Lichens and the Mystery of Life

It is a huge honour to be here tonight to commemorate the life and literary achievements of Bill Condry (and to have Penny in the audience). I was privileged to know Bill and to have spent time tramping the hills and valleys of Wales with him. Sadly not as much time I would have wished as we were robbed of his talents too soon. He was a lovely man - with a huge knowledge of the natural world and a rare gift for communicating that knowledge.

Lichens, the theme of my talk, I know fascinated him. They are part of that enormous kingdom of the living world called the fungi. Their apparently odd mutualistic lifestyle for years has marked them apart from other fungi. By the end of this evening I hope I might have convinced you that they are far from being odd and unravel some of their mystery. Yet for most people the Kingdom of the fungi, unless it rots the fruit in your fruit bowl or you are frying up a mushroom, remains unseen, unknown and even plain forbidding.

I was brought up in the north Midlands in the centre of what had become even before my birth a great lichen desert. The woods and rock outcrops of my childhood were blackened by soot from household chimneys, factories and steam trains. And probably like Bill, brought up on the edge of the Black Country, I don’t recall ever seeing a lichen on a tree.

Moving to West Wales in the early 1970’s was a shock! My old black and grey world had been transformed into one of brilliant colour. Lichens decorated every rock and tree as a sort of living tapestry. Grey tassels of beard lichens hung from every twig. Green, grey and yellow lobes sprouted from the trunks. I was stunned. It was not only the amount of them that was impressive, there seemed to be an awful lot of different sorts. They surely had a story to tell if only I could decipher it.

Working for the then Nature Conservancy Council I was often asked to evaluate the importance of sites for wildlife. At that time lots of the uplands were being planted with conifers and land drainage was heavily subsidized and was happening everywhere. I was sent out, usually with just a few weeks' warnings and all too often it seemed in the depths of winter when a lot of the wild plants were invisible, to comment on these proposals. My knowledge of mosses and liverworts stood me in good stead but I quickly resolved that I must be missing a lot of information that the lichens could supply.

I also quickly discovered there was a lot of new work being done on lichens. For example Dr. Francis Rose, a geographer from Queen Mary College, London with an expert eye for the lichens of woodlands and parklands, was examining huge numbers of sites. By comparing his work with that of the entomologists he was able to identify a group of lichen species that seemed to be confined to sites where ancient trees had been present for hundreds of years. He had discovered the importance of lichens as indicators of ancient woodlands. As a result I became able to use lichens to understand the history of woodlands and evaluate their importance, even in the depths of winter.

Elsewhere in Wales Tony Fletcher, undertaking research on sea-shore lichens based at Bangor University and Peter James at the Natural History Museum were opening our eyes to the importance of the Welsh coast. Steve Chambers from Aberystwyth was surveying areas rich in heavy metal such as lead, zinc and copper for lichens and Alan Orange from the National Museum of Wales was commencing his studies on a very challenging group of lichens that would reveal the importance of Welsh rivers and lakes. Lichens were beginning to enter the mainstream of wildlife conservation activity.

We now have recorded nearly 1,300 lichen species from Wales. That is almost as many as there are flowering plants in all of Britain. It compares very favourably with the just over 1,800 lichen species recorded from mainland Britain. Wales supports 71% of the British lichen flora on only 11% of the land area. This total becomes even more remarkable if you note that there are probably only about 3,000 lichen species in the whole of North America and Wales can fit 37 times into Texas alone and still have some land to spare. What an extraordinary diversity of lichens there are in Wales. For its land area it might be the most lichenologically rich country on Earth.

Why is Wales so good for lichens? To begin with, for its area, it has a remarkably diverse geology. Rocks range from the hard, unyielding and acidic to the soft and calcareous; rock outcrops can be found at sea level, affected by salt spray to mountain tops that experience sub-arctic conditions. Contrast the chill weather of Snowdon with the sunny coastal valleys of the Gower basking in sub-Mediterranean warmth. Or just compare the year-round mild humidity of the Celtic rainforest of Atlantic West Wales with the occasional extreme summer heat and regular winter chill of the continental valleys of the Welsh Marches. Elsewhere you would have to travel hundreds if not thousands of miles to encounter the range of climatic conditions and rock types you can find in a few miles in Wales. Each supports its own unique communities of lichens.

Wales also fortunately seems to have more ancient trees than most countries in Western Europe. They are still almost as rare as hen's teeth.

The trunks with their sheltered and gnarled nooks and crannies and lots of old dead wood provide all sorts of niches you don't find on a younger tree. About a hundred lichen species appear to be confined to veteran trees. For so many species to have evolved, ancient trees must once have been very common. Many survived miraculously because just when the medieval deer parks, that were full of veteran trees fell into disuse, on a fashion whim they were incorporated into the picturesque landscapes of our great houses. If you haven't, you must visit Dinefwr Park in Carmarthenshire. Now owned by the National Trust you can get a hint of what the forests must have looked like to a Palaeolithic hunter. Parks further east in Wales, such as at Powis Castle and at Chirk still have the insects that tell a tale of long continuity but the lichens have largely succumbed to atmospheric pollution from nearby industry.

