couple of species, and those aren't even native. The problem is working out which species are poisonous.

'The key to knowing edibility is to have a good taxonomic knowledge,' he says. 'We know that certain groups of fungi are likely to be edible. But if we don't even know the name of a fungus we can't put it into that taxonomic scheme to say, it's close to that one which is edible, or it's close to that one which is poisonous.'

May says the ignorance of fungi in Australia can be traced back to the early colonial days. Amid the excitement

These diagrams represent contrasting ecosystem states which emphasise the importance of fungi to sustainability. The information is based on forests and remnant woodlands research by CSIRO Forestry and Forest Products.

Top right: A healthy ecosystem. The soil has abundant living organisms, including fungi, involved in nutrient cycling processes and making nutrients available to plants.

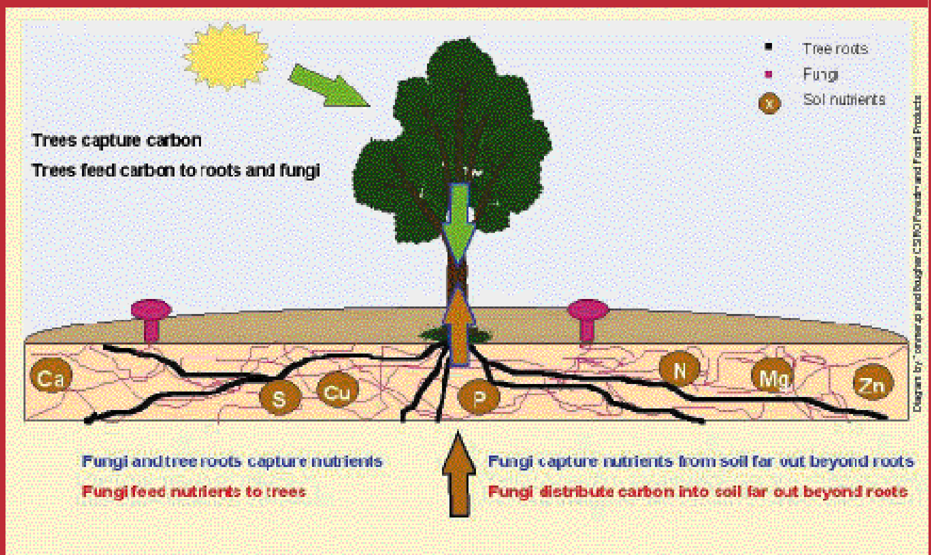
Bottom right: A degraded ecosystem missing key fungi which in healthy ecosystems would provide essential nutrients to roots and make the trees healthier.

Australian soils are generally poor in nutrients. Nutrients often have patchy distributions in soil. Native Australian plants have co-evolved with microbes and fungi to capture and keep scarce nutrients in the ecosystem.

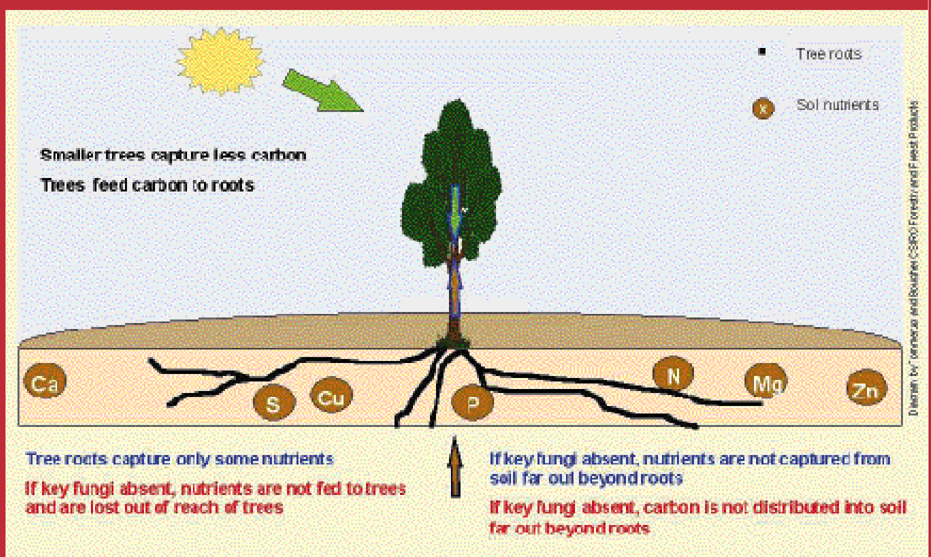
Mycorrhizal fungi enhance the capacity of plant roots to take up nutrients from deficient soils. Mycorrhizal networks act like extra root systems for plants. The mycorrhizal systems are more effective than roots alone. The fungal threads (mycelium) explore and exploit the soil, efficiently capturing nutrients far beyond roots. Simultaneously, the fungi distribute carbon out into the soil.

