FUNGI FORAGERS

No. 26 August 2021

OUR PURPOSE: TO RAISE AWARENESS AND INTEREST IN FUNGI OF THE CAIRNS REGION

This newsletter is not associated with any club or organisation but is emailed free of charge to anyone who may be interested. Anyone who wishes to contribute to the newsletter with observations, anecdotes, corrections, comments or photographs is welcome to do so. Although this “newsletter” is science-based we try not to make it too “scientific”. We recognise that there are school children, bush-walkers and others just interested in fungi, and we hope this leaflet will become a medium for furthering that interest. **The emphasis is on fungal biology and ecology** rather than identification.

Barry Muir, Editor Jenn Muir

Field meetings to find interesting species of fungi (not necessarily edible species) are known as 'forays', after the first such meeting organized by the Woolhope Naturalists' Field Club, Herefordshire, England, in 1868 and entitled "A foray among the funguses" [*sic*]. The Woolhope Club was an early member of the British Mycological Society founded in 1896. (Wikipedia)

A NEW EARTHSTAR FOR THE CAIRNS BOTANIC GARDENS

The Cairns Botanic Gardens has two previously recorded Earthstars, *Geastrum saccatum* and *G. triplex.* Now a third has been added, *Geastrum schweinitzii.* These little fellows have a greyish brown bulb surmounting a star-shaped pinkish brown base, which raises the spore sac above the surrounding soil and mulch. They occur in small groups, often closely attached to each other, and the mature fruit body is 1 - 2 cm in diameter and less than a cm tall. The outside “skin” - called an exoperidium (see the article below), splits into 5–7 petal-like lobes. The mycelial layer from which they develop is visible on and near the ground surface. Spores are dark purple brown, spherical, spiny and look like Corona-viruses! *Geastrum schweinitzii* seems to appear after good rains in the cold moths, usually June, whereas the other eathstars in the Gardens are found at the beginning of the summer rains (usually January). This fungus seems to have a wide distribution and has been found in India, Australia, the Galapagos Islands and North and South America, but has not previously been recorded in the Cairns Botanic Garden.

EARTHSTARS AND FALSE EARTHSTARS – HOW TO RECOGNISE THEM AND WHAT MAKES 'EM TICK?

The largest earthstar[1], *Geastrum triplex*, can have a spore-sac the size of a golf ball and with rays up to 12 cm diameter, but most are smaller and some, such as *Geastrum schweinitzii*, only a centimetre or so across. Both the earthstars and 'false earthstars' are so-named because of star-shaped rays that form under the fruit bodies. Studies of DNA have suggested there may be over 200 species of these bizarre fungi; the commonest genera being *Geastrum* (from geo = earth and astra = star) amongst the earthstars and *Astraeus* being commonest among the false earthstars.

***Geastrum* (probably *G. velutinum*, Litchfield NP, Northern Territory)**

Initially, in both genera, the fruit bodies arise from the underlying mycelial mat of hyphae as an 'egg', similar to those eggs that precede stinkhorns and some other fungi. The egg may be partially or completely buried in the ground and can be quite slow developing, up to three months. During this period, it is unclear what is happening within the egg, but one can assume that the first stage is the accumulation of sufficient nutrients in the mycelial mat to form the egg and then nutrients are transferred into the egg and then stored pending the trigger that causes the fruitbody to mature and expand. Like most fungi, the earthstars and relatives are chemically very complex and many fatty acids, antibiotic-like substances, simple and complex sugars, volatile organic compounds giving a strong odour, and hormone-like substances have been found. It is unclear whether these substances are made in the hyphae and then fed into the egg, made within the egg, or made in the mature fruit body, or perhaps all three!

The eggs, depending on species, may or may not start life fully embedded, partly embedded or on the soil surface. There is no stem. Once opening has been triggered, probably by sufficient chemical and nutrient reserves and sufficient humidity, things really start to happen.