Our demand for lead, zinc and copper has also destroyed almost all of the naturally occurring outcrops containing these metals. A whole group of lichens had evolved to cope with this normally toxic, if rare, environment. Fortunately - messy organism that we are –we never cleared up the mess made by a lot of our mining and smelting activities. In many places spoil-heaps still rich in these metals survive and with open adits, shafts and abandoned excavations metallophyte lichens have found a home in a range of new habitats. The metals have even soaked in places into the walls of old buildings. If you want to find lichens that demand copper, look on the walls below the long-gone bronze bearings of the dismantled machinery. The Mid-Wales Orefield with its wonderfully evocative old abandoned mines such as at Cwm Symlog, Esgair Hir, Cwm Rheidol, Eaglebrook and Cwmystwyth are internationally important for their lichens. Important also are the extensive metal-rich river gravels along the Rheidol and Ystwyth. Only on the River Tyne in north-east England is anything remotely similar found.

Our convoluted Welsh coast with its hard rock and soft cliffs and sand dune systems supports some of the finest maritime lichen communities in the world. The cliffs of West Pembrokeshire and its islands, The Lleyn, Bardsey and north Anglesey-all places that Bill loved, are exceptional. Coastal sand dunes are internationally rare and rarer still is coastal wind-blown sand settled on limestone headlands such as is found at Stackpole in south Pembrokeshire. This has created a special habitat reminiscent of Breckland.

I am particularly fortunate that my four decades in Wales came at a time of such great developments in lichenology. In 1970 we knew little about the current distribution of lichens in Wales. Throughout the first half of the 20th century natural history itself had fallen into a dreadful decline compared to the frenetic activity of the Victorian age. By the 1950s only Arthur Wade at the National Museum of Wales was making any significant lichen records and all the active field lichenologists in Britain could have met in a phone box! From 1970 it was a different story of exciting discoveries and new challenges.

Let's look at lichens in more detail. They are little documented in history. Their medicinal properties were known to the ancient Greeks. Ointments incorporating lichens were applied to the skin. It's remarkable that today we still use creams containing one of the most widespread of lichen substances-usnic acid to treat the skin. The Greeks also used them in perfumes and they are still important today. A lichen called Evernia prunastri with the English name of oak moss is collected by the ton in France and other Mediterranean countries and an extract from it is used in the more expensive of perfumes. The lichen extract produces an outdoor, musky smell often described as “leather” and helps fix or extend the life of the other perfumes on the skin.

Oliver Rackham may claim the discovery of the first written British record of lichens. Numerous Anglo-Saxon charters that describe the village bounds refer to “hoar apple trees”,” hoar hazel trees”, “hoar thorn trees” etc. that he interprets as referring to trees well-clad in lichens.

The Elizabethan period saw the first stirrings of science in the works of the apothecaries. William Turner in his A New Herbal of 1568 includes several recognisable lichens, possibly their first mention in print in Britain. But what exactly were these organisms? They were generally lumped in with moss. It took Robert Morison, a Scotsman and director of the Oxford Botanic Gardens from 1666 to recognise their close affinity to fungi. He saw for the first time the tiny spores they produced and called them musco-fungi.

It was the Frenchman Joseph de Tournefort in 1694 who recognised lichens as a distinct group and coined the term “lichen” that ever since seems to have been dogged by an uncertainty regarding its pronunciation. Is it “liken” or “lychen”? It is derived from a Greek word meaning eruption or wart. And should probably be pronounced “liken”? The British Lichen Society prefers this pronunciation and my Greek dentist definitely insists that this is the only way to pronounce it.

I would, however, have preferred a more flattering derivation of their name! Only a very few look at all like an eruption or wart and most lichens are things of great beauty and certainly don’t need to be pressure hosed off the patio!

Carl Linnaeus, that great cataloguer of the living world, in the 1750’s might also have made a better job of describing their diversity had he not just lumped them all into one genus. It is said he considered them to be "rustica pauperrima" which has been translated as "poor trash of vegetation"! Thankfully a fellow Swede, Erik Acharius rescued the situation by laying down the foundation of modern lichen taxonomy. Scandinavia has long been considered the land of lichens but Acharius, not content, went on to catalogue the lichens of the whole world. Such was his dedication and enthusiasm it is said he died suddenly in 1819 after receiving, in great excitement, a particularly large and fine consignment of lichens from Spain. It's clearly important to keep the study of lichens in proportion.

