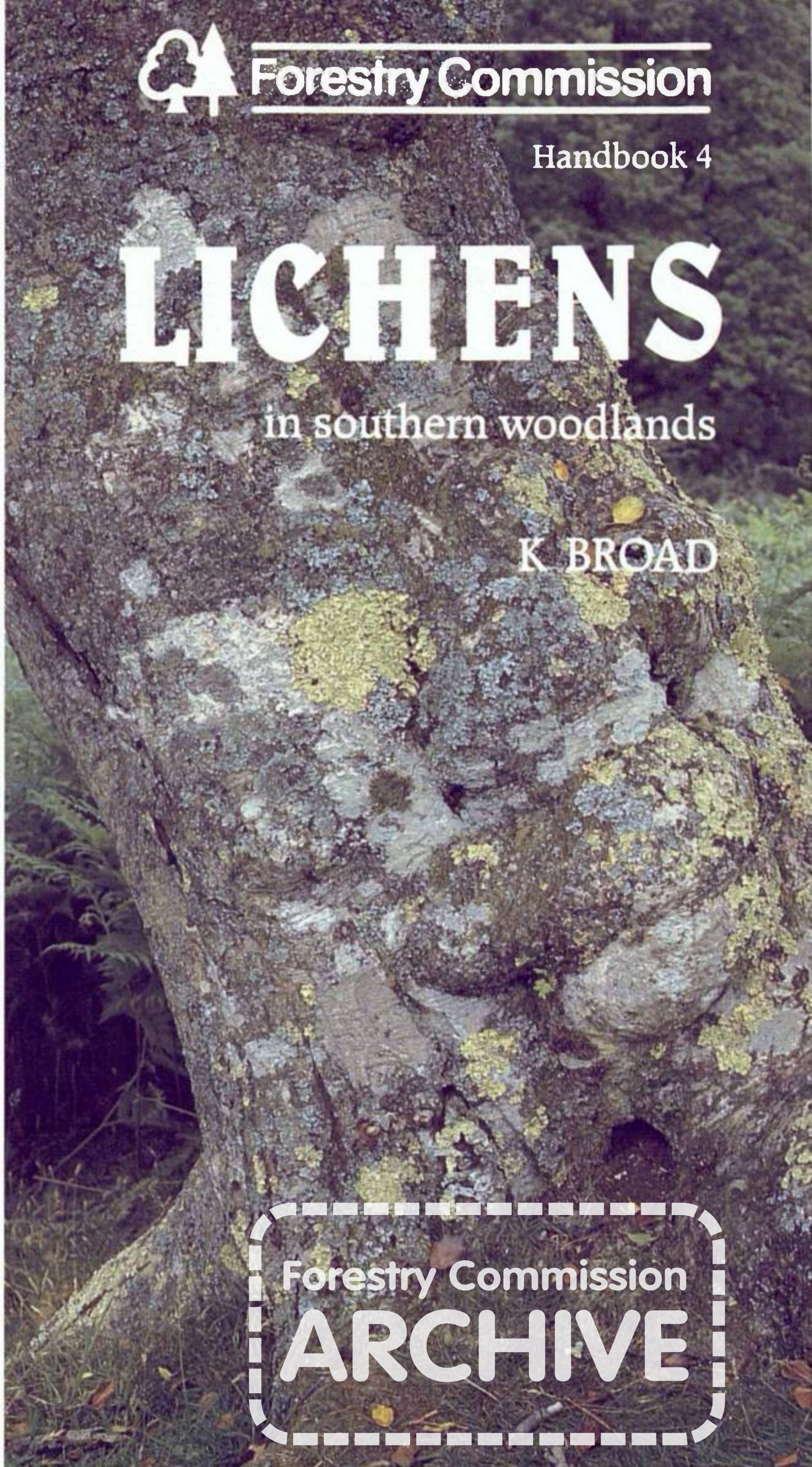
Forestry Commission

Handbook 4

LICHENS

in southern woodlands

K BROAD



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Lichens
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By K. Broad
Forest Officer, Forestry Commission

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Most of the photographs were specially undertaken by Miss I Cameron (Photographic Department, FC Headquarters). Plate 30 *Lichens and air pollution* is reproduced by kind permission of the artist, Claire Dalby, and by agreement with the British Museum (Natural History) and BP Educational Service. Certain information, data and figures are reproduced or adapted from publications by Drs Hawksworth and Rose with their kind permission. Dr Mark Seaward provided Figures 5 and 6.

The author makes no claim to being anything other than an enthusiastic amateur in the field of lichenology and has gained much knowledge on the subject from many of the publications listed in the Bibliography.

Enquiries relating to this publication should be addressed to the Technical Publications Officer, Forestry Commission Research Station, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH.

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Introduction

Why study lichens?

Today's forest manager lives in quite challenging times. Although his main objective is still the economic production of timber, he is having to accept ever-wider responsibilities in environmental and wildlife terms and his actions are without doubt being closely monitored. Furthermore he will be, indeed he should be, held responsible for any adverse or damaging habitat changes that result from the implementation of his policies.

Initially it is perhaps difficult to appreciate how the study of lichens might make a positive contribution towards accepted and conventional forest and woodland management techniques. We would have to acknowledge that these curious scraps of vegetation might hold a fascination for some people simply because they are such extraordinary plants, but if foresters, woodland owners, their agents and even timber contractors are to be encouraged to take an interest in lichens then it is necessary to demonstrate their worth in terms of their functional application in addition to their values from purely aesthetic and natural history standpoints.

The study of a woodland's lichen flora can reveal clues about its past management. It can indicate whether it has been coppiced (which is not always obvious); whether it has been clear felled (even if this took place a century or more ago); or whether it has remained undisturbed for centuries.

An ability to differentiate between ancient (or primary) woodlands and planted (or secondary) woods is essential if the recently introduced guidelines for the management of broad-leaved woodland are to be correctly applied. Recognition of ancient woodland in the field depends upon the identification of a number of indicator plants which, because they are poor colonisers, tend to be rare in woodlands that have been altered to any appreciable extent. Certain lichen species are also used in this context.

Lichens can reveal whether atmospheric pollution has been, or still is, present. They possess an inherent ability to withstand great extremes of natural environmental conditions, but unfortunately this is no defence against a contaminated atmosphere. Their very efficient absorption systems permit the intake and accumulation of harmful substances from the air, often resulting in the plant's deformity or death and the most serious results are brought about as a result of exposure to sulphur dioxide. Lichen species vary markedly in their sensitivity to sulphur dioxide, so the distribution, the abundance, and the luxuriance of the lichen flora of one site when compared with another can be used as a monitor of atmospheric pollution.

About 40 lichen species previously known to exist in Britain have not been recorded this century and in some counties the level of extinction is reported to be as high as 25 per cent. In greatest need of protection are those places known to harbour the rarer species but until all potentially important sites have been surveyed in detail they remain at risk of being innocently destroyed.

The loss of lichens has an effect on the woodland fauna because they are used for food, shelter and camouflage for many animal species. Man has found them useful for medicines, dyes, perfumes and many other uses and their extinction would deprive him of more than simply an aesthetic appreciation of his natural environment. It is essential that the rudiments of lichen ecology be understood by all concerned if we are to halt the downward trend in lichen numbers and perhaps even create conditions conducive to an expansion of the lichen flora.

What are lichens?

Lichenology, once the study of a few specialists, has become considerably more popular as a result of a growing public interest in natural history and ecology. Some lichens are minute and are difficult to see without the aid of a pocket lens but others are large, showy and instantly recognisable. The total number of species known to science has been estimated at around 18 000 of which 1380 occur in the British Isles.

The exact nature of lichens was not fully understood until the middle of the 19th century. In the plant kingdom lichens are unique, consisting of two totally unrelated life forms, one an alga and the other a fungus, living together in a complex but balanced state of mutual interdependence, or symbiosis. Microscopic examination reveals the two separate organisms existing in close association with one another, but forming a plant with its own distinct characteristics (Figure 1).

The algal cells are either green or blue-green, while the fungal threads – or hyphae – are in most cases seen to be colourless. In all but the simplest form of lichen the fungal partner forms the fundamental body of the plant within which the algal cells are arranged, in many species in a well defined layer 10-30 mμ thick just below the surface, but in others scattered between the fungal threads. The algal cells, through the process of photosynthesis, are able to provide the lichen with its organic nutrition while the fungal tissues absorb water, nutrients and gases from the environment and play a structural and protective role.

Of the 1600 known genera of alga very few are potential lichen partners. Of British lichen fungi 85 per cent associate with just three algal genera, namely *Trebouxia*, *Trentepohlia* and *Nostoc*. A single species of alga can, depending on the fungus it combines with, produce quite unrelated lichens.

Actual identification of the algal component can be difficult because the form is often modified and differs from that found in the free-living state. In these cases the alga must be isolated from the thallus and subcultured free from the fungus.

Most lichens contain just one algal component but species in some families regularly contain two different algae, green *Trebouxia* in the algal layer and blue-green *Nostoc* in distinct internal or external structures.

Until 1975 it was generally thought that each species of lichen contained a different fungus but it is now known that the same fungus can, depending on the algal association, form different lichens. Unlike the algae however, the fungi do not appear to exist in a free state in nature, though they too can be isolated and cultured by artificial means in the laboratory where they generally develop as a shapeless gelatinous mass.

The simplest forms of lichen are nothing more than powdery

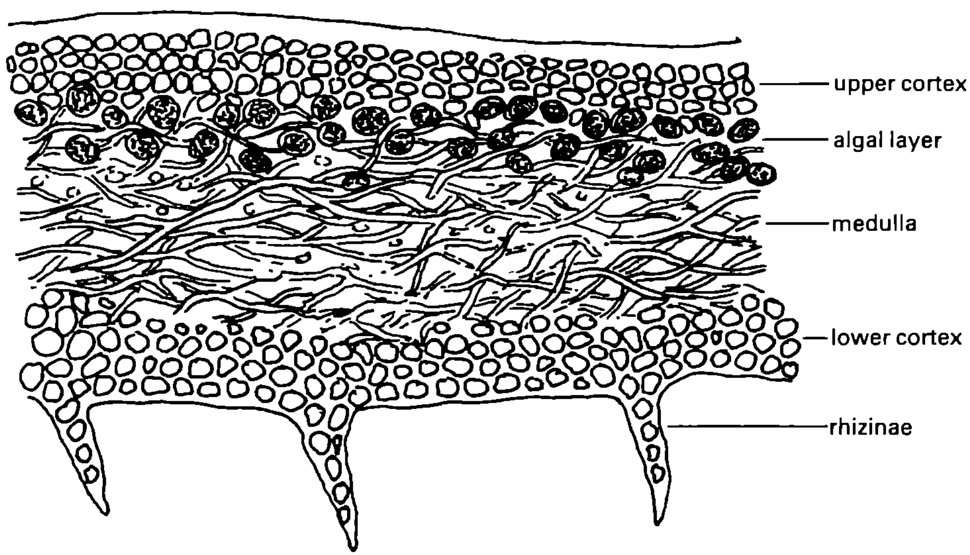


FIGURE 1 Cross section through a typical foliose lichen thallus

crusts of loosely interwoven fungi and algae tissues but in the higher forms the fungal partner predominates and the plants assume complex shapes with specialised organs of attachment, reproduction and nutrition. External differences in structure, form, reproductive characteristics and chemistry can be used to group them into taxa. A useful classification considers growth form:

Crustose — Encrusting forms that spread over and into the surface of substrate on which it grows. (Cannot be lifted off with a knife without crumbling.)

Foliose — Leafy forms that spread horizontally over the substrate. Attached by root-like threads called rhizinae. (Can be easily prised off with a knife.)

Fruticose — Shrubby or beard-like forms that may be erect or pendulous. (Can easily be removed by hand.)

The above forms are not natural divisions but are, at best, points on a scale of continuous differentiation (Figure 2). There are many intermediates and one genus, *Cladonia*, has both vertical and horizontal structures and is best described as cladoniiform (Ahti, 1982). Variation in form may result from sexual hybridisation. Some genera exhibit a bewildering array of intermediate types that appear to be hybrids of two or more clearly defined species.

Where are they found?