Rough-surfaced eggs of the tiny *Geastrum schweinitzii* form above the soil on a thick mat of hyphae Cairns Botanic Garden

The egg is made of several layers of tissue, from two to many. The innermost layer, called the endoperidium (endo = inside, peri = around and derm = skin) stays pretty-much intact and contains the spore mass. The outer layer or layers (collectively called the exoperidium (exo = outside) is protective of the endoperidium containing the precious spores, stops wind or rain causing the spores to be released before they are mature, and probably helps to prevent dehydration. On maturity the exoperidium splits into a number of rays (4 – 20 depending on species and chance) with the broad part of the rays attached beneath the endoperidium and the points extending outwards. In many instances the arms crack as they bend, with the result that the endoperidium seems to be sitting on a separate saucer-like layer,

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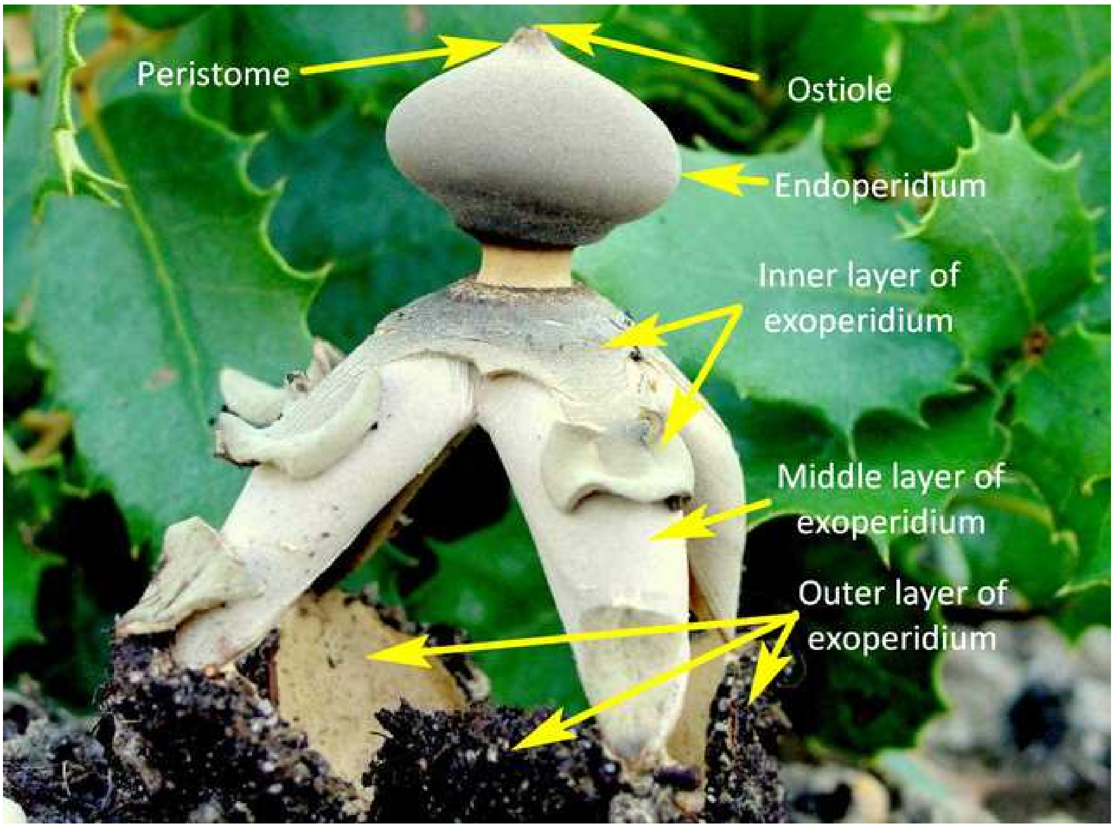
[1] Earthstars, *Geastrum* species, and false earthstars, *Astraeus* species, are very similar in form and have been lumped together, split apart and shifted around many times. Taxonomically, *Geastrum* is put in the order Geasterales, family Geastraceae, in the earthball and puffball morphogroups (for morphogroups refer CFF No. 6, December 2017). *Astraeus,* in contrast, is put in the order Boletales, family Diplocystaceae, most of which are in the stalked-pored morphogroup, which they do not resemble at all. This is because the order Boletales, originally erected to describe just the stalked-pored boletes, was based entirely on gross structure and microscopic features. Recently, based on chemistry and genetic studies, a large number of nonbolete species have been recognised as belonging to the same group, including some gilled mushrooms, the *Scleroderma* earthballs and the *Rhizopogon* false truffles. Nonetheless, the puffball-like structure of *Geastrum* and *Astraeus*, regardless of their taxonomic relationships, means we can probably guess that their ecology is somewhat similar.