As microscopes improved through the middle years of the 1800's so did our understanding of the parts of lichens. The tiny spores, produced in a variety of structures had been observed and correctly identified as the propagules of a fungus. The various specialised bits of the lichen that create many small vegetative propagules had also been described and correctly interpreted. We were making progress.

However things stumbled a bit when it came to deciding what the big green or blue-green football-like structures that lay scattered inside the lichen were. They were mostly considered to be a unique type of fungus spore. The brothers Tulsane in France made a considerable leap forward in suggesting these green footballs were some sort of organ of nutrition. Their extraordinarily fine observation of the very intimate connection between the colourless thread-like hyphae of the fungus with these large green spheres convinced them that the fungus must have grown these structures. The similarity of these spheres to the little heaps of green cells called algae found on trees and rocks was explained by the latter being escapees from the lichen.

It took the German Simon Schwendener in 1867 to turn this theory around. He recognised the green footballs as algae and wrote: "As the result of my researches, the lichens are not simple plants, not ordinary individuals in the ordinary sense of the word; they are, rather, colonies, which consist of hundreds of thousands of individuals, of which, however, one alone plays the master, whilst the rest, forever imprisoned, prepare the nutrients for themselves and their master".

As it transpires, perhaps rather unwisely, he went on to describe the fungus as a parasite and the algae as the slaves of the fungus which "it has sort out, caught hold of and compelled into service". This was a wonderfully inspired deduction that fitted the observations. Yet it was greeted with hostile derision by the lichenologists and mycologists of the day. Most went to their grave in the 20th century still refusing to believe such an implausible theory. Many were "men of the cloth" and were possibly revolted at the concept of human slavery that had only recently been abolished. Perhaps if Schwendener had presented the relationship as one of mutual benefit, the theory might have been more widely accepted? This was probably one of the few occasions when a spin doctor might have been beneficial.

The debate still goes on today as to whether the relationship between the photosynthetic partners and the fungus is a truly mutualistic one or whether the photosynthetic partner is subject to controlled parasitism. Why do I say "photosynthetic partner" and not just simply "the alga"? To be scientifically correct not all photosynthetic partners of lichen fungi are algae proper. Some are bacteria. What we used to call blue-green algae are more correctly called cyanobacteria and are not remotely related to algae proper. So the term "photosynthetic partner or symbiont" is used to encompass both cyanobacteria and green algae.

It is interesting that two so very different organisms should conspire with fungi to create lichens. Consider yourself to be a fungus presented with the choice of life with a cyanobacterium or life with a green alga. Which would you choose? On the plus side with a cyanobacterium you will never be short of nitrates as they can manufacture them from the air just like the bacteria in the root nodules of a clover plant. Lichen fungi have even evolved ways of increasing the number of the special thick-walled cells that cyanobacteria use for the fixing of nitrogen so enhancing the process. On the minus side cyanobacteria are less efficient at photosynthesis than green algae and demand free water before they can function properly. They spring into life only after rain or a thorough soaking in mist. Controlling their growth rate to match the fungus may also be trickier as starving them of nitrates to reduce growth is not an option for the fungus since, of course, they can produce their own. They also tend to prefer base-rich habitats. Green algae by contrast can rewet themselves from humidity in the air and are not dependent on direct rainfall, though they suffer more from the effects of water-logging. If they get too sodden they just stop functioning. On the plus side they can grow in more acid conditions.

Quite a number of lichen fungi have ducked the issue of choosing and have evolved to coexist with both cyanobacteria and green algae in the same thallus. However they never seem to occur mixed up together. A policy of strict segregation applies. The cyanobacteria are usually confined to small parts of the thallus, often creating distinctly different looking patches. In some species these patches are found in just the central parts of the lichen from where presumably the nitrates can be more easily and evenly distributed or on the odd lobe. This begs the question of how does the lichen fungus control the distribution of its photobionts? Do cyanobacteria regularly rain down all over the lichen but only where they are required are they taken into the lichen and encouraged to grow? How else could a fungus shift them about? This relationship of cyanobacteria with fungi is not unique. The advantage of growing your own nitrogen compound factory has been discovered by a number of liverworts and even the odd flowering plant and fern. They all create mucilage filled pockets where cyanobacteria are specially cultivated. How else could the gigantic leaved Gunnera become an undesirable alien on the nutrient-poor blanket bogs of the west of Ireland. It grows cyanobacteria along the top of its rhizomes.

Back to lichens! So whenever a fungus forms a mutually beneficial relationship with a photosynthetic partner is the resultant dual organism always a lichen? What if when you mix the fungus with the alga the fungus just grows within the outer jelly-like sheath of the alga and the latter barely changes form. Is it still a lichen? If you are happy with this definition then lots of seaweeds on the sea shore could be called lichens as many have distinctive and characteristic fungal species living within them without changing the form of the seaweed. At the other extreme there are a number of fungi that can live with or without a photosynthetic partner. They typically live on and in bark. The presence of a few algal cells embedded in the bark amongst the fungal hyphae little alters their form. Are they lichens?