Lichens can be found growing on a wide range of materials, natural and man-made, in practically all parts of the world. Well adapted to withstand climatic extremes they occupy large areas of arctic and mountain terrain where few other plants can

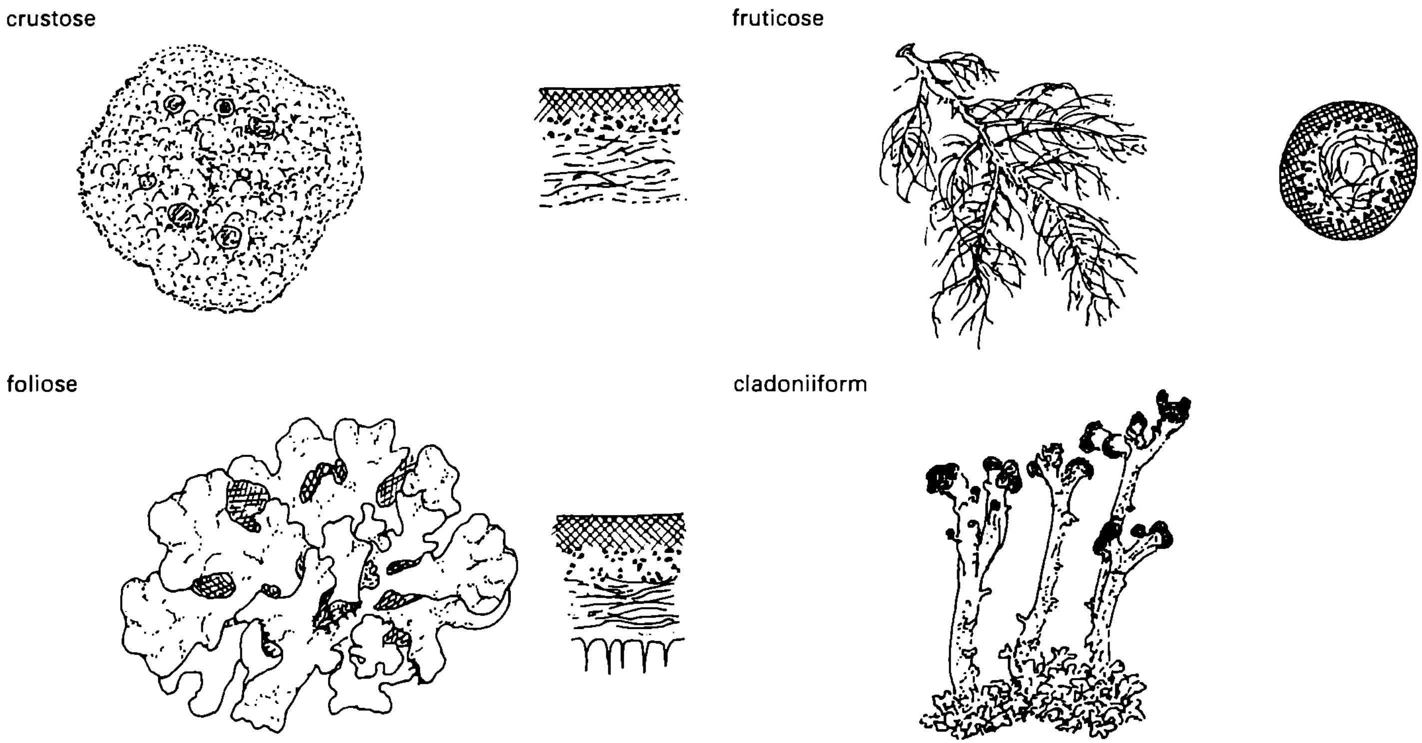


FIGURE 2 Lichen growth forms

survive. Trees, rocks, soil, sand, concrete, asbestos, cement and brick are among the surfaces on which lichens can flourish. Some are found only on one particular substrate, others are more accommodating and can be found growing on a range of surfaces, and a few species that inhabit windswept steppes and desert regions are capable of growth while free of any surface connection whatsoever.

The distribution of lichens has been severely modified by atmospheric pollution. Clean air is essential to most species, so they soon die out or take on a desiccated appearance near large industrial centres. Only a few species are tolerant of atmospheric pollution.

Some other forms of pollution, notably agricultural sprays and artificial fertiliser dust, are believed to cause damage and affect distribution locally, while the effects of heavy metals can be seen by the absence of lichens where water runs off metal surfaces, especially lead or zinc, e.g. on church stonework below water run-off channels, or where zinc coated wire is attached to tree trunks. Nevertheless, lichens have a remarkable ability to accumulate and tolerate, without apparent harm, concentrations of certain minerals that would be lethal to other plants.

The surfaces on which lichens grow provide a further means of classification. Thus:

lignicolous – found on wood

corticolous – found on bark

saxicolous – found on stone

terricolous – found on soil

vagant – free growing

Thus a fruticose, corticolous lichen is one of shrubby form found growing on tree bark.

How do they live?

The substances lichens require for nutrition are contained in rainwater and atmospheric moisture and are apparently absorbed over the whole surface of the plant. The carbon dioxide, water and minerals held in solution and the oxygen necessary for respiration are absorbed by the fungal tissues and are passed to the algal cells in a suitably modified form. The algal cells, by photosynthesis, convert these substances into the carbohydrates necessary for the nutrition of both components. Some species have blue-green cells capable of fixing nitrogen directly from the atmosphere and presenting it in a form which can be utilised by the whole lichen.

Lichens grow at a very slow rate, generally in the order of 1 cm a year among larger foliose lichens and 1 mm a year for some of the crustose species. The growth rate will vary according to species, locality and season. Growth of lichens in temperate zones is thought to be bimodal, occuring mainly in the spring and autumn. Plants in drier or colder regions grow more slowly than those where the conditions are more humid and temperate. Many species are able to withstand prolonged periods of drought and can survive in deserts where rain may not fall for several years and where dews are non-existent. They are very efficient at absorbing water when conditions become moist. In some species air dry plants can become completely saturated in 1 or 2 minutes, although there appears to be no means by which lichens are able to store water or control its loss and saturated plants will dry out again rapidly in dry weather.

The ultimate lifespan of lichens is a matter of some conjecture. Claims have been made for some specimens in Swedish Lapland of 9000 years, while other authorities suggest that, certainly in more temperate regions, much shorter lifespans are the general rule – probably less than 100 years.

A very large number of chemicals are produced within the lichen thallus. About 200 have been recognised to date – phenolic acids, depsides, depsidones, etc., and are termed lichen acids. These products are seldom produced in non-lichenised fungi and about 60 are known to occur only in lichens. Most specimens of the same species will be found to have the same chemistry and different species will often have a different chemistry. This enables some simple chemical tests to be carried out in the field to aid identification.

How do they reproduce?

Lichens reproduce either vegetatively, by shedding a tiny part of the parent body, or sexually by the production of microscopic fungal spores in a fruiting structure on the surface of the thallus. In many species both forms of reproduction are encountered and it is interesting that these structures are not known in other fungi.

Vegetative reproduction is mainly by soredia and isidia (Figure 3). Soredia are tiny powdery masses found on the surface of the thallus. In some crustose species the whole lichen may consist of soredia. Isidia are minute, coral-like protruberances of the upper surface with a definite, firm outer surface or cortex, often forming dense clusters on the thallus. Soredia and isidia are easily detached and, since they are both composed of an amalgam of algal cells and fungal tissues they give rise to new individuals when alighting on a suitable surface.

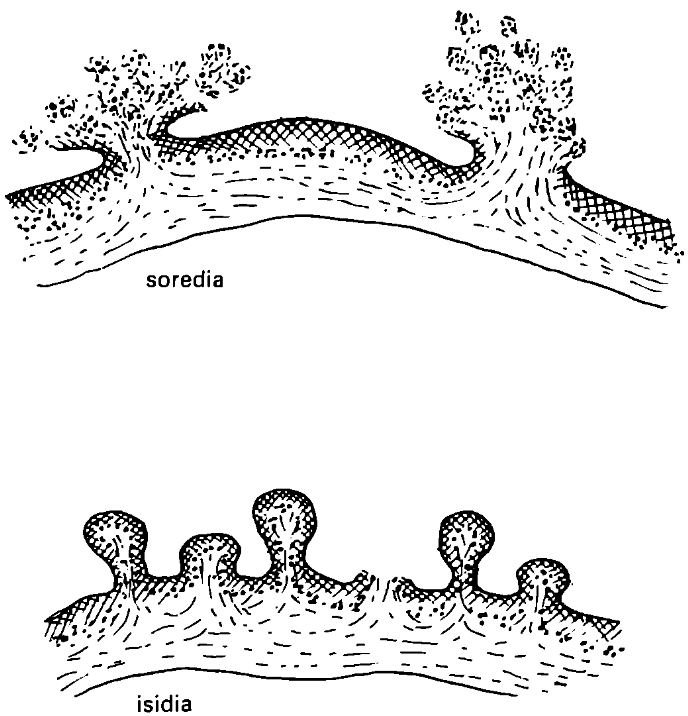


FIGURE 3 Asexual reproduction: soredia and isidia

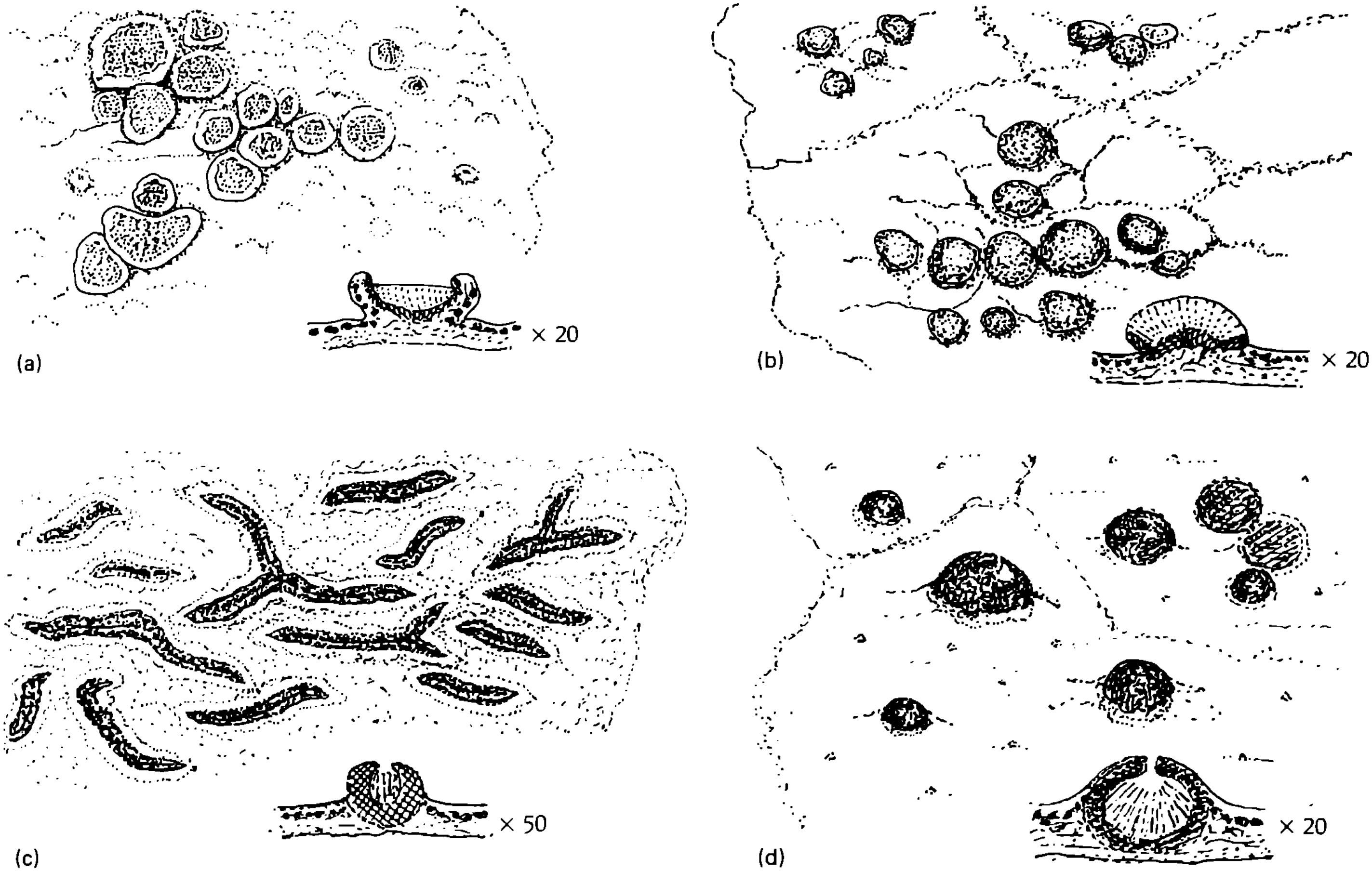
Lepraria incana is one of the simplest forms of lichen and consists entirely of a powdery crust (soredia) containing loosely interwoven fungal and algal tissue (see Plate 30).

Examination of two very similar foliose lichens, *Parmelia saxatilis* and *Parmelia sulcata*, with a ×10 lens will reveal masses of isidia on the former and soredia on the latter (see Plates 4 and 13).