but this does not occur in all species. The outer surface of the rays (the lower surface after expansion) and unopened specimens have a thickened, rough texture (see the *Geastrum schweinitzii* eggs above) which may help to increase surface area and keep them hydrated.

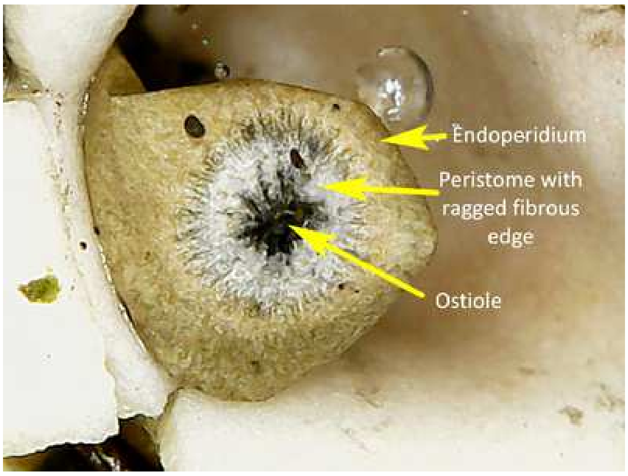


***Geastrum fornicatum* is raised above the ground on the star-arms as the middle layer of the exo-peridium shrinks. Note how the outer layer of the exoperidium remains buried in the soil and is matted with sand.** Modified from picture in The Ultimate Mushroom Guide.

In several *Geastrum* species, dirt and debris adhere to the underside of the rays (see picture and above) and may indicate a sticky coating which would again help to prevent moisture loss from the surface. In *Astraeus* and some *Geastrum*, as the rays extend, they curl downward and may actually lift the endoperidium above the ground, as shown above in *Geastrum fornicatum*. *Fornicatum* means "an arch" and refers to the raised fruit body on an arch of star-arms.

With *Geastrum schweinitzii*, the exoperidium is attached to the mycelial mat in the soil by rhizomorphs, root-like structures, but in *G. fornicatum,* above, there is a buried layer of exoperidium tissue that, when the endoperidium rises on the rays of the star, the points of the rays remain attached to the outer exoperidial layer. This raising process may help to protect the spore mass from attack from soil animals, perhaps lift the endoperidium into the boundary layer of warm, moist air that forms over the soil in calm environments, or, perhaps in litter-rich situations lift the spore-sac above the leaves and facilitate whatever wind there is to spread the spores.