Saprotrophic fungi also increase soil nutrient availability, decompose logs, twigs and leaves and contribute to soil organic matter and soil structure. Networks of saprotrophic and mycorrhizal fungi bind soil particles, improve soil structure and decrease soil erosion. Fungal networks act like sieves, capturing nutrients, making them available to plants and minimising losses out of the ecosystem such as by leaching.

Fungi help to retain soil nutrients and sustain ecosystems



Without key fungi, degraded soil loses nutrients and ecosystems decline



generated in Europe by the new Australian flora and fauna, the fungi were overlooked. Very quickly, a lag developed in fungi collecting and classification that has never been addressed.

'There's never been a division of mycology or even of plant pathology in CSIRO,' May says. 'It's meant that very little work on fungi has been done in CSIRO in a coherent way, and there's never been a national collection centre.'

May notes an extraordinary contrast between the volume of work conducted into fungi and that conducted into certain charismatic plants and animals that may play a relatively minor ecological role.

'Losing any species is a wicked shame,' he says. 'You don't ever want to have to decide which is more important, a koala or a slime mould, but at the moment far too much research emphasis is placed on a small number of taxa.'

At the current rate of species identification, May estimates that it will take about 1000 years to describe the entire suite of Australian fungi, but with more resources the time could be shortened considerably. Both he and Bougher advocate the establishment of a 'national institute of fungal biodiversity', which would allow a coordinated approach to the enormous task of addressing fungal taxonomy.

They are also attempting to marshal the growing band of mycological amateurs. Already, hundreds are scouring the countryside for fungi on weekend forays, often being rewarded by the discovery of new species and even new genera. Others are embarked on the task of determining the distribution of a number of key species (see story on page 16).

Making information available is another key task. Bougher has written a book that describes and illustrates some 125 of the macro-fungi in southern Australia, while a number of mycologists contributed to the first two introductory volumes of *Fungi of Australia*. A third volume has begun a catalogue and bibliography of Australian fungi, the first since 1895.

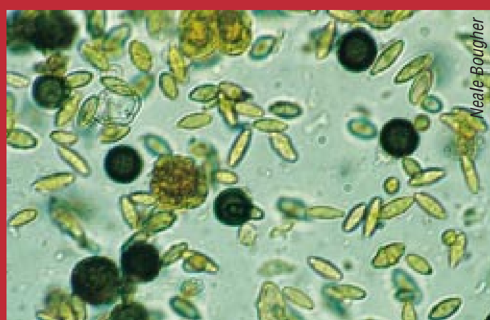
Education in schools and universities is also a priority. Enthusing kids with the subject is not difficult.


Ken Thomas

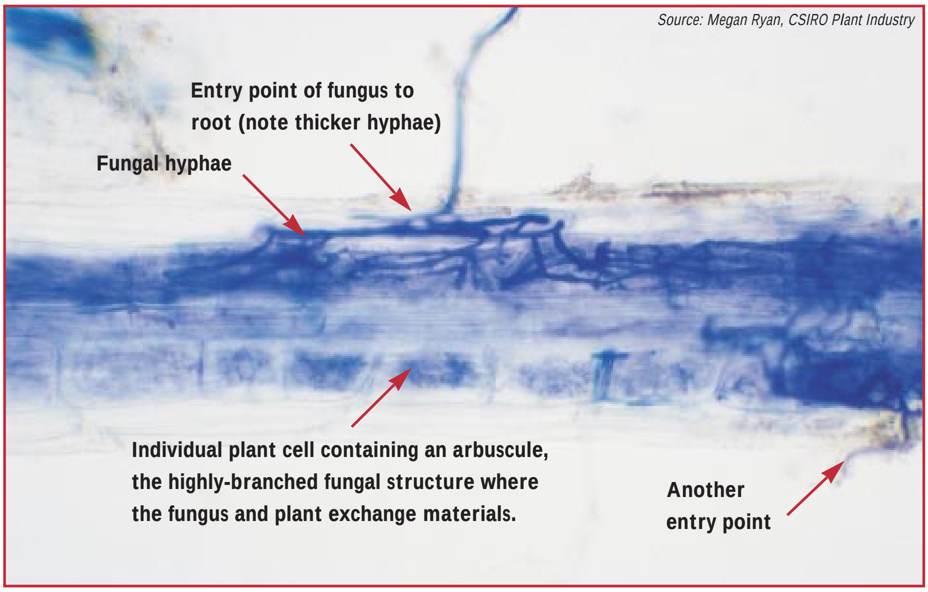
Left: *Boletellus obscurecoccineus*, a mycorrhizal species of eucalypts which fruits among lichen.