Perhaps it's not surprising we have a definition problem since lichens are not a natural evolutionary group. There was no single ancestral lichen. At various times and at least on ten different occasions a great range of fungi have evolved this life style. To have happened so many times and to such a large number of fungus species suggests it must be a very successful life style.

Let's give up on the definition of a lichen and try and define a fungus. This proves to be not too easy a task either.

The classification of living organisms has been revolutionized in the last few decades .It has resulted in a general acceptance that the living world can be split into three domains. Within these three domains are seven Kingdoms. Two of the domains and four of these Kingdoms contain organisms traditionally studied by mycologists and once thought to be fungi. The Actinomycetes, however, turned out to be bacteria that just looked like fungi. The slime moulds and club root organisms are now placed in the ranks of that single celled animal group-the Protozoa. Potato blight and other Phytophthoras, along with the water fungi have now found a home in a completely new kingdom called the Chromista. Unlikely as it seems they are close relatives of the brown seaweeds and diatoms. This is quite a revelation and no doubt explains the poor progress made in developing effective fungicides against Phytophthora when what was needed was a "chromisticide" not a fungicide after all!

So how do we define the Kingdom Fungi proper. What unites them? It turns out to be the unique shape of their mitochondria. All the higher organisms, if they use oxygen for respiration, have these tiny sausage-like structures in their cells. Once upon a time they were free living bacteria but now, incapable of independent existence, they manufacture the chemicals which provide the power to drive the processes of the cell. To create a large surface area the outer wall grows into the centre of the mitochondrion in numerous finger-like processes. Unlike all the other higher organisms these finger-like processes are flattened in the fungi.

Fungi also uniquely absorb their food directly through the cell wall, not engulfing it as Protozoa do. Fungi are also completely different from bacteria in that they have much more complex cells with organelles such as a nucleus and the unique mitochondria.

Their evolutionary history is problematic too as they have left only fleeting glimpses in the early fossil record. There are equivocal fossils of lichen-like organisms from 2.5 billion years ago in the pre-Cambrian. If true they predate the evolution of all the other plants and animals with cell organelles by half a billion years. There are traces of what might be fungal mycelia amongst the earliest cyanobacteria colonies forming large football-like structures called stromatolites. Very similar structures still grow today along a few scattered coasts such as at Shark Bay in Australia and Stocking Bay in the Bahamas. Whilst their direct descent cannot be proved it is tempting to label them as a rather successful life form with a history of two and a half billion years to prove it!

It appears very likely that these first multicellular photosynthetic bacteria formed an alliance with fungi. Initially the fungi perhaps fed on the dead bacteria or even became parasites. The disadvantage of parasitism, particularly if you kill your host is that you have to keep finding a new one. A better strategy might be to join forces. The fungi with their extensive network of hyphae were better able to scavenge for nutrients. They had an enormous surface to volume ratio compared to a blob of cyanobacteria and so were far better able to scavenge for nutrients that could be passed on to the cyanobacteria. The cyanobacterium, unlimited in its growth by a shortage of nutrients, could then manufacture enough carbohydrates to supply both its needs and those of the fungus. What could be a better marriage? Were the first fungi a sort of lichen?

Life on the early Earth was also a faltering process. Despite the possible existence of helpful fungal relationships, nutrients were likely to have been in short supply. At various times a failure in nutrient recycling could have caused the death of many of the cyanobacteria that now populated the oceans. As they sank to the ocean depths they took with then most of the carbon dioxide. The result was a rapid cooling of the Earth and its entry into what has been called snowball phases with ice stretching from the poles to the equator.

The last series of such episodes took place around 700 million year ago. How the Earth broke out of these frozen phases is the subject of much debate. Volcanic activity could have released large quantities of carbon dioxide and methane into the air temporarily causing the Earth to warm enough to allow ice to melt and supply new nutrients so permitting life to restart. With the cessation of volcanic activity and nutrient input the freeze cycle would set in again. Something happened at the end of the last frozen episode that broke this cycle. It also resulted in the huge explosion of life forms that marked the start of the Cambrian period. I suspect it was the evolution of lichens capable of colonizing terrestrial rocks. Many lichen-forming fungi have an amazing ability to dissolve rocks, creating cavities in which to live and reproduce. This surface mining would have created a whole new weathering system capable of delivering enhanced nutrients to the oceans so preventing the boom and bust cycle of the past. Without lichens we might not be here today.