Sexual reproduction is effected by the production of fungal spores from a fruiting body, of which there are two major types. *Apothecia* typically appear as small disc or cup-like structures 0.5-20 mm in diameter, generally on the upper surface of the thallus, while *perithecia* occur as tiny immersed flask shaped pustules usually less than 1 mm in diameter each with a minute hole in the apex through which the spores are extruded. In some apothecia the disc is surrounded by a rim – the proper margin – which is usually the same colour as the disc. This condition, which is characteristic of many lichen families, is called *lecideine*. Some apothecia have a second, thicker margin surrounding the proper margin. This is an upgrowth of, and will be the same colour as, the thallus and is called the thalline margin. Such a condition is called *lecanorine*. Less common are stellate and elongated fruiting bodies called lirellae, which are modified apothecia. The above characteristics are important in identification and classification (Figure 4).

The spores produced by apothecia and perithecia are purely of fungal origin and exactly how, when and where these spores make contact with the algal cells necessary for the development of a new plant is still a mystery.

Unlike the fruits of most other plants which have a life of days or perhaps weeks, the fruiting structures of most lichens can have a spore producing life of several years, although spores are generally released only at certain times of the year. The dispersal of spores and vegetative structures is probably carried out by the action of wind, water, insects, birds and animals.



(a) lecanorine apothecia of *Lecanora chlarotera* (× 8)
(b) lecideine apothecia of *Lecidella elaeochroma* (× 8)
(c) lirellate fruits of *Graphis scripta* (× 7)
(d) perithecia of *Pyrenula chlorospila* (× 20)

FIGURE 4 Sexual reproduction: fruiting structures of lichens

What are their uses?

Before the discovery of coal-tar dyes, lichens were of considerable economic importance for the commercial dyeing of wool. The basic technique involved bruising the lichen thalli and boiling them in water to which certain chemicals were sometimes added. Specific lichens have their own particular dye colour and the duration of steeping, controlled the intensity of the colour. Further variations were achieved by mixing different lichen species when some delicate shades of purple, red, yellow and brown were obtained. Today they are only used on a very small scale in cottage industries and their collection for dyeing as a hobby is discouraged for conservation reasons.

Litmus, a dye used as an acid/alkaline indicator in chemistry, is derived from depside-containing lichens. They are also important in the perfumery industry; enormous amounts of 'oak moss', chiefly *Evernia prunastri* and *Pseudevernia furfuracea*, are collected in Yugoslavia, southern France and Morocco for processing in France and Germany.

In the past some lichens were held in high esteem by medical practitioners. There was believed to be a relationship between the plant's appearance and the disease or the affected organ. *Lobaria pulmonaria* (tree lungwort) was therefore used to treat lung disease, because of its resemblance to lung tissue, and rabies was sometimes treated with a mixture that incorporated powdered *Peltigera membranacea* (the dog lichen). Hippocrates recommended *Usnea articulata*, with its intestine-like inflated segments, for uterine trouble, and in medieval times the orange-yellow *Xanthoria parietina* was believed to help in fever. Gradually the use of lichens in medicine went into decline, paradoxically just before the discovery of the antibiotic properties of some species. Research has increased in the last few decades and it has been shown that the growth of some strains of bacteria, viruses, moulds and fungi can be inhibited by certain lichen derivatives. Drugs incorporating lichen acids are, at times, more effective than penicillin. Usnic acid, one of the more important antibiotic derivatives, can be extracted from *Cetraria islandica*, the reindeer moss. This lichen is also exploited in arctic regions by the Laplanders who practice controlled grazing for their reindeer. They also harvest it as a winter fodder.

In Japan an *Umbilicaria* species (rock tripes) is considered a delicacy and is eaten in salads or fried in fat, but most lichens are considered by man to be unpalatable and are only resorted to in times of famine. In the southern Sahara some species are used in pipe mixtures for smoking, while in Ancient Egypt lichens were used as packing materials for mummies. In Derbyshire *Parmelia* species and *Xanthoria parietina* have traditionally been used to make well-dressings during summer festivals.

Lichens have also been used to date substrates of unknown age. The principle, known as lichenometry, was developed in the 1950s to date arctic glacial moraines. In such regions lichens grow extremely slowly and persist for hundreds of years. Growth rates are assessed from historical photographs, dated moraines or by direct photography over several years and average diameter increases per 100 years are estimated for different species. By measuring overall diameters of colonies the approximate ages are extrapolated. Some colonies have been estimated to be 9000 years old. The same principle has been used to date archaeological remains, to establish the frequency of earthquakes by dating rockfalls and even to assign a date to the stone images on Easter Island.

Ecology

Lichen distribution

Geographical distribution

The natural distribution of epiphytic lichens in primeval woodland was influenced by the species of trees and the microhabitats available, especially with regard to humidity and the availability of light through the canopy, as well as general ecological factors such as climate, topography and geology. Although this natural distribution has been gradually modified since the Neolithic and Bronze Ages when forests were first cleared to make way for agriculture, the greatest impact came in the 18th century when the Industrial Revolution resulted in steadily increasing volumes of smoke and gaseous effluents being released into the atmosphere.

Nowadays only in parts of Kent, Sussex, Hants, Wilts, Dorset, Devon, Cornwall, Somerset, Hereford, Northumberland and Cumbria in England and parts of Dyfed, Gwynedd and Powys in Wales are atmospheric conditions sufficiently pure to permit the existence of normal lichen populations; while large zones around the industrialised and heavily built-up regions of the Thames Valley, the Midlands, north-east England and south Wales have very poorly developed lichen floras.

The accelerated clearance of mature broadleaved woodland for two World Wars added further to the loss of lichen habitat and since then many woods have been converted to commercial plantations and some have been cleared for agricultural use.

In 1964 the British Lichen Society initiated a scheme to produce distribution maps of individual species and the present-day lichen flora of most of Great Britain can now be considered reasonably well known. Many of these maps have now been published and two are illustrated showing the markedly different distributions of *Enterographa crassa* and *Bryoria fuscescens* (Figures 5 and 6). Where particular habitats have been destroyed, or are naturally absent, corresponding gaps will appear on the maps. The scarcity of trees in the Fenland Basin of East Anglia is an example which is clearly seen on the maps of many corticolous species.

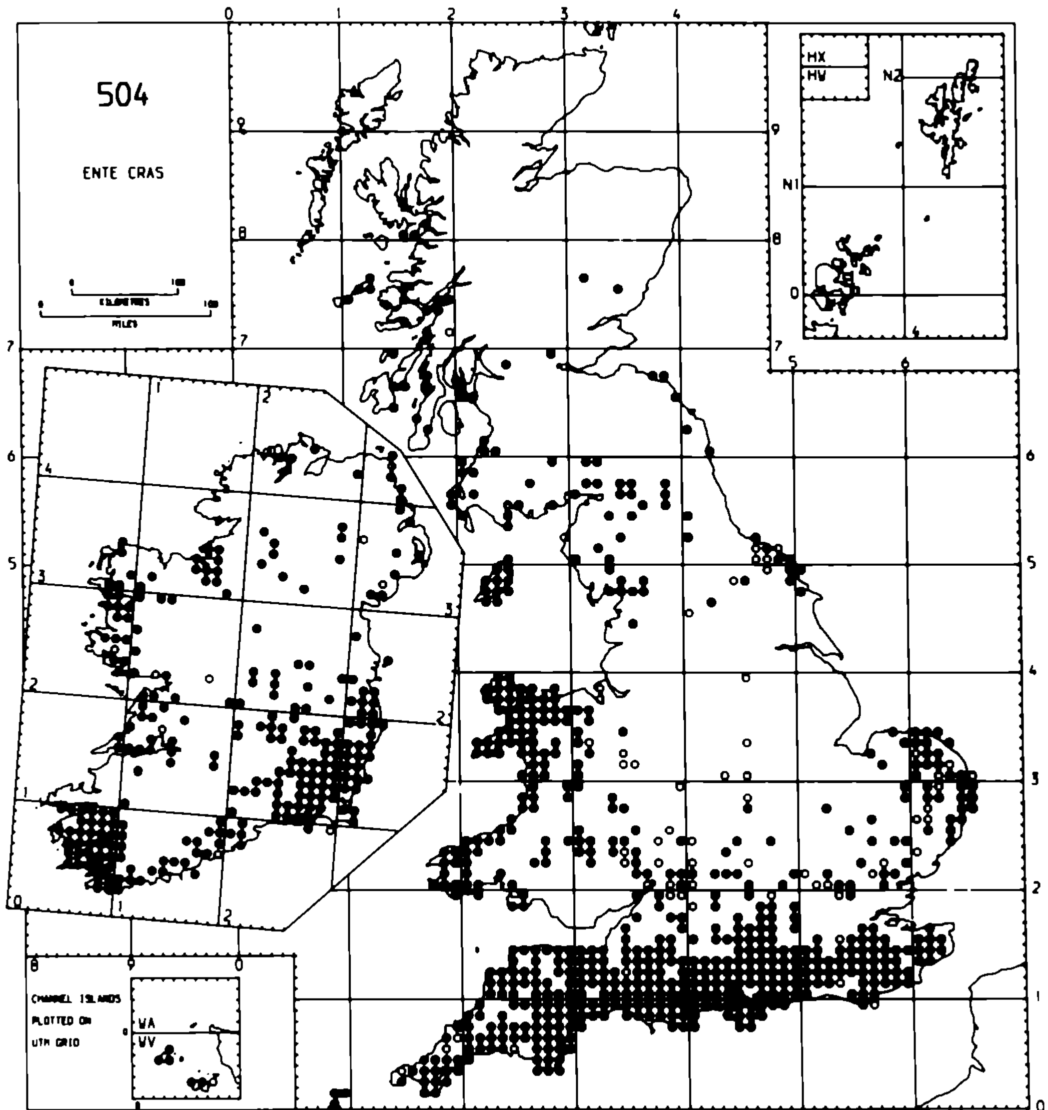


FIGURE 5 *Enterographa crassa* (DC) Fee.
(From British Lichen Society's mapping scheme database, University of Bradford.)

A generally southern species in the British Isles becoming scarce in nothern England and Scotland. Its absence from large areas of central England must be attributed to a combination of air pollution and the clearance of old woodlands. Through most of its range it acts as an indicator of sites with a long history of ecological continuity but this correlation is less well marked in the extreme south-west, where its powers of dispersal are evidently optimal.

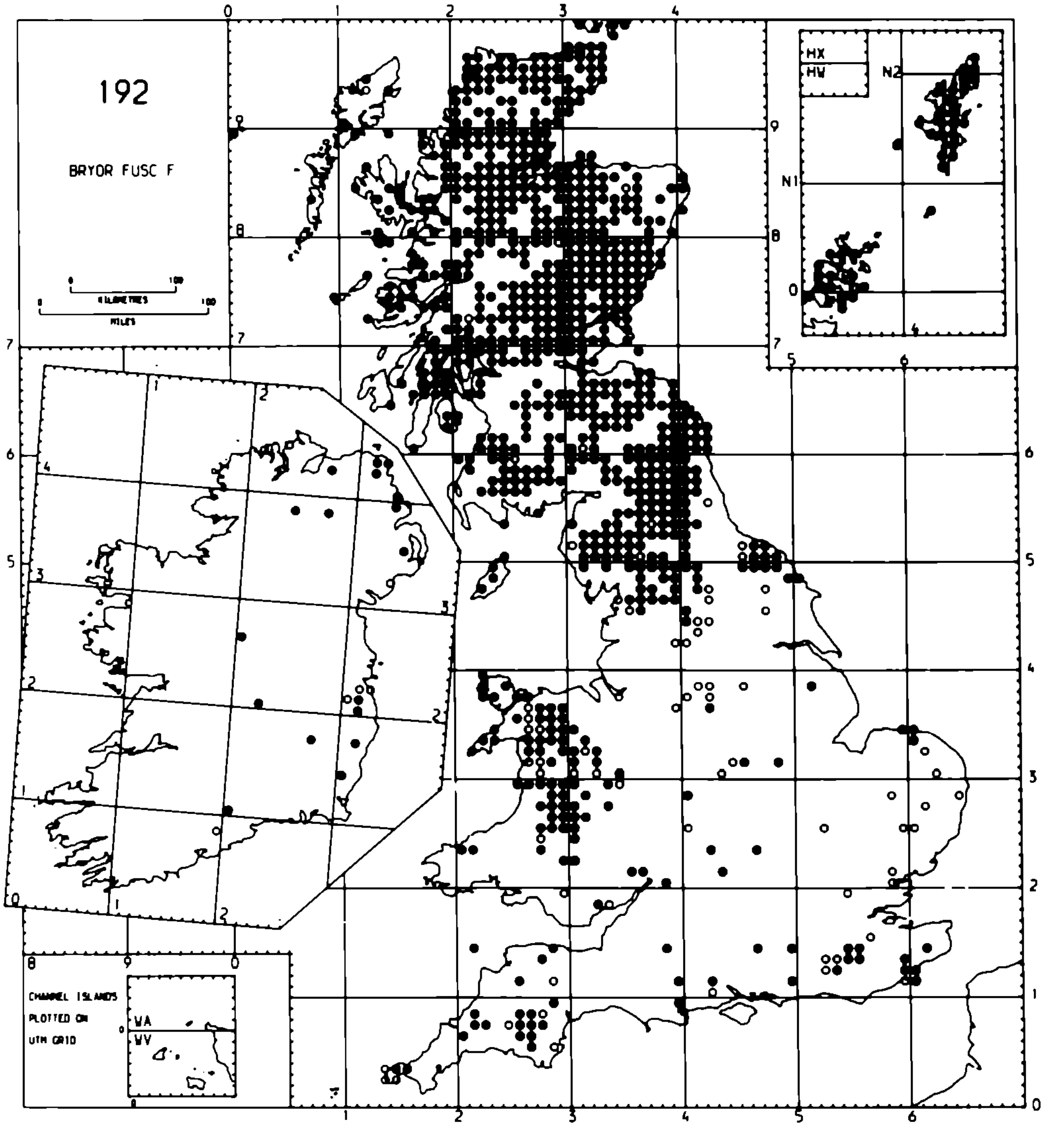


FIGURE 6 *Bryoria fuscescens* (Gyelnik) Brodo and D Hawks.
(From British Lichen Society's mapping scheme database. University of Bradford.)

