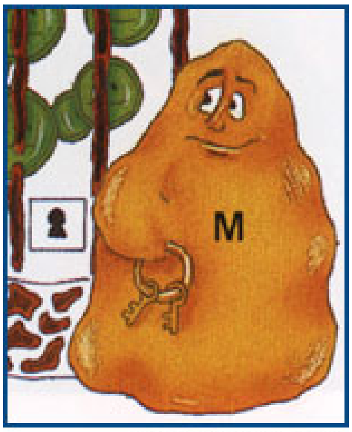
Lichens: Born Survivors of Extreme Environments

Editor's Introduction | Lichens are organisms that consist of two partners that live together symbiotically and they occur almost everywhere. They can be found in some of the most extreme environments on earth--arctic tundra, hot deserts, rain forests, rocky coats and toxic spoil heaps. Since these environments are among the most sensitive to destruction and pollution, our rich and varied lichen heritage is incredibly useful in allowing us to assess what we are doing to our environment. William Purvis, lichenologist at The Natural History Museum, explores the complex and changing world of lichens.

Lichens are organisms that consist of two partners that live together symbiotically--in association with each other. One partner is fungal (mycobiont) and the other, the photobiont, can photosynthesise using sunlight to make carbohydrates. The photobiont may be a green alga or a cyanobacterium (previously called a 'blue-green alga'). Some lichens are more complex and consist of three or more organisms.

Ian Murroe

Xanthoria parietina. This lichen has orange, disc-like fruiting bodies.



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Detail from cartoon:
Is the lichen thallus a controlled form of parasitism?

Lichens are not simply organisms--they are mini-ecosystems. The fungus traps the algae between the upper protective cortex and medulla, which is the central air-filled region of the lichen. The discovery of this controlled form of parasitism was made in the 1860s by the German scientist Simon Schwendener. He considered green algae to be 'slaves' that were compelled into the service of the fungus. His ideas were not widely accepted at that time!

The photobiont photosynthesises to produce carbohydrates, which the fungi use for their nutrition. It is this symbiotic relationship that allows lichens to colonise extreme environments. The association of partners is not a simple mixture but results in the formation of a distinctive lichen body called a thallus, with no division into root, stems or leaves. In this body, the photobionts are housed to the best advantage for photosynthesis.

Lichens exhibit an extraordinary variety of forms, and colours range from dull grey-browns to brilliant yellow- or orange-red. The smallest are crust-like (crustose) growths growing on rocks, wood or soil and can be almost invisible to the naked eye. They are often brightly coloured and can cover rocks almost completely, often making it difficult to detect the rock type beneath. Shrub and beard-like (fruticose) lichens are much more obvious. Beard lichen (sometimes popularly known in Sweden as the 'Christmas tinsel lichen') can grow to lengths of up to two to three metres in coastal rain forests in the Pacific Northwest. A strange lichen is the Worm lichen because it resembles flat, worm-like growths. This lichen is completely unattached and spreads out amongst the thin vegetation at high altitudes on mountains throughout the world. Other types include the tiny stalked Pixie Cup and Matchstick lichens (Cladonia) which often have brightly coloured fruiting bodies at their tips. These produce spores that once disseminated must meet with a compatible alga to form a new lichen.

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Beard lichen, *Usnea longissima*.

Leaf-like (foliose) lichen species have an upper and a lower surface, for example, *Parmelia sulcata* , one of the commonest lichens in the world. The tree lungwort, *Lobaria pulmonaria* has a broad expanded lobe and is restricted to ancient woodland areas in the British Isles, rather than recent ones, and is therefore a very good indicator species of this type of environment.

The fungus or mycobiont, is one of the two fundamental components of lichen. It is usually an Ascomycete, related to the familiar cup-shaped fungus the common orange-peel fungus or the highly-esteemed edible morel. However, a few lichens contain the more familiar fungi, the Basidiomycetes, more commonly known as toadstools.

Most ordinary fungi are very transient and their fruiting bodies disappear after the autumn period. Lichenised fungi, however, often have perennial bodies that are present throughout the year. Many produce tiny, powdery asexual propagules (mini packets of intertwined fungi and algae), which permit reproduction to occur on a regular basis, without the need for spore dissemination and a compatible alga. The powdery propagules break up and are spread by a variety of different processes such as the wind, animals or migratory birds.

The other fundamental component of a lichen is the alga, or photobiont. Relatively few algae are found in lichens, and of the twenty or so different genera known to occur, only three are common: the green *Trebouxia*, the orange-pigmented *Trentpohlia*, and the cyanobacterium, *Nostoc*. Cyanobacteria are commonly called blue-green algae, although they are not strictly algae. They are classified as photobionts because they photosynthesise and live within lichens.