The first definite fungi appear as fossils in rocks laid down in the Ordovician and Silurian periods over 400 million years ago. At Rhynie near Aberdeen a volcanic eruption 430 million years ago pickled with hot, silica-rich water the first semi-aquatic plants living in a nearby pond. These plants had a rather well-developed system of root-like structures anchoring them to the mud. Standing in water these structures are more than is required for simple anchorage or the uptake of water. They were, however, packed with what look exactly like the fungi that you can find in most plant roots today. These so-called Glomalean fungi are all but ubiquitous in higher plants and are also frequent in liverworts. They form a useful mycorrhizal association, assisting the plant in the uptake of nutrients. This was almost certainly the case at Rhynie. It is also probable that this association drove the early evolution of root-like structures in order to house the fungi. These structures then required little adaptation to create the water absorbing roots for plants to conquer the land and therefore facilitated this process. Without this pre-adaptation it may have taken far longer for plants to conquer the land. So we have another reason to thank the fungi.

Once on land, even with fungi to help take up phosphates, supplies of nitrates would have almost certainly been in short supply. Unless that is cyanobacteria and probably lichens containing them had already evolved a terrestrial lifestyle, fixing nitrogen from the air that the new land plants could use.

Recently studies on nitrogen cycling in natural ecosystems have identified the important part still played by cyanobacteria, whether free-living or inside lichens. All living organisms are surrounded by leaky membranes. Substances leach out all the time. In near-natural old growth forests in N. America it is estimated that cyanobacteria containing lichens on the trees and rocks contribute over a third of the total nitrogen compounds passing through the system. Free living cyanobacteria amongst moss cushions add to this total. Ancient trees with broad moss and lichen-covered branches and trunks and consequently a larger standing crop of cyanobacteria make a significantly greater contribution of nitrogen compounds to the ecosystem compared to the young regrowth of plantation and coppice woods. Oliver Rackham has recently estimated that to achieve coppice regrowth of the same size, the coppice rotation cycle has doubled in length in woods in eastern England today compared with medieval times. He postulates this is the result of nutrient drain through the removal of timber and brash over the years. I believe it is much more likely to be due to the almost total loss of cyanobacteria from eastern England due to atmospheric pollution and a lack of suitable habitat for them now.

This may also explain why so many of our oak woods in central and West Wales look and are nutrient poor. Mosses and liverworts dominate. This group of plants is known to be miserly with nutrients. They are very good at recycling within themselves whatever they have got hold off. They are very poor at sharing. The radiation problems following the Chernobyl accident persisted longer than predicted as the experts had not factored in the ability of mosses to take up and hang on to the radioactive cesium.

If you visit Western Scottish Highland woods that are rich in cyanobacteria-containing lichens, they mostly also support a rich ground layer of herbs such as primroses despite sheep, deer and goat grazing. These species in Wales are now rare and are confined to the more basic parts of the woodland. We know we have lost lots of cyanobacteria-containing lichens from Wales because at Hafod in Ceredigion we can glimpse the pre-industrial Welsh lichen flora. Specimens were collected in the 1790's by Thomas Johnes' daughter Mariamne and the Queen's botanist James Smith and they are still preserved in the Natural history Museum, London. Their enormous size and the number of fungus fruit bodies on them is astonishing to a 21 century lichenologist. They barely look like the same species we find today so dwarf are many of our current specimens. Species described then as common are now found in just a few very sheltered base-rich sites. Some lichen species described as "frequent" in the 1790's have gone completely.

Cyanobacteria hate sulphur dioxide and acid rain. We have cleaned up the sulphur dioxide but it is still raining nitric acid even in remote rural areas of Wales. As long ago as 1985 it was a concerned Liz Fleming-Williams who personally organised the first conference on acid rain in Wales at which I was recruited to speak. I could give almost the same talk today so little has changed regarding the impact on lichens.

The revolution which she hoped to engender has been long in coming and has now been overtaken by concerns over global warming. Acid rain still dogs the lichens of most of Wales. We have learned that just here and there by a combination of local topography, usually in the shape of high ground to the east and with a somewhat basic soil and the naturally basic bark of trees such as ash and willow a fragment of what would have been the lichen cover of a lot of Wales survives. In these deep sheltered ravines the trees are covered with enormous growths of tree lungworts, jelly lichens, fish-smelling Stictas and other specklebelly lichens as the Americans call them. A recovery might just be possible if we can get rid of acid rain.

Only recently has the ubiquity and extent of mutualistic fungal relationships been established in flower-rich ancient grasslands. Here thirty flowering plant species or more can occur in a few square metres. Ask any gardener to create such diversity in an herbaceous border and they would be dubious that so many different sorts of plant could be grown side by side. In no time a few species will outgrow all the others. Why doesn't this happen in ancient grassland? It appears that the roots of the plants are all linked together by fungi. Through this network nutrients are redistributed, so if one species does well its nutrients are redistributed to the less well-off and a balance is struck.