Widespread in upland, northern and eastern parts of the British Isles but becoming scarcer in extremely oceanic areas. Particularly characteristic of coniferous forests in the north but also occuring on siliceous rocks, amongst mosses, on walls, and, especially in lowland England, on fence rails. Moderately sensitive to sulphur dioxide pollution and absent where this exceeds about 55 micrograms per cubic metre, the species consequently declined in many parts of lowland Britain, but has started to expand again in the last few years as evidenced by its recent discovery as young plants in Buckinghamshire and Surrey.

Distribution on trees and within woods

Lichens are colonisers of bark. Although the larger lichens are conspicuous on the trunks and branches of mature trees, lichen colonisation begins, in suitable conditions, on 3-5 year old twigs of young and old trees alike. The early colonisers are frequently inconspicuous crustose or endophloeodal (below the bark) species. As the branches and trunk increase in age and girth, foliose and fruticose forms appear, and in permanently humid areas quite young branches may be festooned with a grey-green covering of lichens. With age the bark is able to support an increasing variety of epiphytes and each tree species acquires a characteristic lichen flora which often covers the entire surface. However, lichens are only weakly competitive and they are easily displaced by mosses, liverworts and climbing plants such as ivy. On any one tree, lichen communities quite distinct in appearance and species will develop on the root buttresses, the main trunk, the branches and the twigs in response to the particular environmental conditions. The most important factors influencing community development are given in Table 1. These communities can be named and are characterised by the species found in them, e.g. the *Usneion* containing the fruticose *Usnea* species, the *Parmelion* with an abundance of *Parmelia* species and the *Lobarion* with *Lobaria* species dominant (Figure 7).

In Britain the most luxuriant communities are found on the south and south-west sides of a tree – the side which receives most sunshine and rainfall. On the undersides of branches and those within the more shaded parts of the tree crown, lichens are less evident and are represented mainly by crustose forms. Where foliose types do occur they are often of a more subdued colour, e.g. *Xanthoria* species are pale orange or even yellow in shaded habitats and deep orange-red in full light. The upper surfaces of leaning trees provide particularly suitable habitats for many species.

The total diversity of sites increases not only with age and species of tree, but also with their spatial distribution within the woodland. Trees on boundaries, alongside roads, rides and clearings and those adjacent to streams and ponds are richer in lichens. In areas of pollution the health and diversity of lichens tends to increase towards the centre of the wood or where more sheltered conditions prevail such as in deep ravines. Altitude also influences lichen development – some species being more common in hilly districts; and nitrogen-enriched sites, such as might be found near farms, are typified by the showy growth of the yellow or orange coloured *Xanthorion* community.

By comparing lichen species in documented woodlands, Rose (1976) has shown that certain species and communities are associated with ancient trees, relics of the original primeval forest e.g. Royal Hunting Forests and old wood pastures.

Most corticolous lichens appear to be characteristic of bark type rather than of a particular tree species and the acidity of bark is considered to be of particular importance possibly affecting the germination of spores and the growth of free living algae. Trees vary in the acidity of their bark. Ash bark is of low acidity, oak is moderately acid and alder has a markedly acid bark. Within any one species acidity varies in different parts of the tree. The upper parts of the trunk are generally less acid than parts lower down and in polluted areas rainfall can become acidified tending to increase the acidity of the surface on which it falls. The acidity of bark will increase with age in an unpolluted atmosphere so that ancient ash and oak trees may have the same degree of acidity.

Table 1 The most important factors influencing community development

1	Degree of illumination
2	Humidity of environment
3	Age of bark
4	Degree of corrugation of bark
5	Degree and rate of bark shedding
6	Continuity and age of woodland cover
7	Inclination of surface
8	Aspect
9	Degree of bark leaching by rain
10	Degree of impregnation of bark with organic nutrients
11	Degree of air pollution
12	Degree of pollution by agricultural chemicals
13	Acidity of bark surface
14	Basic nutrient status of the bark
15	Presence of tannins, betulin or resins, etc.
16	Moisture retaining and absorbing properties of the bark

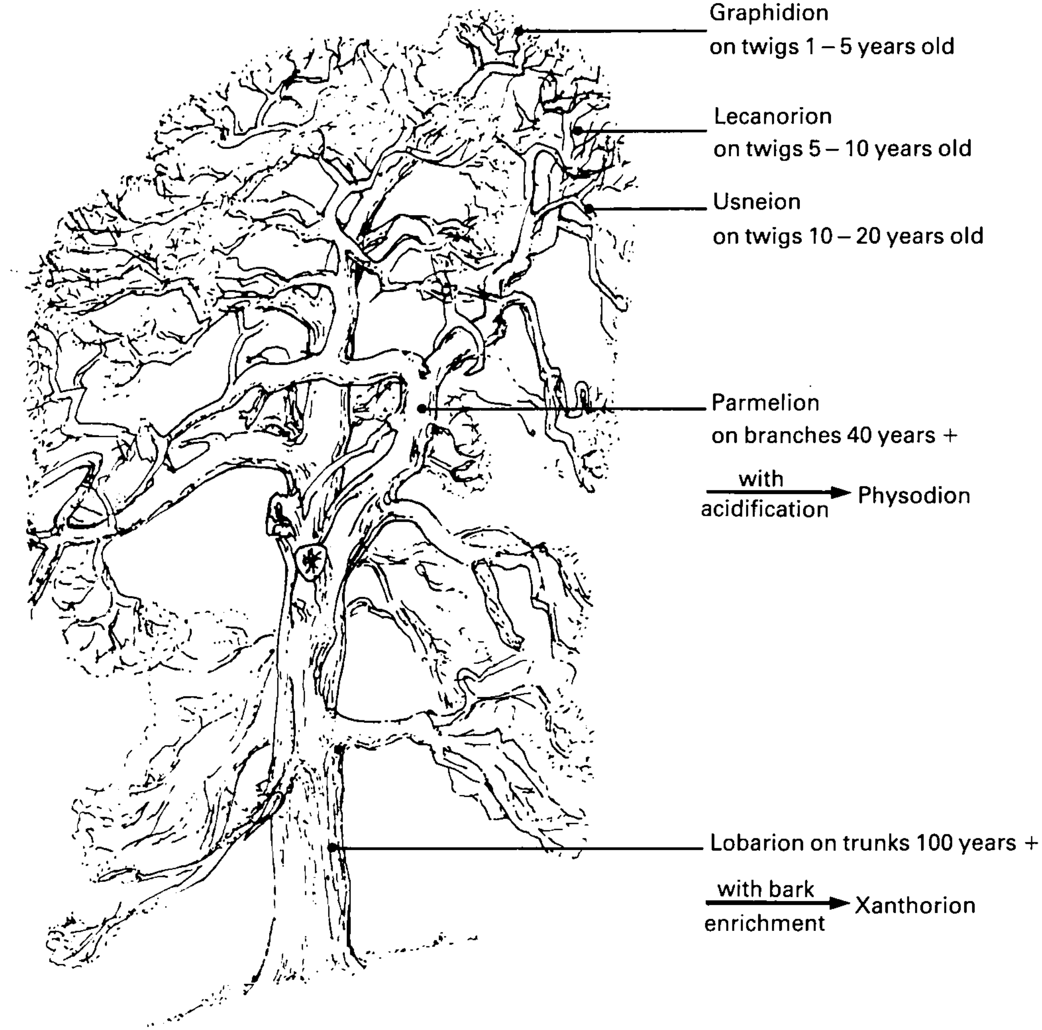


FIGURE 7 Showing the 'normal' succession of lichen communities on an oak tree in unpolluted lowland old forest.

Lichens are sometimes thought to have a detrimental effect on the trees on which they grow and it is true that a quite profuse growth of lichens can often be seen on trees of low vigour. Many lichen species have root-like organs called rhizines that can penetrate bark and occasionally even the cambial layer, however these structures seldom, if ever, penetrate to the wood beneath and there is no question of them gaining nutrition from tree sap. The lichens on ailing trees owe their luxuriance to the slower than usual rate of bark expansion, and to the increase in light in the canopy. Nevertheless in some European and American orchards lichen growths on fruit trees are destroyed with fungicides in the belief that lichen-free trees are more robust.

Occurrence on broadleaved trees

A considerable number of lichens occur as epiphytes on woody plants in Britain; our two native oaks (pedunculate and sessile) are particularly rich in this respect. Some 324 species have been recorded on oaks compared with 255 on ash, 206 on beech, 187 on elm, 183 on sycamore, 160 on hazel, 160 on willow species, 126 on birch, 125 on rowan and 105 on alder (Springthorpe and Myhill, 1985). The greatest number recorded for a single tree is 52 taxa on an oak (Rose, 1974).

The lichen communities that might be encountered on, say, a mature oak are quite varied. At the base and some way up the root buttresses, the typical community will consist of several species of *Cladonia* – a large group, many of which, such as *Cladonia pyxidata*, the Pixie cup lichen, have distinctive stalked outgrowths; *Peltigera* species – spreading foliose lichens with veined undersurfaces, often found with finger-nail-like structures on the margins e.g. *Peltigera membranacea*, the dog lichen; and perhaps *Leptogium* species.

Higher, on the rough bark of the main trunk, a large number of lichens might be present and these may include several *Parmelia* species. One often seen is *Parmelia caperata* – a light yellow-green foliose lichen sometimes as large as a dinner plate; *Hypogymnia physodes* – a very common lichen with smooth, grey, incised lobes will almost certainly be present; *Evernia prunastri* with its soft, flattened, strap-shaped thallus is another frequent species and, providing the region is relatively free of atmospheric pollution, one or more of the *Usnea* species – the beard lichens, might occur. Some of these can grow up to 50 cm long. Closer inspection should reveal a number of crustose lichens such as the powdery green *Lepraria incana*; the white powdery *Pertusaria amara* – recognised by its bitter taste; the grey-green and warty *Pertusaria pertusa*; and usually confined to the crevices in the bark, the bright yellow, powdery *Chrysothrix candelaris*.

On the larger horizontal branches *Hypogymnia physodes* and *Platismatia glauca* are often abundant. The latter is recognised by its crisp, undulate lobes, grey above and shiny dark brown beneath. On the smaller branches *Parmelia glabratula* may be common, though its dark brown rosettes closely attached to the bark may make it difficult to see. On the twigs crustose forms are often dominant, e.g. *Lecanora conizaeoides* which has a powdery green thallus with tiny flesh-coloured discs or *Lecanora chlarotera* which has a grey thallus with reddish discs like tiny jam tarts. Other species frequently found in this zone are *Lecidella elaeochroma* – a green powdery lichen with black dot-like apothecia and *Graphis scripta* with its thin, black, elongated fruiting bodies that resemble scribbled writing.

Occurrence on conifers

In Britain exotic conifers generally grow at a faster rate than broadleaves; they possess a less stable type of bark which in some species tends to flake off as the tree expands; and they have comparatively shorter life spans. Conifer bark has a poorer water holding capacity, is often smoother, and has a more acid reaction than that of most broadleaved trees, and consequently, as a class of trees, they are less conducive to sustained lichen growth. Nevertheless, epiphytes can be plentiful, certainly on older trees where distinctive communities can be formed.