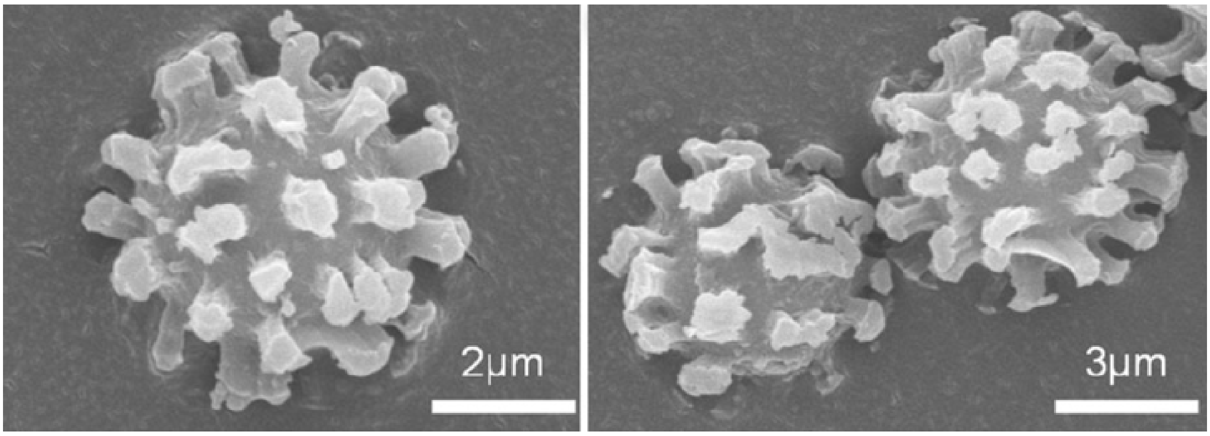
Astraeus hygrometricum takes this to extremes – bobbing up and down as the rays open and close in response to levels of moisture in the environment, opening up and raising the endoperidium in high humidity, and closing and lowering it when the air is dry. This adaptation enables the fruitbody to disperse spores at times of optimum moisture and reduces evaporation from the endoperidium during dry periods because it is again enclosed or partly enclosed within the exoperidium.



Close-up of mouth of *Geastrum schweinitzii.*

In the top of the endoperidium is a raised zone known as a peristome (peri = around, stoma = mouth) and in its centre a hole called an ostiole (ostiole = opening) through which the endoperidial spore sac releases spores when the wind blows across it. The peristome is made of radially arranged fibrils that clump together at the apex in groups of unequal length to form an opening that appears jagged or torn. The peristome is sometimes surrounded by a fuzzy ring of hairs as well. In the species where the peristome is raised, it may help the wind blow spores out, a bit like making a noise by blowing over the mouth of a bottle. The wind becomes turbulent just inside the bottle neck and makes a humming sound. In the same way the wind blowing over the raised hole with the surrounding hairs may create eddies which help to lift the spores out.

The spore sac contains a mass of spores and fibrous mycelia called a capillitium. The spores are produced on basidia (see CFF No. 11 October 2018) as in other basidiomycete fungi. The basidia have between two and four spores (up to eight in *Astraeus*) attached to them. When the spore mass is young it is white and firm, but ages to become brown and powdery, same as the earthballs. In *Geastrum* the spore mass is uniform in texture, but in *Astraeus* it is divided into cell-like structures but either method probably doesn't provide any particular advantage to the fungus.



Electron-microscope image of spores of *Geastrum triplex*. Source: Taiga Kasuya *et al.* (2012).

The spores of all species are covered in small spiny warts and look a bit like Corona-viruses! The spores turn brown when stained with iodine, indicating that they contain dextrin, a sugar used by the spores as an energy source. There is some debate about the purpose of spininess on spores but the thought is that this may permit better distribution with wind-blown spores as they are less likely to become 'glued' to a damp surface than if they were smooth. Although wind-distributed, spores are puffed out of the endoperidium by raindrops or drops from wet vegetation that hit the soft skin of the endoperidium, creating a bellows-like effect that puffs spores out through the opening. There is also a species in Brazil, in South America, called *Geastrum entomophilum*, that has been found with beetles inside the endoperidium and carrying spores in their gut. Nonetheless, the spores are similar, again with spines. I have found mites inside *Geastrum* and some had spores attached to their skin, so maybe these also help to distribute spores a short distance.