Why should plants tolerate this redistribution of nutrients that almost amounts to theft? Phosphates in particular are thought to be in short supply and fungi are superbly adapted to release phosphate molecules otherwise trapped on the surface of clay particles in the soil. Get rid of the fungus and you lose your main supplier of essential phosphates. In such a competitive environment seedling establishment could also be critical. Fungi might help channel nutrients into the seedling-even linking it to the parent plant. The inadvertent loss of materials to your neighbours might be a price worth paying if it assists the establishment of your own offspring. The fungus network ranging deeply into the soil might also help with the uptake of water, particularly in times of drought. OK-so sometimes you are taken advantage of. Plants such as the yellow bird's-nest, a relative of the heathers, have done just this, giving up chlorophyll production and photosynthesis and using the fungi to channel nutrients in from adjacent trees, whilst probably offering nothing in return. Orchid seedlings are classic examples of a cheat who seem to just parasitize the fungi. There will always be a few who try to cheat the system.

This network of interconnecting hyphae-as many as a couple of hundred miles in a square metre of soil- also has the ability to transmit information between plants. If you are being attacked by, for example, some ghastly caterpillar and you share your genes with lots of your neighbours, your genotype could be better preserved if you could let the neighbours know of the imminent danger and they could prepare to ward off the attack by secreting appropriate chemicals. With such a warning system the expense of producing defensive chemicals is limited to when they may actually be needed.

If you add fertilizers to these flower-rich grasslands, unless it is in small amounts and bound into other organic matter such as in farmyard manure, the results on plant diversity can be catastrophic. Within a few seasons their species diversity declines and a few plants come to dominate such the annual grass called soft brome, sorrel, dock, plantain and thistles, all species that generally have fungus-free roots.

The suspicion is that the fertilizer destroys the fungi and their nutrient dispersing web. Is this why recreating flower-rich grassland is so difficult? In the last 60 years we have destroyed 98% of the species-rich lowland grassland in England and Wales. This may have been a costly mistake.

Unfortunately and without any long term future planning, we have become dependent on agricultural systems that can only deliver the food if we add in large quantities of nutrients. Nitrates and ammonia can be manufactured at a high cost in energy. Each year now we all but double the quantity of nitrate and ammonia in the terrestrial ecosystems of the Earth by fertilizer usage. No wonder excessive nutrient enrichment is one of the greatest threats to our wild plants and fungi. Such fertilizers are mostly manufactured using fossil fuels which is undoubtedly not sustainable.

But more worrying still is our dependence on phosphates. They cannot be manufactured. Since we learned to till the land, in those 2000 or more years we have developed crops most of which require additional phosphate. In farming systems without livestock, to meet this requirement we have been scraping phosphate up from a range of now rapidly diminishing resources. The sub-fossil bird guano of the Pacific has all but gone, leaving only narrow seams of rock phosphate to be mined at great expense. A lot of the rock phosphate is also in politically strife-torn areas such as North Africa. The best estimates give us about 200 years of supply left. In that time we may need to replace the crop plants that have a high phosphate requirement. Many of these plants originally evolved in naturally phosphate-rich areas such as sea cliffs-for example all the members of the cabbage family, the beet family and plants such as carrots and parsnips. They did not need mycorrhizal fungi since seabirds regularly delivered fresh supplies of phosphate. Without mycorrhizal fungi these plants were also easier to cultivate provided we continued to supply them with phosphate in place of the seabirds.

As an alternative to replacing these crops we could try and fit mycorrhizal fungi into their roots so they could grow in soils low in phosphates. Where would we seek such fungi? Probably amongst the plants in those few remaining old flower and fungus-rich meadows. How ironic that as I was writing this last week I heard that the Grasslands Conservation Trust had felt compelled to wind up due to a lack of funds whilst an osprey project received in one grant, enough money to keep the Grassland Trust going for 30 or more years.

With our new-found ability to sequence cheaply the DNA of organisms all sorts of mycological surprises are occurring. Most plants it seems are full of fungi that live in their cells. Over 60 different sorts of these endophytes have been found in, for example, oak leaves and bracken fronds. Is this the trick that protects them so well from a range of potential pathogens? Both of these species have enormously long generation times that seem to compromise their ability to evolve to meet new challenges. Our crop plants succumb to new diseases in but a few years yet little seems to successfully attack the ubiquitous and very long-lived bracken.

As yet we understand little about the function of endophytes. Until recently they would have been considered some sort of undesirable parasite-after all fungi have a generally bad name! From initial studies many of these fungi appear to be beneficial. Yes, the plant pays a price to house them, but in return it seems to receive ample reward in the protection they confer against other pests and diseases. A study of the simple squirrel-tail grass provides a telling example. This grass normally contains a handful of endophytic fungi. Dose it with fungicide to kill them and plant it in sterile soil and it continues to grow well. In this case the fungi don't appear to assist in nutrient uptake. But plant it out back in the wild without its fungi and it immediately succumbs to that widespread of pathogenic fungi-the snow mold. If you re-inoculate it with its fungi before planting it out it does not succumb. Does this help to explain the widespread occurrence of endophytic fungi? Let's consider another example.