Cladonia species are of frequent occurrence around the roots and lower parts of the trunk while higher up and on the branches *Hypogymnia physodes*, *Platismatia glauca*, *Evernia prunastri*, *Parmelia sulcata* and *Parmelia saxatilis* can be common. The last two are very similar lichens with grey, reticulate, deeply incised lobes, but *Parmelia saxatilis* almost always has a dense coralloid growth of *isidia* on its surface while *Parmelia sulcata* has instead, powdery *soredia* that occur in white furrows on the lobes (see Plate 30). *Parmelia glabratula*, *Parmelia caperata* and *Usnea* species may also be plentiful but crustose types are normally fewer in number.

A few species are characteristic of conifer substrates. Examples are: *Bryoria fuscescens*, a dark brown, filamentous lichen of hilly districts in the north and west; *Hypocenomyce caradocensis* a localised species associated with old pine trees and other conifers throughout England and Wales; *Hypocenomyce scalaris* found on conifer fence posts in the north; and *Foraminella ambigua* once almost confined to conifers but now found also on broadleaved trees as a result of increasing acidification of bark in polluted areas.

Our native Scots pine, with 132 lichens recorded, ranks no less than eighth in order of priority in the list of trees which are of value to lichens. See Table 3 on page 39. The native Caledonian pine wood relics have a rich and specialised lichen flora which, however, is totally lacking in nearly all its components in the planted of sub-spontaneous pine woods of Scotland and England.

Lichens and the woodland fauna

Misshapen lichens may be the result of animal, insect (or sometimes fungal) attack, and it is probable that the distribution of some lichen species may be actively controlled by the animals that feed on them. Many woodland slugs graze on lichens, and sheep, ptarmigan, hares, snails, beetles, moths, barklice, stoneflies, earwigs and mites, have all at one time or another been observed feeding on them. Some birds are known to use them as nesting materials, long-tailed tits have been observed selectively collecting *Evernia prunastri* for their nests (Plate 1). Some insects feed exclusively on one lichen species and a few are so selective that they will consume only specific parts of the lichen, even to the extent of starving to death if those parts are not available.

Lichens often provide shelter to those insects that feed on them. Some insects have developed a mimicking coloration used either as a protective camouflage against predators or to improve their chances of capturing unsuspecting prey. Moths and their caterpillars, spiders, weevils, grasshoppers and stick-insects have been noted displaying these camouflaging characteristics in various parts of the world.

In Britain the best known example is probably that of the peppered moth. The wing markings so resemble the pattern of shade and light found on lichen encrusted trees that it was practically invisible when at rest on tree bark. However, its camouflage gradually became a liability when lichens began to perish as a result of increasing levels of atmospheric pollution. The light coloured moths then stood out clearly against the blackened soot-covered tree trunks. Fortunately the moth was able to survive due to its ability to produce mutations of an abnormally dark strain. The darker coloured individuals blended into their new surroundings and two distinct types of peppered moth are seen today. The typical form is still abundant in open countryside where lichens are sufficiently plentiful to provide good cover, while in the vicinity of large industrial complexes where lichens have largely died out the dark form predominates.

Another moth with excellent camouflage when resting on lichen covered bark is the merveille du jour (*Griposia aprilina*). In spring the caterpillars feed on young oak leaves and the moth flies in September/October. Plate 2 shows a puss moth on an oak trunk.

PLATE 1
A long-tailed tit with its nest made of lichen.

35766

E7647

PLATE 2
A well camouflaged puss moth on an oak trunk

E7599

PLATE 3
Parmelia caperata

E7600

PLATE 4
Parmelia saxatilis

E7601

PLATE 5
Parmelia laevigata

E7602

PLATE 6
Graphis elegans

PLATE 7
Evernia prunastri

E7603

E7604

PLATE 8
Pertusaria multipuncta

PLATE 9
Chrysothrix candelaris

E7607

E7608

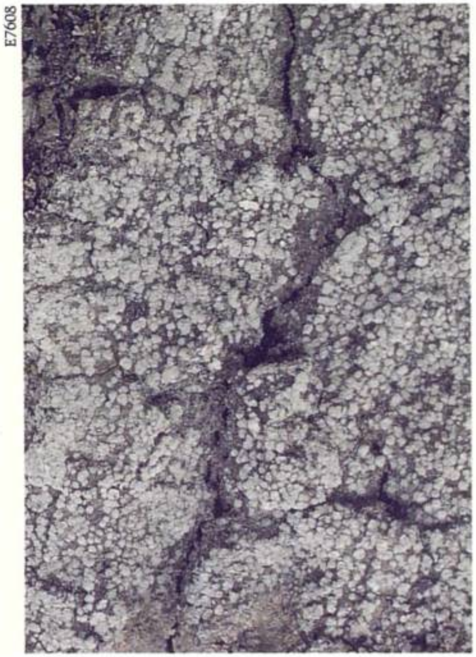


PLATE 10
Pertusaria amara

E7610

E7611

PLATE 12
Hypogymnia physodes

PLATE 11
Usnea florida

E7612

PLATE 13
Parmelia sulcata

E7620

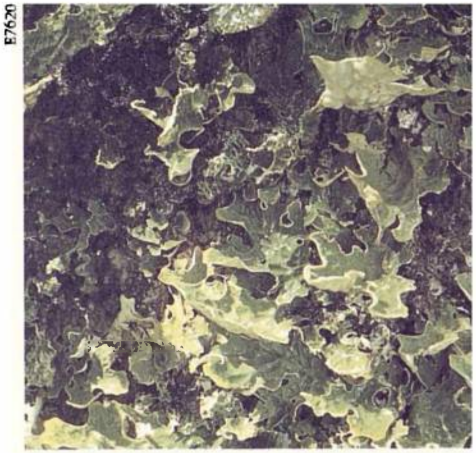


PLATE 14
Lobaria pulmonaria

E7617

PLATE 15
Xanthoria parietina

E7618

PLATE 16
Diploicia canescens

PLATE 17
Peltigera horizontalis

E7623

E7624

PLATE 18
Usnea inflata

E7625

PLATE 19
Parmelia perlata

E7630

PLATE 20
Usnea articulata

PLATE 21
Platismatia chlorophylla

PLATE 22
Usnea rubicunda

PLATE 23
Ramalina farinacea

PLATE 24 *Cladonia macilenta*

E7633

E7634

E7638

E7640

PLATE 25
Ochrolechia androgyna

E7605

PLATE 26 *Peltigera membranacea*

PLATE 27
The effects of atmospheric pollution: tree bark typical of a polluted atmosphere. Sessile oak near Avonmouth Industrial complex, Avon.

E7642

E7636

E7639

PLATE 29
Woodland sympathetically managed to actively encourage lichen growth.

PLATE 28
In comparison with Plate 27: tree bark typical of an unpolluted atmosphere. Sessile oak at Watersmeet Estate near Lynmouth, Devon.

viridis (alga)
dispersa
physodes
Ramalina farinacea
Pseudevernia furfuracea
Buellia punctata
Physcia tenella
Evernia prunastri
Bryoria fuscescens
Lecanora conizaeoides
Lecanora chlarotera
Opegrapha varia
Diploicia canescens
Xanthoria parietina
(exposed form)
(shade form)
Lepraria incana
Lecanora expallens
Parmeliopsis ambigua
Parmelia caperata
Lecanora chlarotera
Platismatia glauca
Anaptychia ciliaris
Cladonia macilenta
Parmelia saxatilis
Lecidella elaeochroma
Graphis scripta
Bare bark
Parmelia acetabulum
Cladonia coniocraea
Parmelia sulcata
Parmelia glabratula
Graphis elegans
green (wet) brown (dry)

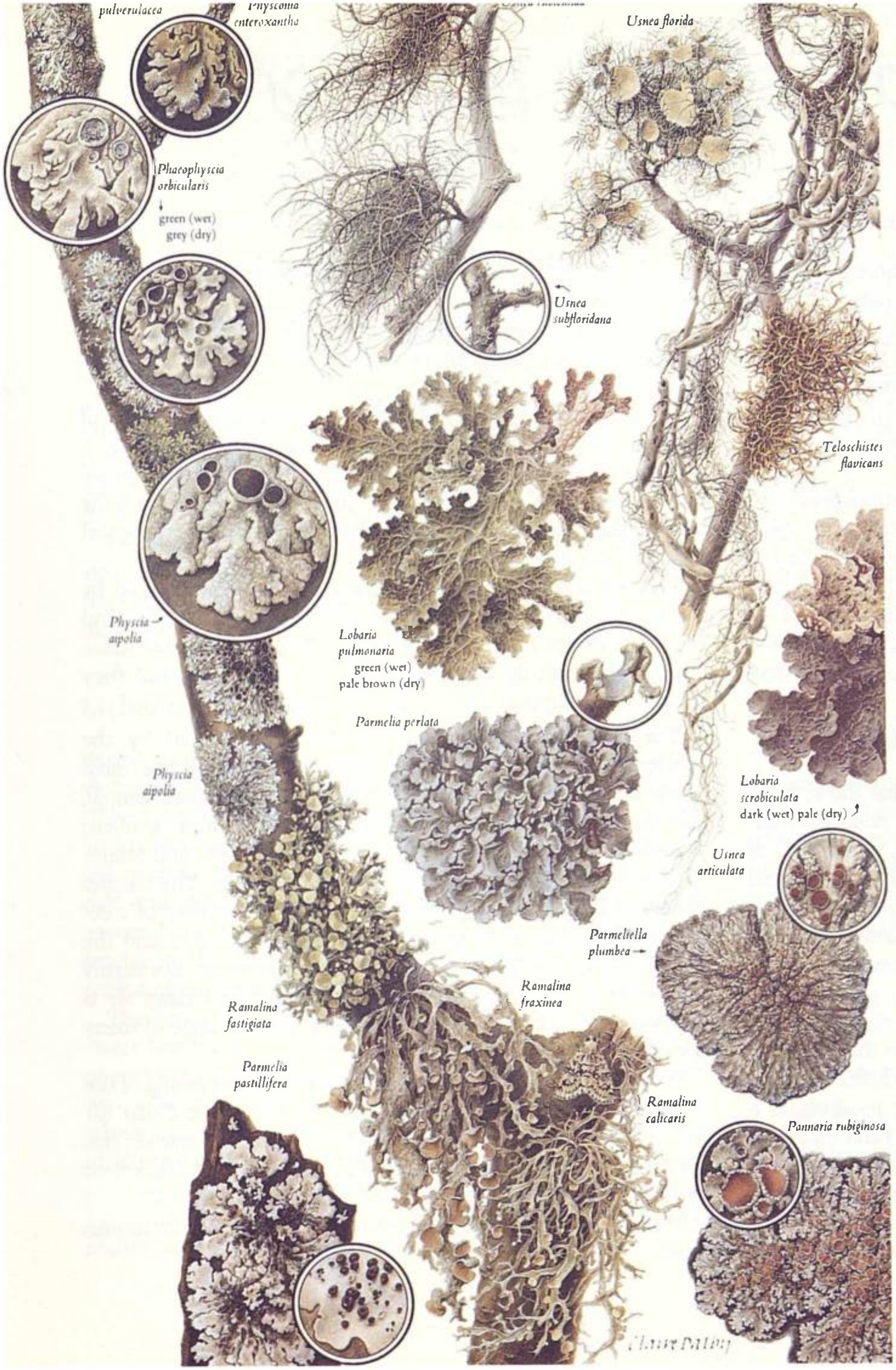


PLATE 30 A selection of lichen illustrations from the *Lichens and air pollution* wallchart. (© *Claire Dalby. 1981*)

The lichens appear from left to right according to their occurrence in relation to decreasing levels of sulphur dioxide pollution.
Opposite page:
left side = 150 $\mu g\ m^{-3}\ SO_2$
centre = 60 $\mu g\ m^{-3}\ SO_2$
right side = 40 $\mu g\ m^{-3}\ SO_2$
This page:
left side = 40 $\mu g\ m^{-3}\ SO_2$
centre = 30 $\mu g\ m^{-3}\ SO_2$
right side = 'pure' air

Lichens and atmospheric pollution

The components of atmospheric pollution

Sulphur (S) is an important minor constituent of the atmosphere. A certain amount originates from natural sources e.g. sulphate (SO_4) from sea spray, and hydrogen sulphide (H_2S) from the decay of organisms in sea water and on the land but in an industrial country the majority of atmospheric sulphur is derived from the activities of man. The principal component of air pollution is sulphur dioxide (SO_2) emanating from the burning of fossil fuels for energy.