The lichen life style is remarkably adaptable and they will often have different photobionts at different stages of the life cycle. At certain times it may be advantageous for the lichen to contain cyanobacteria because they are able to fix atmospheric nitrogen to form amino acids and other complex organic molecules. The lichen fungus is able to then break these down. *Lobaria pulmonaria*, which has internal accessory cyanobacteria, and *Placopsis lambii* , which has external cephalodia (special wart-like structures containing cyanobacteria), are two species that always contain them.

One of the great advantages of this ability is that it enables lichens to grow in nutrient-deficient situations, where there is very little nitrogen. Lichens are therefore extremely effective colonisers in environments such as surfaces that are newly exposed after volcanic eruptions or other environmental disasters, shingle beaches, moorlands and areas where glaciers have retreated. All these areas may be colonised by lichens containing cyanobacteria.

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The two different forms of *Sticta canariensis*.

Lichen algae play a major part in determining what a lichen looks like, how it functions and where it grows. Sometimes two lichens may contain the same fungus, but their different algae may render them completely dissimilar in appearance. For example Sticta canariensis can either be small and grey with dissected lobes or a large bright green leafy structure with fruiting bodies. Although they grow in different environments, and have varying chemical and physiological makeup, both fungi are actually the same, as is reflected in both lichens sharing the same name.

Lichen hitch-hikers are those that grow on other lichens. Some of these relationships can be extremely complex. A hitch-hiker can either have its own alga or share that of the host. They may be parasitic or apparently live in harmony with its host.

Even in geographically isolated locations in the Northern and Southern Hemispheres, there are remarkable degrees of similarity between lichen floras, certainly in comparison to the distribution of flowering plants. One of the reasons for this is the immense power of dispersal through such methods as asexual reproduction. Some lichens have strange methods of reproduction. One such example is the mechanical hybrid formed by Xanthoria parietina (yellow lichen) and Phaeophyscia (grey lichen). The former reproduces sexually by forming spores and the latter asexually (by powdery 'soredia' containing fungal and algal cells). Both propagules can infect each other creating so-called 'mechanical hybrids'. In addition, some lichens exist either as an asexual form producing soredia, or as a sexual form. Despite often containing identical chemical substances, the fertile form is usually restricted geographically, whereas the asexual form is far more widespread. Recent molecular studies are providing valuable clues to their precise relationships (i.e. whether these 'forms' should be regarded as the same or different species).

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Mechanical hybrid between a *Xanthoria* lichen (yellow) and a *Phaeophyscia* lichen (grey with a yellow tinge).

Unfortunately, very little lichen (or indeed fungi material as a whole) is preserved in the fossil record. Although many consider lichen to be among the most primitive organisms, evidence neither proves nor disproves this fact. The earliest records date back to the Devonian period, about 400 million years ago, although these particular lichen-like associations do not contain green algae, but cyanobacteria. Similar modern day lichen species grow in cloud forests and other temperate rainforests in Chile and Australia, and the relic species found there are considered to originate from Gondwanaland--the landmass that existed when South America and Australia were joined together. As most lichens that produce powdery propagules are associated with green algae and not with cyanobacteria, so the ancient fossils may display a very rare form of reproduction. Scientists have discovered that lichenisation did not just occur at one particular time, but on many different occasions and in many different fungal groups, so it has been impossible to prove or disprove the fact that they are any more ancient than non-lichenised fungi.

Lecanora vinetorum (vine lichen) is just one of several lichens whose origins are unknown but which grows in an unusual and restricted environment. It might be an example of recent evolution, but it is definitely an example of an extraordinary adaptation to human activity. This lichen is completely restricted to vine supports, and is regularly sprayed with fungicides containing copper on which it appears to thrive. A similar example is seen with the pollution lichen, *Lecanora conizaeoides*, which is now declining in many areas following reductions in sulphur dioxide air pollution.

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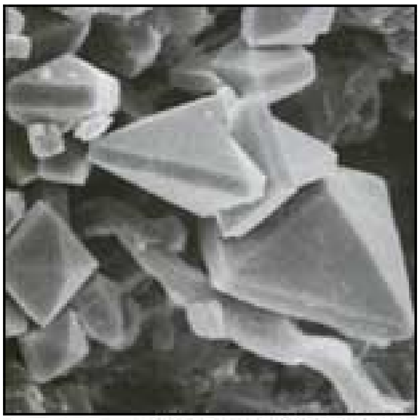
Lecanora vinetorum.