A cluster of *Geastrum saccatum* growing on mulch, compost and fibrous tree roots at the base of a *Barringtonia calyptrata* tree. Cairns Botanic Garden

The earthstars *Geastrum* are found under both hardwood and conifer (pines, firs, etc.) trees, in tropical rainforests, in grassland and in arid zones. It is claimed that in tropical regions, with high temperatures and humidity, the fungus egg expands rapidly, whereas in more temperate areas they develop more slowly and the lifting of the endoperidium may not occur at all. *Geastrum* is reported as saprobic, i.e., to be one of the recycling fungi and to gather nutrients from decomposing organic matter such as mulch or leaves. I think it is odd, knowing where and how they grow, that they do not also have some mycorrhizal function, although fruit bodies of some species are also found around well-rotted tree stumps and there is a record of at least one species growing on wood or termite mounds.

Occasionally they form fairy rings (common with many mycorrhizal species) or lines of fruit bodies following a root, again reminiscent of mycorrhizal species. Perhaps they are both mycorrhizal and saprophytic either at the same time or with different species – the research has not been done, although *Geaster triplex* has been found in India to be ectomycorrhizal with the native tree *Terminalia paniculata*.

Astraeus hygrometricus, the false earthstar, is a known mycorrhizal fungus exploiting an association between tree roots and the mycelium of the fungus. The fungus extracts nutrients (especially phosphorus) from the soil and passes it to the plants and is 'paid' in carbohydrates made by the plant using photosynthesis. The fungus has been associated with many trees of both hardwood and conifer species and, interestingly, the false earthstar is found mainly on the ground in open fields which tends to contradict its mycorrhizal status, unless it is mycorrhizal on the pasture grasses and weeds.

With regard the substrate on which they grow, a Dutch study reported *Geastrum triplex* to favour calcium-rich soil and in England *Geastrum elegans* seems to favour chalky calcium-rich soils. *Astraeum* is reported to favour nutrient-poor, sandy or loamy soils and has been reported to grow on rocks and to prefer acid substrates like slate and granite, while avoiding substrates rich in lime - very contradictory to the story for *Geastrum*. Both genera have been recorded from every continent except Antarctica in both tropical and temperate climates from sea -level to mountains. Many geasters occurring in the European region have been categorized under threatened or critically endangered and Red listed by the International Union for Conservation of Nature (IUCN).

Both genera appear to be triggered by intense or extended rainfalls, but some seem to be high-temperature fruiting while others are cold-temperature fruiting. Around Cairns all except one species appear at the start of the hot, wet season around January. The exception is *Geastrum schweinitzii*, which appears after good rains in the cold months, usually June.

References:

Karun, NC. & Sridhar, KR. (2014). Geasters in the Western Ghats and west coast of India. Acta Mycol 49(2): 207–219 DOI: 10.5586/am.2014.023 reviews some of the background of geasters.

Taiga Kasuya, Kentaro Hosaka, Kunihiko Uno & Makoto Kakishima (2012). Phylogenetic placement of *Geastrum melanocephalum* and polyphyly of *Geastrum triplex*. Mycoscience 53(6). DOI 10.1007/s10267-012-0186-z discusses genetic relationships.

Wikipedia, under the heading 'Boletales' discusses recent changes in bolete taxonomy.

THE HUMONGOUS-EST FUNGUS?

About 25 years ago, researchers discovered an *Armillaria gallica*, the Honey Mushroom, near Crystal Falls, Michigan, in the USA, where the mycelium covered about 38 hectares, weighed about 110 tonnes and was about 1,500 years old, setting a new record for the largest organism. It's fruiting bodies, the mushrooms, were of normal size. There was some uncertainty at the time as to whether it was, indeed, a single fungus or whether it was many clones, i.e., separate organisms with identical genetics. Later research confirmed that the entire fungus is just one individual. This DNA study also showed a very slow mutation rate, meaning that the honey mushroom isn't evolving very quickly. The study led the researchers to revise the fungus's age to 2,500 years and determine that it is four times as massive as the original estimate, or about 400 tonnes, the equivalent of three blue whales!