Sulphur dioxide is removed from the atmosphere by vegetation, by gaseous absorption into water and more importantly by precipitation in rain. In a damp atmosphere it rapidly oxidises to become sulphur trioxide (SO_3) and then forms dilute sulphuric acid (H_2SO_4) with water. Pure rain, itself slightly acidic, increases in acidity as it falls through a polluted atmosphere.

The effects of sulphur dioxide pollution

It is now 120 years since it was first suggested that the absence of lichens in the vicinity of towns was due to air pollution from industrial and domestic chimneys. Since then, examples of lichen deterioration have been observed from towns and industrial complexes all over the world, and it is recognised that the British lichen flora has been severely depleted in many regions by the high level of pollution in the atmosphere (see Plates 27 and 28).

Analysis of lichens in areas affected by sulphur dioxide shows that their sulphur content rises with proximity to the source of pollution. Sulphur in the air enters the lichen thallus both in dilute solution and in gaseous form, sometimes resulting in a reduction of growth and in a decrease in fertility. Parts may take on a bleached appearance and reddish hues may occur as a result of the breakdown of lichen acids. In the case of some foliose types the lichen may become crescent-shaped due to the older, more central parts breaking off. Colonies of these characteristic crescent-shaped lichens may persist for several years before they too flake away.

Trees, such as birch, with normally acidic bark are the first to lose their lichens while those with a more alkaline bark retain them longer.

Lichens vary in their sensitivity to pollution so the number of species able to survive diminishes along a gradient from a polluted zone to an unaffected one. The most sensitive species are the first to disappear; and in the centres of heavily industrialised areas few lichens remain. In the zones of highest pollution none survive at all.

The size and shape of these lichen 'deserts' is influenced by the pattern of industrial development, the local topography, and the directions of the prevailing winds. They often extend miles beyond the built-up area, well into the countryside and they usually have elliptical and elongated boundaries.

The outer fringes of lichen deserts are denoted by the incidence of pollution-damaged specimens of only the most hardy lichen species, these being confined to tiny specimens on the bases of trees. Further along the pollution gradient somewhat more healthy plants will become evident and foliose lichens in crescent form may be seen in this zone. The hardier lichens will be found to have extended up the trunks of trees and, beyond this, more sensitive foliose lichens occur and the hardier types are much larger and more luxuriant. Eventually fragments of fruticose types are encountered and clean air is reached when the lichen flora displays a normal range of many species in full health.

Damaged lichens can recover in the event of a lessening of the atmospheric pollution. Since the introduction of the Clean Air Act in 1956 the release of visible, particulate smoke has considerably decreased because of the greater use of smokeless fuels. Sulphur dioxide emissions have decreased since 1970, but the total amount released still stands at about 3½ million tonnes a year.

One particular lichen – the crustose *Lecanora conizaeoides* – has a most unusual distribution. It is conspicuously more tolerant of atmospheric pollution than any other epiphytic lichen. In fact, it increases in abundance as a pollution source is approached. It is found as a dense, granular, green covering on the bark of trees in urban parks and woods where all other species have been eliminated (Plate 30). Unrecorded before the middle of the last century, it is now widespread and is expanding its territory to fill the lichen deserts of Britain and Europe. In areas unpolluted by sulphur dioxide it is rare. It is not clear why *Lecanora conizaeoides* behaves in this way. The lichen is almost unwettable in its natural state which must contribute to its sulphur dioxide avoidance mechanism. When artificially saturated it behaves much like some less tolerant species. Perhaps it has some nutritional requirement that is satisfied by urban pollution or it may be a recently evolved lichen capable of thriving in the absence of competition.

Desmococcus olivacens (formerly *D. viridis*) is a single celled alga and not a lichen. It occurs as bright green patches on the tree bark (Plate 30). It also withstands high levels of sulphur dioxide pollution.

Lichens and acid rain

Recent field evidence for an acid rain effect on epiphytic lichen vegetation in the United Kingdom has been published by Dr O.L. Gilbert (1986). Components of acid rain, presumably dilute nitric acid (HNO_3) and dilute sulphuric acid (H_2SO_4) have apparently led, in some high rainfall areas, to an increase in bark acidity of oak and ash. Lichen communities have undergone change especially in exposed sites at higher altitudes (but also at lower levels) to the extent of producing communities much more typical of normally acid barked trees like alder, birch and pine.

The best documented site is an ancient oak wood in south-west Northumberland which in 1969 contained a flourishing population of *Lobaria pulmonaria* (Gilbert, 1986). The species was well established on the trunks of 20 oak trees, some of which it covered to a height of 6 m, and also on a single large ash in adjacent parkland. By 1978 the lichen was present only on five oaks, in 1981 it could be found only on two, and a re-survey in 1984 showed it extinct in the wood though surviving with undiminished vigour on the parkland ash.

Normally such a rapid decline would be attributable to rising levels of sulphur dioxide air pollution, disturbance of the woodland microclimate or contamination of the habitat by agricultural chemicals. None of these explanations applied at this site. All the evidence suggests that the cause of extinction over the period 1969-84 was increasing acidity of the rainfall.

Throughout the period of decline, rainfall over northern Britain is believed to have become steadily more acid. *Lobaria pulmonaria* in England normally occurs on trees with neutral to mildly acid bark, particularly ash and wych elm. It is less frequent on oak, which has rather acid bark. Since 1960, the acidity of oak bark in rural Northumberland has been shown to have increased. During the period under question the bark of ash and elm trees in south-west Northumberland has remained relatively static and has continued to support healthy populations.

This phenomenon, the recent selective survival of *Lobaria pulmonaria* on ash and elm bark compared with oak, has been widely noted by other lichenologists in areas of the United Kingdom remote from direct sources of SO_2 pollution.

Pollution mapping

In 1866 Nylander concluded from studies in Paris that lichens may serve as practical indicators of air quality. Subsequent studies in many parts of the world confirmed his views. Because they are more sensitive even to low sulphur dioxide concentrations epiphytic lichens are particularly well suited to surveys in rural areas where conventional recording equipment is often difficult to install and expensive to maintain. The most reliable and useful indicators are those lichens which:

1 would be expected to occur in the area were it not for pollution;

2 still occur in adjacent areas where pollution levels are lower;

3 are known to be affected by pollutants under investigation;

4 are characteristic of open habitats;

5 show a range of sensitivities; and

6 are easily recognised in the field.

Table 2 Zone scale for the estimation of mean winter sulphur dioxide levels in England and Wales using corticolous lichens

Forestry Commission zone	Zone	Moderately acid bark	Basic or nutrient-enriched bark	Mean winter SO_2($\mu g\ m^{-3}$)
0	0	Epiphytes absent	Epiphytes absent	?
	1	*Desmococcus viridis* s.l. present but confined to the base	*Desmococcus viridis* s.l. extends up the trunk	170
1	2	*Desmococcus viridis* s.l. extends up the trunk; *Lecanora conizaeoides* present but confined to the bases	*Lecanora conizaeoides* abundant; *L. expallens* occurs occasionally on the bases	about 150
	3	*Lecanora conizaeoides* extends up the trunk; *Lepraria incana* becomes frequent on the bases where *Cladonia coniocraea* and *C. macilenta* also occur	*Lecanora conizaeoides* and *Buellia punctata* abundant; *Diploicia canescens* appear	about 125
2	4	*Hypogymnia physodes* and/or *Parmelia saxatilis*, or *P. sulcata* appear on the bases but do not extend up the trunks; *Lecanora expallens* is often present	*Diploicia canescens* common; *Physcia adscendens*, *P. tenella* and *Xanthoria parietina* appear on the bases	about 70
	5	*Hypogymnia physodes* or *Parmelia saxatilis* or *P. sulcata* extend to 2.5 m or more up the trunk; *P. glabratula*, *Foraminella ambigua* and *Lecanora chlarotera* appear; *Ramalina farinacea* and *Evernia prunastri* if present largely confined to the bases; *Platismatia glauca* may be present on horizontal branches and inclined trunks	*Physconia enteroxantha*, *Phaeophyscia orbicularis*, *Physcia tenella*, *Ramalina farinacea* and *Opegrapha varia* appear; *Diploicia canescens* and *Xanthoria parietina* common; *Parmelia acetabulum* appears in the east	about 60

Note: For an explanation of the two systems of zonal classification see p.32.

Table 2 (*continued*)

Forestry Commission zone	Zone	Moderately acid bark	Basic or nutrient-enriched bark	Mean winter SO_2($\mu g\ m^{-3}$)
3	6	*Parmelia caperata* present at least on the base; species of *Pertusaria* richly present; *Graphis elegans* and *G. scripta* appearing; *Psueodvernia furfuracea* and *Bryoria fuscescens* present in upland areas	*Physconia pulveracea, Physcia aipolia, P. enteroxantha, Phaeophyscia orbicularis* and *Opegrapha varia* become abundant	about 50
	7	*Parmelia caperata, P. tiliacea* extend up the trunk; *Usnea subfloridana* appears	*Physcia aipolia* abundant; *Anaptychia ciliaris, Ramalina fastigiata, R. fraxinea* and *R. calicaris* appear	about 40
	8	*Usnea rubicunda* and *Parmelia perlata* appear	*Anaptychia ciliaris* occurs in fruit; *Parmelia perlata* appears; *Ramalina fraxinia* and *R. calicaris* well developed	about 35
4	9	*Lobaria pulmonaria* or *Usnea florida* present; if these species are absent, crustose flora diverse and will be well developed with often more than 25 species on larger well-lit trees	*Ramalina calicaris* and *R. fraxinea* well developed; numerous crustose species present	under 30
	10	*Lobaria scrobiculata, Pannaria* species, *Usnea articulata, Parmeliella plumbea* or *Teloschistes flavicans* present to locally abundant; wide species diversity	*Ramalina calicaris* and *R. fraxinea* well developed; numerous crustose species present	'Pure'

[Adapted from Hawksworth, D. J. and Rose, F. *Nature, Lond.* 227, 145-148, 1970.]

In order to eliminate from consideration factors other than air pollution, trees chosen for sampling should all be of the same species (or at least of similar bark characteristics), they should be situated in comparable situations (preferably exposed and open grown rather than confined in woods and ravines), they should be of similar age (in practice trees in the diameter range 0.5–1.0 metre at breast height are preferred), and only trees with upright main stems should be included. Wherever possible several trees at a site should be examined and a mean value computed. In order to make allowances for pollutants other than sulphur dioxide, trees along woodland edges and those in pastures should be avoided as they may be subject to agricultural sprays.

Following extensive fieldwork in England and Wales and comparison of the lichen data with that derived from air pollution recording gauges, Dr D.L. Hawksworth and Dr F. Rose compiled in 1970 a scale of zones relating the lichen vegetation of trees to the average concentrations of sulphur dioxide in winter, the time when lichens are most active physiologically (Table 2). Lichen communities on moderately acid bark (e.g. oak) are considered separately from those growing on bark rich in organic and mineral nutrients (e.g. elm). The scale is based on the occurrence and frequency of a few carefully selected lichen species so that it can be used to provide an assessment of average air pollution levels over relatively large areas with the minimum of effort. The scale ranges from Zone 0 (all lichens absent where concentrations are greater than 170 micrograms of mean winter sulphur dioxide per cubic metre of air), to Zone 10 (apparently unaffected lichen vegetation where concentrations are less than 30 micrograms per cubic metre). A map of southern Britain has been compiled showing the approximate limits of these lichen zones (Figure 8).

The relatively poor rate of conifer tree growth in the forests of the South Wales Coalfield has been the subject of research on several occasions. In the early 1970s a map of lichen zones based on this system was produced so that a comparison might be made between tree growth and pollution levels (Figure 9). Financial resources were limited and large areas of land had to be examined so a decision was made to re-group the eleven point scale of Hawksworth and Rose to produce a simplified five zone scale, again with 0 representing the most severely polluted zone.