The basic physiology of lichens is what determines their efficiency at growing in extreme environments. Because they lack roots, they are able to grow on rock surfaces and bark, relying on absorbing substances throughout their upper surface, which lacks a waxy protective outer cuticle. Minute pores are often present and the upper layer contains polysaccharides (carbohydrates), which attract water. The algae rest just below the surface, which also contains light-screening compounds to protect them under high levels of ultraviolet radiation. Green algae produce the sugar alcohol ribitol and cyanobacteria produce glucose (sugar), which are passed over to the fungus and rapidly converted to the sugar alcohol mannitol. This process ensures that lichens have the extraordinary ability to maintain themselves during very long dry periods, where they hardly metabolise at all. In the Antarctic, many lichens can function under very low temperature conditions and actually photosynthesise under the ice.

The huge chemical arsenal lichens possess helps ensure their survival under extreme conditions. Some species contain up to 30 percent dry weight of organic compounds, which act as 'stress metabolites' Others have antibiotic activity, and this acts as a deterrent to other organisms that may prey on the slow-growing lichens. The same compounds also act as detoxifyers where toxic levels of metals are present, and play an important role in keeping some lichen tissues dry to allow gaseous exchange and carbon fixation. Examination of lichen under the microscope reveals the presence of calcium oxalate crystals in some cases, giving the appearance of a more mineralogical, rather than biological, structure. The production of oxalates is one way lichens can tolerate extreme environments.



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Calcium oxalate crystals on the surface of the lichen *Aspicilia mashiginensis*.

Lichen-dominated vegetation accounts for about 8 percent of land surface. They grow in almost all natural environments apart from the deep sea, and in a variety of different climatic conditions. They also grow in cities (e.g. churchyards) and, depending on pollution levels, many other environments created by humans. They play a very important ecological role as carbon fixers, and recyclers of the elements and nutrients, nitrogen, phosphorous and sulphur. They also assist in breaking down rocks. On rocky coasts, lichens form one of the classic examples of ecological zonation, with each level subject to different exposures to salt. The fact that lichens have adapted to these particular conditions can be seen in the variation of species and colours.

Many species are restricted to rocky coasts but others have been able to colonise new habitats, especially as a result of humans having changed the environment. The orange lichen *Xanthoria* is frequently seen growing on gravestones originated from a coastal habitat. It usually grows on the top of gravestones where it is enriched by bird guano. Stonehenge, an extremely famous ancient monument in Great Britain, carries some maritime elements that would normally only be seen over a hundred miles away on the coast, suggesting that it has been exposed to salt-laden winds, or else they originated with the stones.

In Britain, lichens occur from rocky coasts to the tops of mountains. In many mountainous areas and Arctic regions the tundra-like vegetation is dominated by reindeer lichens while in the scorching Atacama desert in Chile *Usnea* clothes cacti. Lichens are able to thrive in desert areas, which are subject to off-shore mists and sufficient air humidity to absorb moisture. The boreal forests of Russia and Canada are also carpeted with lichen-rich heaths and in these environments the lichens play an essential part in fixing nitrogen, which helps the trees in these nutrient-poor habitats. In these habitats *Cladonia* or reindeer lichens are dominant and form an important part of the food chain. Studies of the gut contents of reindeer at various times of the year in Hardangervidda, Norway found that of the various dietary components--woody plants, grasses and shrubby lichens--the lichens constitute up to 50 percent of the dietary intake, particularly in the winter months when many other plants are unavailable.

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Usnea lichen growing on cacti in the Atacama desert, Chile.

Because usnic acid gives a unique spectral reflectance, it is possible to use remote sensing techniques to plot the arctic heaths of northern Russia, northern Norway and other localities. Satellite pictures taken by the Norwegian scientist Hans Tommervik have charted the decline and reinvasion of lichen heaths as a result of changing emissions from metal smelters.

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Neuropogon aurantiaco-atra in the herbarium of The Natural History Museum.

The Antarctic also supports lichen populations. The majority is covered by ice but the ice-free areas, particularly the maritime regions, are dominated by lichens. Such is the abundance of the shrub-like Neuropogon aurantiaco-atra, that Charles Darwin first mistook this lichen for grass when viewed from a distance around Cape Horn during his voyage on the Beagle in 1833! Many yellow and black lichens contain melanin-like pigments and yellow usnic acid, 'natural sun-screens', particularly useful in areas that are subject to very high levels of UVB radiation. These levels might vary in response to changes in the levels of UVB radiation, providing us with information about the thinning of the ozone layer, and giving lichens the ability to cope with dangerously high levels of UVB.