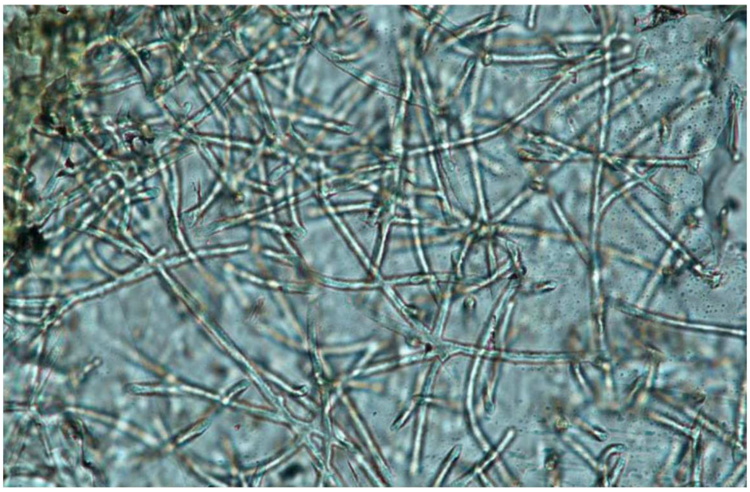
Fruit bodies of *Armillaria gallica*. Source Wikimedia Commons

Since its discovery another *Armillaria* found in eastern Oregon's Blue Mountains covers 7.8 square kilometres and may be over 8,000 years old, holding the current title for humongous-est of the funguses.

An investigation of this type has never been undertaken in Australia – the oldest continent. Could there be even bigger fungi in Australia?

THE OLDEST FUNGUS?

Scientists have found evidence of what could be the oldest fungal life on the planet, discovering traces of microfossils buried in ancient volcanic rock dating from some 2.4 billion years ago. The discovery was identifed in hardened lava formations found 800m below South Africa's Northern Cape, The filaments form mycelium-like structures growing from a basal film attached to the internal rock surfaces. Filaments branch and rejoin, touch and entangle each other. They are indistinguishable from mycelial fossils found in similar more recent habitats, where they are attributed to fungi on the basis of chemical and structural similarities to living fungi.



Geologist Birger Rasmussen from Curtin University in Perth, Western Australia, discovered the fungi by accident when examining basalt samples from the Ongeluk Formation – a Soth African region made up of volcanic rock that once flowed as lava under the seafoor.

Before that discovery geological evidence for fungi only extended as far back as 385 million years ago. The researchers aren't claiming that what they've found is definitely evidence of ancient fungi – although signs are positive, as the appearance of tangled filaments is highly similar to other fungal fossil discoveries.

The Ongeluk fossil fungi. Source: Bengtson, S, Rasmussen, B, Ivarsson, M, Muhling, J, Broman, C, Marone, F, Stampanoni, M. & Bekker, A. (2017). Nature Ecology & Evolution Vol. 1, Article number: 0141.

THE ROLE OF CAIRNS BOTANIC GARDEN IN FUNGUS CONSERVATION

In 2012 the World Conservation Congress called for greater emphasis and priority in the conservation of fungi. Consequently, the role of Botanic Gardens as repositories for fungi conservation is now recognised and the botanic gardens in Kew (England), New York, Melbourne, Denver, Komarov (near St Petersburg, Russia), Paris, Kunming (China), Xalapa (Mexico), and Cuba now house both preserved collections and living communities of fungi.

Of course, many parks and gardens support fungal populations by default, even if not a recognised part of their management plan. The Cairns Botanic Gardens, for example, is known to support at least 192 species of large fungi. Microfungi, of which there are probably many thousands, are largely unseen and so this inventory is based solely on taxa large enough to be easily visible. The 192 taxa found so far are based solely on the presence of identifiable fruiting bodies and have been found as a result of 115 searches over four years. Many taxa were only found during the wet season but irrigation of many parts of the Gardens allow some taxa to fruit at almost any time.