As far as possible the recommended principles and methods of survey were adopted with some minor exceptions:

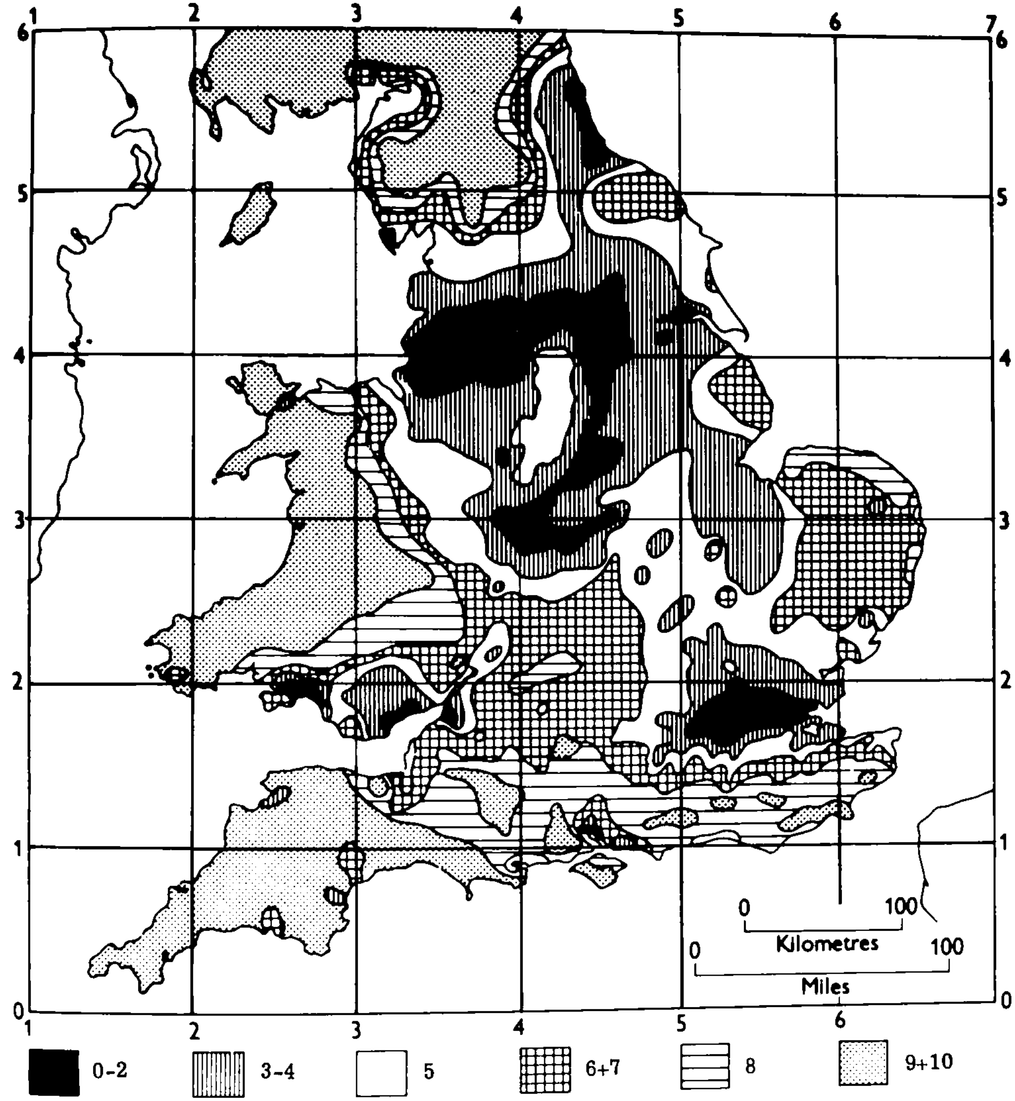
1 In the absence of free standing trees, edge trees of plantations *had* to be used.

2 In the absence of oak or ash, larch was used.

3 The absence of suitable older trees, or in some areas (especially those at higher elevations) the absence of any tree, necessitated the use of other substrates such as *old* fence posts.

No example of Zone 0 was found in the South Wales forests surveyed but conversely the most pure zone, Zone 4 of the Forestry Commission's simplified scale, was not represented either. Results from the survey revealed no senescent lichens on a large scale and it was thus concluded that the pollution levels within the forests were not deteriorating, in fact the indications were that the situation was improving – as in Great Britain as a whole. The range of lichens found did, however, indicate high levels of sulphur dioxide especially in some areas. With some minor exceptions it was considered that sulphur dioxide levels were not sufficiently high to inhibit the growth of Corsican pine – a species known for its resistance to pollution. This was demonstrated by the consistency of its mean Local Yield Class (cubic metres of timber production per hectare per annum) rating of 14 on particular soil types (brown earths and intergrades) in six major forests – three of which were near to known sources of pollution. There was, however, limited evidence to suggest that the Yield Class of Scots pine *is* being adversely affected by pollution. It is widely accepted that spruces are more sensitive to pollution than are the pines and this is demonstrated by the tendency for Sitka spruce to perform poorly in Zones 1 and 2. Norway spruce showed the same trend. The influence of such other factors as distance to the sea, annual rainfall, elevation, soil type, etc., introduced a degree of uncertainty into the interpretation of the data but it appears likely that SO_2 pollution is implicated in the reduced rates of growth observed. As a result of the exercise a modified choice of tree species has been recommended for subsequent crop rotations in some of the South Wales Coalfield forests.

FIGURE 8
Lichen based pollution map of southern Britain.



Approximate limits of lichen zones in England and Wales. *Note* (1) Local variations cannot be shown adequately at this scale and in the construction of boundaries emphasis has been placed on optimal sites, parts of most urban areas have zones lower than those indicated in regions mainly of zone 4 and above: (2) where boundaries are close intermediate zones have been omitted.

FC zone	Approx. winter mean SO_2 level ($\mu g\ m^{-3}$)
1	>125
2	60-125
3	35-60
4	<35

N.B. No zone 4 readings recorded in S. Wales.

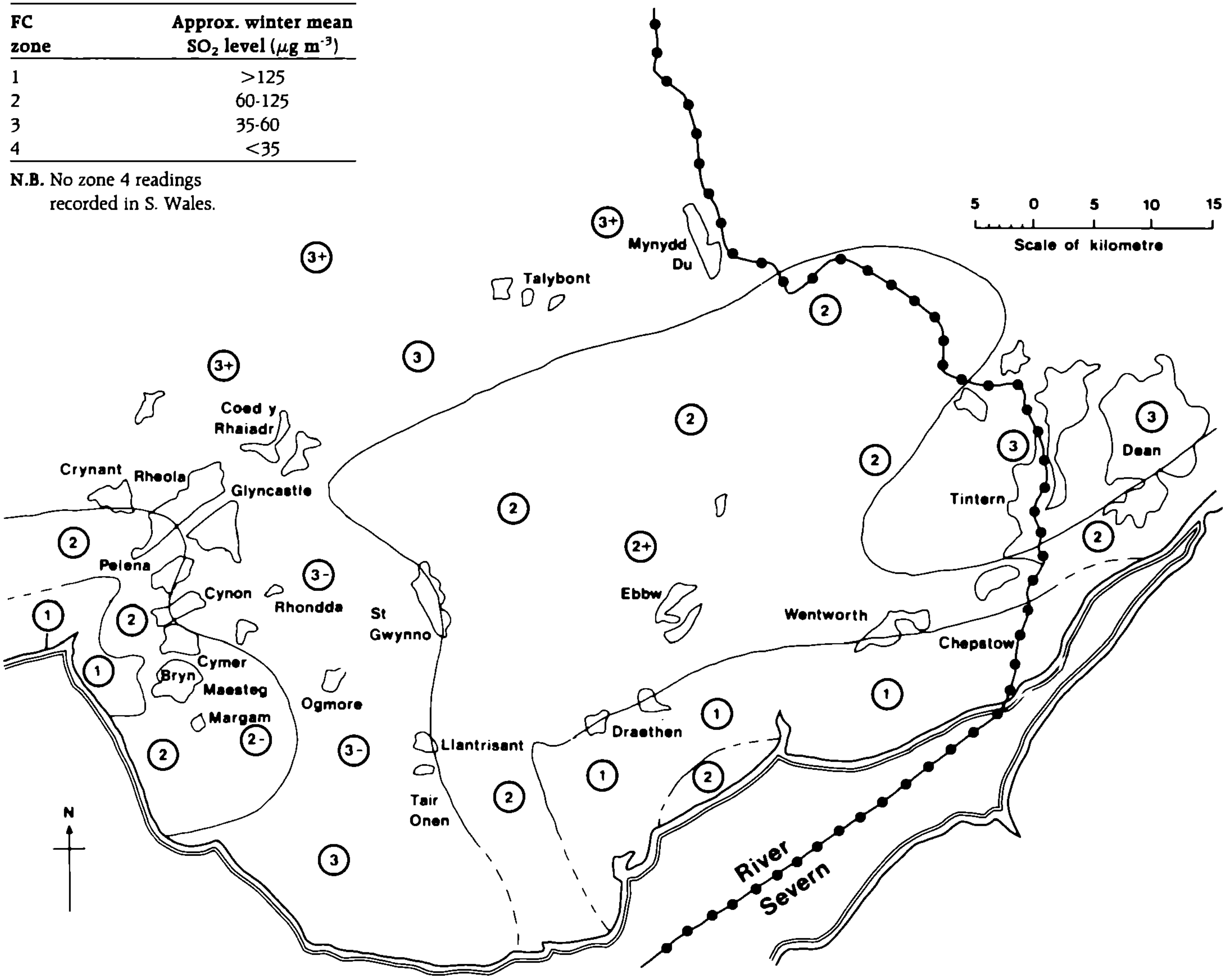


FIGURE 9
A lichen-based pollution map of the South Wales Coalfield area produced by the Forestry Commission. Major forests and forest blocks are named. See Table 2 for definition of Forestry Commission zones.

Lichen transplants

Another type of field investigation designed to demonstrate the severity, extent and pattern of atmospheric pollution involves transplanting pollution-sensitive lichen material into the study area in order to record, over a period of months or perhaps years, the time taken for each sample to die. Discs of tree bark bearing the chosen species of lichen are cut with a purpose-built circular punch and secured into holes of the same diameter on trees in the affected area. Similar transplants are also fixed on to control trees at an unaffected site. The discs are photographed at intervals using colour film so that comparisons may be made with the controls.

In areas where trees are scarce other methods of distribution need to be employed. In one study in the Ruhr, discs of tree bark bearing the lichen *Hypogymnia physodes* (a common foliose species of moderate sensitivity) were attached to boards and secured to posts 1.5 metres above ground level located at strategic positions facing the air pollution source (Brodo, 1961; Schönbeck, 1969). Other investigators have used a range of lichen species so that the differences in tolerance may be simultaneously studied. Experimental work can be extended to involve laboratory assessments of anatomical and physiological changes and the rate of accumulation of pollutants in the lichen thalli.

Other experiments have shown that it is possible to attach lichen transplants free of any bark directly on to other trees in an area to be sampled by gluing them into place with a non-volatile epoxy resin. This takes less time and does not damage the trees. An added advantage of studies that utilise living trees rather than boards as the transplant support is that any continued growth of surviving lichen material on to the bark enables the study to be prolonged.

Other monitoring techniques using lichens

Apart from its use to record colour changes and survival rates of transplanted lichen material, photography can provide a reasonably precise method of recording rates of growth or other periodic changes in the surface areas of selected, naturally-occurring lichens within a study area, providing that rigid standards are adopted and maintained at each follow-up visit.

Alternatively, the outlines of sample lichens can be traced on to sheets of clear plastic at intervals. At each visit the tracings are carefully re-positioned to align with permanent pre-positioned marks on the substrate and the increases and decreases in surface area are recorded. This method was used in a Forestry Commission investigation at Cannock, a forest on the edge of the Midlands, in 1974. Foliose lichens were found to be scarce but an exhaustive search revealed minute specimens of *Hypogymnia physodes* on a scattering of trees in the forest area. They appeared to be fresh young thalli rather than the last survivors of a depleting population. Tracings were taken at three annual intervals and the surface area in almost all cases were found to be gradually increasing, indicating an improving situation.

Other pollutants

Fertilisers

In general, man's influence on lichen communities leads to a reduction in the number of species. However, the widespread use of natural and artificial fertilisers has resulted in changes to, rather than a simplification of, the lichen flora. It accounts for the present abundance and continued expansion in the range of the orange-coloured genus *Xanthoria*, and its associated lichens (*Physcia*, *Caloplaca*, etc.) on farm buildings and trees. In its natural range this community would be restricted to nutrient enriched sites such as bird perches, trees near watering places where larger animals congregate, and trees with a relatively high bark pH such as field maple, sycamore and elm.

Herbicide sprays

Although herbicides are widely regarded as having contributed to the impoverishment of the lichen flora in lowland Britain, Gilbert demonstrated that some widely used herbicides (paraquat/diquat, MCPA, 2,4-D) may not be toxic to a range of terricolous, corticolous and saxicolous lichen species.

Smoke

Once considered to be equivalent to sulphur dioxide in its effects on lichen growth, smoke is not now considered to be an important factor in the decline of lichen communities. There appears to be no evidence to indicate any correlation of smoke levels and the incidence of lichens, although where very heavy particulate smoke (soot) fallout occurs damage is possible.

Automobile exhaust gases

The scarcity of lichens on some roadside trees does not appear to be due to exhaust gases. Trees by roads carrying very heavy traffic sometimes have luxuriant lichen floras. The scarcity is most likely caused by the salt used on roads in the winter months which is splashed on to trees by passing traffic.