Grasses that succumbed to the ergot fungus slightly reduce their seed set because the fungus takes over the odd ovary. This initially seems rather undesirable. But ergot contains chemicals that cause abortion in grazing livestock. Perhaps in the long term an infected grass is more likely to be successful if by growing a few sclerotia of ergot there will be fewer herbivores that might otherwise have eaten most of their seeds? Grasses that evolved to resist ergot might end up having all their seed heads eaten by herbivores and so loose in the struggle for survival. We have benefitted from this relationship. Ergotamine, originally obtained from ergot is still a very useful drug to reduce the debilitating effects of migraine and help staunch blood loss in childbirth.

Remember also the tamoxifen story? This drug, effective in the fight against breast cancer, was expensively extracted from the clippings of yew trees. The discovery that it was actually produced by a fungus in the yew and the identification of a strain of fungus, cheap to grow in the laboratory, has so reduced its cost it can now be offered as a prophylactic. How many more such beneficial drugs are endophytic fungi producing that we are unaware of?

Another revolutionary discovery is that many endophytic fungi have within them bacteria. Some of these bacteria, like their relatives the cyanobacteria, fix nitrogen from the air. Developing crops with this ability would reduce our requirement for artificial nitrate and ammonia fertilizers and reduce our dependence on the clover family. Sugar cane for example has been found to get a substantial quantity of its nitrogen from this source. How many plants in these old meadows make use of this symbiotic relationship that we could turn to good advantage? Have we conserved enough to ensure their survival or have we already unwittingly wiped out potential treasures?

In fact have you said thank you to a fungus today?! Did you enjoy your bread, beer or wine? Thank the yeast fungi. Have you enjoyed a glass of fruit juice? Thank the fungi that produced the enzymes that have so cheapened fruit juices we can all enjoy them. Enjoyed a pickle? Fungi produced the acetic acid. Enjoyed tea or coffee? Fungi played a part in the fermentation processes that gave then their distinctive flavor. Are you taking statins? They are the most widely prescribed drug in the world and were derived from fungi. Many antibiotics come from fungi. If you need an organ transplant then thank a little soil fungus. It provided the original essential immuno-suppressant that makes transplants possible.
Fungi contribute directly to our diet in a range of delicious mushrooms. Their high quality protein can be produced from what otherwise would be waste products. There is also growing evidence that many fungi produce chemicals that improve the functioning of our immune systems.

Yet still we are probably the most mycophobic of races on planet Earth. Why? Well I suppose I frightened my children with dire tales of what would happen to them if they ate toadstools. Some fungi are after all very poisonous. I gleefully bought them a book entitled Fungus the Bogeyman by Raymond Briggs. An older generation read Lewis Caroll - where Alice in Alice's Adventures in Wonderland, suffered strange and disturbing size changes from eating a fungus. Caroll would have read stories of Siberians who ate fly agaric mushrooms, the one with the red cap and white spots to while away the long dark winter. Still intoxicated by it, the journey home was apparently fraught since it greatly affected their perception of an objects size. Encountering a straw lying in the road the intoxicated reveler would take a gigantic leap to cross it. The Siberian shaman also administered dried fly agarics to ward off the worst effects of “SAD”-that depression created by a lack of sunlight. Their ceremony was completed by an exit from the yurt up into the roof and out through the smoke hole, an action perhaps later imitated by Father Christmas? When consumed this fungus also created the illusion of flight and was an essential constituent of the “flying ointment“ that witches smeared on their broomstick handles. Reindeers eat fly agarics and then behave strangely. Father Christmas is red and white like the fungus and that this gentleman and his reindeers fly through the night sky is perhaps no coincidence.

Let a Magic mushroom grow on your lawn and you now face the sort of legal penalty reserved for the possession of a bag of heroin as it is considered to contain a Class A drug. The National Museum of Wales has had to get rid of collections of any fungus that might contain a trace of psilocybin as it cannot afford the cost of the licenses necessary to keep them. The pharmaceutical industry is also forced to jump through legal hoops to research the potential benefits. And the benefits could be great. Anxiety and depression dog us yet these fungi have created chemicals that can shut down bits of our brain-the bits that at times can be too active for our own good. Is all this why we are so uncomfortable with fungi?

You can hunt in vain for the “book of the good fungus”. John Wyndhams novel of 1960 entitled Trouble with Lichen was such a success that few people of that decade will not have the word association of “trouble” and “lichen” fixed in their head. Yet lichens weren’t the trouble. For those unfamiliar with the book the plot starts with a young research chemist discovering a substance in a rare lichen that stops humans aging.