Less than 10 % of the species found in the Gardens are known pathogens, although it is recognised that some decomposers may have a pathogenic phase, and some pathogens become decomposers after they have killed their host. Based on current knowledge, over 25 % of all macrofungi recorded in the Garden are primarily mycorrhizal, and therefore play a vital role in maintenance of plant health. The remaining macrofungi are predominantly decomposers/recyclers.

It is known that Eugene Fitzalan, who started the Gardens in the 1890s, brought in seeds, and possibly even plants from other countries as there were no quarantine restrictions at that time. It is suspected that about 18 of the taxa recorded in the Garden may have come from other global sources, but DNA reference data are not yet available. All the pathogenic species found so far also occur more widely in

Australia, and it is probably safe to say that there is no evidence that Flecker Garden is the epicentre of any kind of spread of exotic pathogens, or even of exotic decomposer-recyclers.

"No, 'tofu' isn't short for 'toe fungus'!"

FUNGI FOR REMEDIATING POLLUTED SOIL AND WASTEWATER

Fungi have been proven to be an inexpensive, effective and environmentally sound way for helping to remove a wide array of toxins from damaged environments or wastewater. Fungi have a strange and unique set of enzymes and the ability to absorb or break down a huge range of different substances. Many are hyperaccumulators, which means they can concentrate toxins in their fruiting bodies for later removal. That is why one should be extremely careful where edible mushrooms are collected – if the area has been sprayed with pesticide or is contaminated by metals and toxins, such as along roadsides, the fungi may have very high concentrations of nasties in them. A good example of this is with *Coprinus comatus*, the Shaggy Ink Cap, an edible mushroom which accumulates mercury in toxic concentrations.

The world is suffocating in toxic waste. This is unwanted polystyrene on its way to landfill
World Press

Fungi which have been exposed to pollutants for a long time develop a high tolerance to the poisons and often attach the toxins to the surface of their cells rather than absorbing them into the tissues. This is especially true of metals. Pollution from metals is very common, as they are used in many industrial processes such as electro-plating, textiles, paint and leather manufacture. Toxic metals are also present in agricultural fertilisers and are accumulating in our foodstuffs because the agricultural soils no longer contain the beneficial fungi that bind the metals. The wastewater from industry is often used for agricultural purposes, so besides the immediate damage to the ecosystem from the waste metals and fertiliser, the metals can enter livestock, wildlife and humans through the food chain. Metals selectively absorbed by some fungi include lead, cadmium, nickel, chromium, mercury, arsenic, copper, boron and zinc, all of which are very toxic to animals and people in high concentrations.

This ability by some fungi has been used in prospecting for some minerals and also in their extraction. For example, a strain of *Fusarium oxysporum*, a mould fungus, found near Boddington, south of Perth in Western Australia attaches gold to its hyphae by dissolving and precipitating particles from the environment. The gold-coated fungus was found to grow larger and spread faster than those that don't interact with the precious metal.

Many fungi are decomposers of wood and have special enzymes for that purpose. The fibres of wood are similar in chemical structure to many organic pollutants and the fungal enzymes can also break those pollutants down. The fungi can destroy polycyclic aromatic hydrocarbons (PAHs), a common pollutant in seawater, petroleum fuels, diesel, toxic phenols in wastewater and even polychlorinated biphenyl (PCB) and TNT explosive in contaminated soils. The common fungus *Pleurotus ostreatus* has that ability as well as *Phanerochaete chrysosporium, Trametes versicolor, Bjerkandera adusta, Lentinula edodes, Irpex lacteus, Agaricus bisporus, Pleurotus tuber-regium and Pleurotus pulmonarius.*