Bottom: Studies of the effects of fire history on fungi in eucalypt forests suggest that some fungi are favoured by fire. For example, the orange cup fungus *Pulvinula* fruits in large numbers after fire in WA eucalypt forests, including urban bushland.

Below: These fungal spores, seen under a light microscope, are in a dung sample of Gilbert's Potoroo, an endangered Australian mammal. Truffle-like fungi are a dominant part of this potoroo's diet. The fungi in turn have mycorrhizal associations with many plants in potoroo habitats. Fungal spores are dispersed in the dung of the potoroos. Many hundreds of truffle-like fungi species occur in Australia (more than anywhere else in the world). All probably rely on animals such as potoroos and bettongs for dispersal.


Neale Bougher


Neale Bougher



Some plants are highly colonised by mycorrhizal fungi. This wheat root has been stained to show up vesicular-arbuscular mycorrhizal fungi. All the dark blue material is fungal. It occupies all the root cortex.

A B S T R A C T

The role of fungi in Australian ecosystems is vastly underestimated. They are by far the dominant component of the microbial network that recycles nutrients. Relationships between Australian fungi, plants and animals are complex and interlinked. Many Australian trees and some mammals rely on fungi for their existence. Research into mycorrhizal fungi is expanding rapidly, mostly due to their importance to agriculture and plantation forestry. Only about 5% of Australian fungi are estimated to have been named. A dedicated band of mycologists and amateur enthusiasts are working to identify more species. At the present rate of research, however, describing the whole suite of Australian fungi would take about 1000 years.

Keywords: Fungi; fungal taxonomy; saprotrophic fungi; mycorrhizal fungi; Fungimap.

'They love it,' Bougher says. 'You can take a bunch of kids out into the bush and they will see things you will never see. And they are fascinated by some of the more bizarre fungi, like the ghost fungi which glows in the dark.'

Ken Thomas, who did a PhD on freshwater fungi involved in decomposition, now works in a policy role with Environment Australia. He sees tertiary education as a major hurdle.

'Mycology has died out in universities, so there is little opportunity for postgraduates, particularly in taxonomy,' he says. 'If you don't have people who can teach, the whole system's stacked against it. In any case, taxonomy is a start, but we also need to know what a given species does.'

He's pessimistic about the future for fungal taxonomy.

'Australia has a population of only about 20 million and can't do everything in science,' he says. 'Perhaps this is one area that won't be addressed.'

If he's right, it won't be for a lack of passion from the likes of Bougher, May and Tommerup.

'Australians are brought up to think of fungi as awful, dangerous and just to be kicked over or stomped on,' Bougher says. 'We want people to know that they are actually quite beautiful, varied, of different colours, and that they're doing lots of important things.'

And, one might add, they've been hidden in the half-light for far too long.

More about fungi

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Many hands making Fungimap

FUNGIMAP is a community-based mapping scheme with a network of more than 200 volunteers Australia-wide recording the distribution of 50 target species of readily recognisable fungi. Activities include forays and workshops, and participants receive a regular newsletter.

The project addresses a number of scientific questions, including:

- are most fungi localised, or do they have wide distributions?
- what are the major patterns of distribution? Examples might be species found in south-east and south-west Australia, or species restricted to one of these regions; and
- what factors determine the boundaries of distribution? Are species limited by rainfall, temperature, soil type, host or combinations of these factors?

For more information about Fungimap and to participate, visit the webpage: http://calcite.apana.org.au/fungimap.

Fruiting bodies of an unidentified slime mould.