Perhaps the most extreme environments on earth are the dry interior Antarctic valleys. Such environments are the closest terrestrial equivalent to Mars in terms of temperature extremes. There's very little precipitation and the only areas where life can exist are embedded within rocks. The organisms that live in this habitat are known as cryptoendoliths and are uniquely adapted to this environment. They only occur in certain porous rocks. Light is transmitted through a translucent upper layer of quartz or some other similar mineral overlying a pigmented area, which absorbs the ultraviolet radiation. The rocks also contain fungal and algal zones, which consist of loosely differentiated organisms. Under certain environments, if conditions become suitable they may form an ordinary lichen.


Chris Gilbert/British Antarctic Survey
Antarctic cryptoendolith.

Erasmus Darwin, father of Charles Darwin, observed how lichens failed to grow near Copper Smelters at Parys Mountain over 200 years ago. But it was not until sulphur dioxide, a product of fuel combustion, was identified as a major factor influencing lichen growth, distribution and health in the 1960s that the exponential growth worldwide in biomonitoring studies occurred, with now well over 1,500 papers published on the subject. Many substances may be detected and monitored using lichens, including ammonia, fluorine (e.g. from aluminium smelters), eutrophication (e.g. fertilisers), alkaline dusts (e.g. from quarrying), metals (e.g. from incinerators), radionuclides (e.g. from nuclear accidents), chlorinated hydrocarbons (e.g. from pesticides) and 'acid rain' (fossil fuel combustion).


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Parys Mountain.

Lichens are so useful because:

- They are found almost everywhere and at all seasons
- They absorb nutrients and pollutants from the air, often to high concentrations
- Different species show different sensitivities and accumulation abilities
- They are symbiotic organisms. The fungus cannot survive if the alga is killed by pollution
- Instruments are vulnerable to theft and vandalism

Many studies have shown that the more lichens present in an area the better the air quality. High concentrations of sulphur dioxide result in the formation of lichen deserts where few lichens can survive. Today, as levels are greatly reduced following changes in fuel use, many lichens are returning to our cities. Many methods are available to record lichen diversity, health and distribution.

Chemical analysis. Chemical analysis of lichens provides information on the types of metals and their concentrations in the environment. Several studies have shown a relationship between the quantities of pollutants in the environment and those concentrated in the lichen body. Lichens are usually unharmed by metals and they can be monitored over wide areas.

Aerial metal contamination. A good example is the catastrophic nuclear disaster in May 1986 in the Chernobyl district of the Ukraine, which resulted in a radioactive cloud being spewed over much of Europe. This had important ecological consequences, especially in sub-arctic areas in

Norway and Sweden where reindeer lichens absorbed high concentrations of radionuclides. In turn, the reindeer that relied on these lichen-rich heaths as their source of food absorbed fairly high levels of the radionuclide, caesium 137. In some areas this had a dramatic effect on indigenous people, particularly the Sami, who relied on reindeer for their livelihood. Levels were such that in many cases they were unable to eat and sell reindeer meat and the herds were either culled or moved off the area. Thus the Sami lost their primary source of food and livelihood and their future is still under threat. One positive outcome is that by analysing lichens, scientists were able to plot the distribution of the radioactive cloud.

Mineral Prospecting. Steve Czehura, an exploration geologist working in the US in 1977, was one of the first to realise the potential for rock-growing lichens as exploration tools. He found that the intensity of the green colour of crust lichen *Lecanora cascadensis* was directly proportional to the copper concentration of rocks in Montana. Different lichens have evolved various mechanisms to avoid the toxic effects of metals, some forming unique metal compounds not known elsewhere. Several such lichens look so odd that they have been described as different species on several occasions. Indeed, herbaria throughout the world may provide clues to the existence of undiscovered ore bodies. By understanding how lichens accumulate metals we may develop novel technologies to clean up the environment as well as monitor its success.

Lecanora cascadensis accumulating copper.

Never before has there been such a demand to monitor our environment. Pressures to control pollution are growing throughout Europe; stringent limits are being placed on releases of pollutants to air, land and water and we need to understand what these substances are doing to both ourselves and our environment. Biomonitoring using lichens is emerging as a key answer to this problem and promises to be an extremely valuable collaboration between those involved in instrumental monitoring, modelling and other life and earth scientists. There are opportunities for everyone, at all ages, to get involved. Biomonitoring with lichens will not only help the environment and human health, it will also promote the public understanding of science.

Books:

Title: Lichens (Natural World Series)
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