One year of growth of Spinifex and other plants on copper-contaminated soil treated with mycorrhizae. The copper has been immobilised and the plants are thriving. B. Muir

Polyurethane and polystyrene plastic in landfills can be destroyed using two species of the Ecuadorian fungus *Pestalotiopsis*, and will probably become more widespread in it's use. Other fungi have the ability to destroy insecticide waste. Printing and textile dyes are difficult to break down and many are directly poisonous or cause cancer. *Aspergillus niger, Phanerochaete chrysosporium* and *Pleurotus* are effective in destroying these chemicals.

Use of plants to absorb toxins in soil is a frequently-used process. The plants are then harvested and removed to a safe place where the toxins will do no harm. Mycorrhizal fungi greatly improve the absorption capacity of the plants because the stress the plants suffer because of the pollutants is greatly reduced in the presence of the mycorrhizae. The fungi provide more nutrition, especially phosphorus, and promotes the overall health of the plant. The mycelium quick expansion also greatly extends the influence of the plant roots, providing the plant with access to more nutrients and contaminants. Improving the health of the root zone also means an increase in the bacteria population, which, in turn, can contribute to the toxin removal process. This relationship has been proven useful with many pollutants, such as using the plants *Rhizophagus intraradices* and *Robinia pseudoacacia* in lead contaminated soil, and *Calendula officinalis* in cadmium and lead contaminated soil and in destroying petroleum fuels and PAHs. In wetlands, mycorrhizal fungi in aquatic plants greatly enhance the degradation of organic pollutants like benzene and ammonia.

Many pollutants such as pharmaceutical chemicals, shampoos and fragrances are very difficult to destroy. The common pain treatment drug Paracetamol, for example, is toxic in traditional wastewater treatment, and pigments in winemaking wastewater are hard to destroy but fungi do the job nicely. Even some not-so-toxic materials such as starches, celluloses, fats, oils, chitin, and keratin, paper pulp residue and wastes from cotton, jute and linen processing are readily degraded by *Aspergillus* and other moulds.

Mushrooms growing on radioactive soil. Chernobyl

Fungi can even be used to absorb radiation. Fungi have been found with high concentrations of radioactive contamination after the Chernobyl and Fukushima nuclear plant disasters and can be harvested to remove some of the contamination.

Proponents say it's a natural, more benign, and potentially cheaper alternative to the traditional 'scrape-and-burn' approach to environmental clean-up, which involves digging up contaminated soil and incinerating it. The problem with the traditional approach is that it can remove potentially fertile topsoil and can release undesirable contaminants into the atmosphere.

One difficulty is that Environmental Protection agencies usually require the removal of 100 percent of targeted contaminants within a short time frame. Current remediation solutions using fungi simply work too slowly to be embraced on an industrial scale. The speed of remediation and the degree of success vary depending on species of fungus, what contaminants are present, and local growing conditions such as heat and moisture, which means treatments must be customized and that makes the process slow and unwieldy.

With time mycologists and remediators will accumulate enough evidence for certain common pollution scenarios, such as oil spills, that it will be possible to build 'off-the-shelf' remediation protocols. What impact these fungi will have when released into the wider environment is not known.

In the meantime, the use of fungi for remediation has languished because it does not attract financial investment. It is not a product that people want to buy; it is something that the contaminating companies are forced to do, so they want to minimise financial input. Additionally, because of the (usually) urgency, it is not something years can be spent on trying to get it right.

Likely fungal species need to be screened to determine what grows best on, for example, oil, herbicides, insecticides, or synthetic compounds, and what the contaminants break down to and how long that process takes – at present it's just not feasible on a large scale.

If you are interested in this subject and wish to study it further I recommend Stamets, P. (2005). *Mycelium Running: How Mushrooms Can Help Save the World*. Berkley: Ten Speed Press.

THE EARTH IS *OUR* PLAYGROUND

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