Humans then rapidly become the trouble. How prescient of Wyndham to link lichens with substances that correct the defects associated with aging. In the last few months scientific papers have been published regarding a potentially important new compound, found in a range of lichens that break down the badly folded proteins called prions, the cause of BSE, "mad cow" or Creutzfeldt–Jakob disease. Perhaps it should not be surprising that such long-lived individuals, as many lichens appear to be, have evolved substances to mop up and destroy badly deformed proteins. The tree lungworts (Lobaria species) contain the prion busting enzyme. Due to the loss of ancient trees and acid rain, like Wyndham's anti-aging lichen, they are now desperately rare in much of Britain. Perhaps now we ought to take their conservation more seriously. A cure for prion protein diseases might free us from the necessity to burn at high temperature and at great expense all the fallen farm livestock in Britain.

If we don't conserve fungi we have much to lose. Fungi have evolved countless relationships with all manner of organisms to the benefit of both and with huge potential benefits to us. Fungi and bacteria appear to have founded so many mutualistic relationships with plants and animals that an organism living on its own now looks decidedly odd. Darwin's "survival of the fittest species" as a driver of evolution remains sound but so equally would be the concept of survival of the fittest consortium of species.

The survival of these consortia requires that there should be mutual benefits to the partners. In many cases the benefits seem to have come from the creation through natural selection, of a whole wealth of chemical systems that offer one or other partner benefits and which we might yet be able to put to good use. Why therefore do we commit such scant resources to the conservation and study of fungi? Is it because fungi have such a bad press? Yet none of us would be here today without them. Fungi keep the life support systems going on spaceship earth. A substantial proportion of the food we eat today depends on fungi for its production and a lot of us would not be here now but for drugs derived from fungi. Keeping an increasingly large human population fed is going to be a serious challenge and at present fungi could offer a solution to some of our most pressing resource problems.

The temptation has been to assume that if we conserve a range of habitats other organisms such as fungi will also be conserved. For some species this is may be true but for many it is a dangerous assumption.

For example we nearly lost the best grasslands for fungi. The waxcaps, pinkgills, fairy clubs and earth tongues amongst other fungi unfortunately favour such heavily grazed or mown sites, they were unlikely to be defended for other groups of organism. Despite Dr. Gareth Griffiths best efforts at the University of Aberystwyth we still understand little of the life histories and biology of many of these species. How is it that as many as 28 species of waxcap can apparently coexist together on a single ancient unfertilized lawn-apparently the most uniform of all habitats?

Pasture woodlands were another classic case. Ill-favoured by woodland experts as being woods on their last legs due to overgrazing and by grassland experts as not proper grasslands, it took the lichenologists, mycologists and entomologists to recognize their special qualities before conservation action was taken.

We probably now know enough about lichens to at least begin to consider how threatened they are and determine how well current conservation designations cover their diversity. For almost all the other fungi the work has still to be done. For most we have no idea of their status. Perhaps of greatest concern is the reduction of funds to organizations like the Countryside Council for Wales. In recent years it has been forced to curtail its advice on none specially protected areas. Now only those species listed in the European Habitats and Species Directive tend to be considered. No need for CCW to employ a mycologist then since only a single fungus and no lichens appear on the specially protected species schedules of the Directive. Interestingly the only fungus listed is a rather odd Sicilian endemic. It is probably best not to pry too deeply into the selection process! There should certainly be lots of fungi and lichens on the schedules, but the politicians ducked out of the selection process. Bats, otters, newts and dormice appear to be enough of a political challenge. So fungi now lie beyond the conservation pale of the Welsh, British and European Governments. Their conservation is now left almost entirely up to us the public and the voluntary bodies.

I hope I have convinced you that we ignore the conservation of fungi and lichens at our peril. They literally and metaphorically thread through the ecosystems of our planet in a way we could not have guessed at a few years ago. A mutualistic lifestyle, for so long considered to be special to lichens, now turns out to be more the norm in nature. The relationships of species are richer and more complex than we ever imagined. Darwin always left me feeling uncomfortable with a living world perceived to be full of self-serving solitary species struggling for survival. I feel happier that survival for most species seems to involve the creation of mutualistically beneficial relationships. As these dreadful events unfold around us here in Machynlleth tonight I hope that the new relationships they will undoubtedly create will strengthen the human community here.

I believe that we, the human species, for too long the wrecker of the complex webs of the natural world, have no option but to reconnect with this great web so we can gain the full benefits that a truly mutualistic lifestyle obviously brings.

And finally can I offer a particular challenge to all you nature writers to rehabilitate the fungi and celebrate the lifestyle of lichens? I know Bill would have risen to the occasion!

Ray G. Woods, Newbridge-on-Wye 2012

Further reading

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