Quarry dust

Dust from the quarrying of basic rocks and from cement works can raise the pH of tree bark for miles around. This can influence the development of lichen communities characteristic of nutrient rich habitats. If the dust deposition is particularly heavy it can interfere with the photosynthetic process and prove fatal.

Fluorides

Fluorine (F) is not particularly common as an air pollutant. Some is emitted from those industries burning low grade coal, but the main sources are aluminium smelters, potteries, brickworks and the glass and steel industries. Field observations, transplant experiments and laboratory fumigation investigations have shown that fluorine is toxic to lichens, although some differences from the accepted pattern of sensitivity to sulphur dioxide are indicated (Ferry *et al.*, 1973).

Woodland management

The primary objective of state forestry in Great Britain is the production of an economic crop of timber, but there are many secondary objectives and conservation is among the foremost of these. Most state forests now have conservation plans and local staff receive guidance on how best to integrate nature conservation with other aspects of forest management.

Owners of private woodlands can obtain management advice from the Forestry Commission's Private Woodland staff and from professional forestry consultants. The Commission also administers the Woodland Grant Scheme for private owners. The scheme is intended to encompass a wide range of management objectives. In order to comply with statutory requirements, the production of utilisable timber must be one of the objectives, although it will not necessarily be the principal one. In an important lichen wood, for example, the conservation and enhancement of the lichen flora might well be the main objective.

The effects of management practices

Lichens attain their greatest abundance and diversity where the environment remains relatively stable for long periods of time. Studies by Dr Francis Rose in woodlands where conditions are thought to closely resemble those of the primeval forest led to speculation that the undisturbed primary woodland of Britain probably accommodated 120 to 150 lichen species per square kilometre. None of this primary woodland survives today, for almost all woods have been influenced by man to some extent. Nevertheless the marked differences in lichen cover within, for example, a neglected semi-natural broadleaved woodland and a well managed even-aged conifer stand, would be apparent even to an untrained observer.

How does the management of woodlands and forests affect lichens and what measures can be taken to minimise or perhaps even reverse any adverse trends? These questions are considered below.

New planting

Whenever land is newly planted with trees a certain amount of ground preparation is normally required. The degree of disturbance will vary according to the nature of the site and can take the form of anything from a series of spade 'screefs' (to remove a small section of vegetation in the vicinity of each planting station), to the wholesale ploughing and draining of an area (where conditions are less favourable to tree growth). With some exceptions (notably improved grassland, arable land and dense bracken-covered areas), close inspection will often reveal some soil- or rock-borne lichen communities, so before work starts it is worth considering whether any parts are worthy of conservation. To abandon substantial areas of useful land can rarely be justified but if rocky knolls or patches of skeletal detritic soils exist these might be left unplanted with minimal loss of financial return. Wide rides with occasional unplanted glades are recommended for reasons of general nature conservation so the opportunity might also be taken to plan out these features for the benefit of the lichen flora. The size of these unplanted areas must obviously depend on the scale of the undertaking, but as a general guide anything less than 30 metres in width for a ride and 50 metres in diameter for a glade is unlikely to be effective in anything but the short term. Sighting is important, for, as the trees grow, the increasing levels of shade and the gradual build-up of leaf litter will result in changes at ground level which must adversely affect lichen development.

Valuable lichen habitats can be innocently destroyed where scrub tree growth has to be cleared prior to planting – especially so where the scrub is old and open-grown. Such trees are often festooned with a large number of lichen species, and groups of these trees could be retained to provide 'reservoirs' of source material within the newly planted woodland. Similarly any ancient, crooked or pollarded trees are worth leaving. It is essential to keep the boundary of the planting area away from retained trees in order to minimise the long-term effects of increasing amounts of shade, shelter and atmospheric humidity.

Where lichens are to be encouraged the choice of tree species should include as many native broadleaves as possible. Provided they are suited to the site, the choice should take account of trees in Table 3 which are ranked in order of their value to lichens. Where useful lichen-bearing trees are being retained a natural spread will be made more possible by planting similar tree species nearby.

Random intimate mixtures (where each tree and its neighbour are of a different species), are generally considered difficult to manage. This is due to potential differences in rates of growth and the more complicated harvesting techniques that will ultimately be required. It is therefore considered preferable to plant a number of irregular shaped groups of the same species. The recommended minimum number of trees in any one group is about 25. Given adequate management all the species planted should then be represented throughout the life of the crop. Although undoubtedly more difficult to lay out, the extra effort and the slightly increased costs of this type of mixture should prove well worthwhile.

If broadleaves and conifers are to be used, the broadleaves are best confined to discrete zones, drifts or groups. These might be sighted along boundaries, rides and road alignments; adjacent to ponds and streams (allowing for a reserve strip on each bank of at least 5 metres and preferably at least two or three times the stream width); on the lower slopes of hills and in valley bottoms; in gullies, and also around quarries and natural rock outcrops. In more featureless terrain broadleaves can be introduced to good effect to add variation within large tracts of conifers.

The spacing of plants can also be of importance. Close spacing results in earlier canopy closure – an obvious advantage in suppressing ground vegetation and promoting the development of straighter tree stems with lighter branches – but it is bound to inhibit the early establishment of lichens. The current trend is to a wider spacing than in the past so this is to be welcomed.

Treeshelters are frequently used to promote early establishment and to protect trees against certain predators. Their life is transient, for being biodegradable they tend to disintegrate from around the fifth or sixth year. Their use is therefore probably not significant in terms of their effect on lichens.

The aim throughout should be to create the greatest degree of structural diversity. Careful planning at the outset will ultimately lead to improvements not just to lichen habitats but will generally enhance nature conservation, landscape, and possibly other environmental values simultaneously.

Maintenance of plantations

Regular cutting of roadside and rideside vegetation may be required if the shade cast on to the lower parts of tree trunks is affecting lichen growth. One cutting every 3 or 4 years is usually adequate. If done more frequently there is a risk of reducing the diversity of herbaceous and shrub species with corresponding loss of conservation value. Hand or mechanical weeding carries little or no risk to lichen growth but financial considerations may preclude these methods and chemical control may have to be employed instead. Although the effects of chemicals on lichens are not yet fully understood, carefully applied selective applications may not be harmful. Operations should be carried out on calm days when the risk of spray drift is low.

Careful brashing to remove lower branches, and high pruning of selected trees, will assist in maintaining adequate light intensities and should thus promote the developing lichen flora. In some places ivy may need controlling.

The early life of a plantation whether it be conifer, broadleaved or mixed, is typified by relatively uniform conditions that can be exploited by only a very limited number of lichen species. However, with increasing age a more diverse pattern will gradually emerge. Height growth will vary in response to differences in the depth and fertility of the soil; failed patches may occur (either to be left to develop as a glade or to be replanted – often with a different species); access roads may have to be constructed; shallow-rooted crops may be subject to windblow; fires or insect attack may occur; and inevitably some natural tree species will invade. The developing plantation will therefore gradually provide a more hospitable environment for lichen growth.

Thinning

As the trees close canopy a programme of silvicultural thinnings is normally required. Thinnings are designed to remove a proportion of the crop at regular intervals – typically every 3 to 7 years, and in the earlier years the trees chosen for removal tend to be those growing in the lower canopy. In later thinnings some of the upper canopy trees competing with the final crop trees

Table 3 The value of trees for lichens
This table gives the numbers of epiphytic lichens which have been recorded in association with some common trees and shrubs in Britain.

Tree or shrub	Number of associated lichen species	Notes
Oak (penduncculate and sessile)	324	
Ash	255	Bark fissured and rather similar to oak but often of higher pH and therefore can support the *Lobarium* at a younger age
Beech	206	In spite of smooth bark, carries a flora very like oak in the New Forest, but has few epiphytes in chalk woodlands or in the south-west. Bark of low pH
Elm	187	High water retentively and pH, has a specialised but very rich flora
Sycamore	183	Carries a flora remarkably like elm (pH high)
Hazel	160	Quite rich especially in humid western areas and may carry *Lobarion* species.
Willow species	160	Quite rich especially in humid western areas
Scots pine	132	
Birch (silver and hairy)	126	Very acid bark
Rowan	125	
Alder	105	Has a very acid bark of low water retentive capacity
Holly	96	Has a limited but specialised flora
Field maple	93	Very favourable bark of high pH, but of limited occurrence as a large tree
Lime	83	Bark lacks water retentive character
Hornbeam	44	Limited by its smooth bark and its occurrence only in the driest part of England

may also be felled. Provided the interval between thinnings is not too great the microclimatic changes will be minimal and will usually be just sufficient to reverse any debilitating effects the shade may have on the developing lichen communities.

Coppice

Broadleaved woodland managed for short or medium term coppice differs from a plantation. Growth is more vigourous leading to very early canopy closure and the crop is rarely thinned. From a general wildlife point of view coppice is considered by many authorities to be among the richest of our woodland types, but by its very nature it is particularly unfavourable as a lichen habitat. Even those lichens adapted to survival on the smooth bark of young trees growing in dense shade are doomed to elimination at the end of each rotation (which is usually from 10 to 35 years depending on species and potential markets).

Coppice with standards

This is a system of two stories forest and the technique provides for a number of 'standard' trees (typically oak) which are allowed to grow on at the end of each coppice rotation. When the coppice is cut the oldest standards are felled and those of intermediate age are thinned out. The rotation for the standards is a relatively long one (100 to 140 years) and the wood is never entirely clear felled. There is ample opportunity for lichen spread and continuity, but generally only on the upper parts of the main stem and branches of the standard trees. The lower parts are subject to the extreme changes brought about by the coppice cutting regime and the total number of lichen species for this system is correspondingly low.

Harvesting

At the end of an economic rotation – around 50 years for conifers and about twice as long for broadleaves – tree crops are usually harvested by clear felling and as a consequence almost the complete lichen flora is destroyed. What little material remains on branchwood and tree stumps is mostly lost to subsequent clearing up work. The area is replanted in due course and the young trees, having to rely on outlying sources of spores and vegetative material, will only slowly be colonised by lichens. A limited number of species can and will colonise freely but others occur only in woodlands with a history of continuous tree cover, i.e. where clear felling has never taken place. Nowadays the relic woodlands in which the 'old forest' lichens still survive are mainly isolated and fragmented and this seriously handicaps any potential that might exist for their re-establishment elsewhere.

Clear felled areas that are not replanted may re-establish themselves naturally over a period of years. If broadleaved stumps exist, coppice growth can arise, suckers may spring from the old roots of some species, and saplings will grow from seed shed on the site. The result will be a semi-natural woodland with a variety of tree species of different ages. Such a wood might be expected to support a near natural epiphytic flora, but this surprisingly is not the case. Even in woods where clear felling took place a hundred years ago or more the number of lichen species will be well below the previous level (Table 4) (Rose, 1974).

What alternative to clear felling might be considered? Two methods widely used on the Continent are the shelterwood and the selection systems.

A shelterwood system involves the gradual removal of the original tree crop in discrete groups with the object of securing natural regeneration to replace the felled trees.

Table 4 Lichen content of oak woodland related to history of management (after Rose, 1974)

	Average number of taxa in $1km^2$ or less
Ancient mixed oak forest	118
Mature oak clear felled and replanted during 18th century and 19th century	50
Old coppice with oak standards	42

In a selection system the object is to maintain a full and intimate mix of trees of all ages, the largest of which are felled at intervals while the remainder of the working area is thinned. Provided the frequency of cutting is comparatively low both these systems provide for a relatively high degree of continuity with obvious advantages for the lichen flora.

Where lichens are deemed important the aim must be to design a system of harvesting which will minimise the severity of environmental loss without seriously jeopardising economic return. The woodland should never be entirely felled. Some trees should be identified for long-term retention. These retained trees can be the poorer shaped and least valuable ones but they should be substantial trees and not just the weak remnants of the former crop. They can be scattered at large over the area or, preferably, be contained in discrete groups. As many edge trees as possible should be kept and, where it survives, elm should be given special consideration. Minor species and shrubs should be encouraged and most importantly some trees should be retained until they die naturally. Important ailing trees may require surgery, and pollarding can be useful where upper parts degenerate or cause a hazard.

Finally, it is worth considering old untreated wooden fence posts and gates which carry their own unique communities. It is useful to leave some of these when new fences have to be erected so as to provide continuity of habitat.

Artificial introduction of lichens

The techniques for transplanting lichens are relatively simple and can achieve a fair measure of success. The possibility of augmenting declining populations or re-introducing locally extinct species would appear to be a logical move but the concept does not attract universal approval among botanists and should not be arbitrarily undertaken. However, where some interesting lichen material is under immediate threat – perhaps as a result of tree disease or windthrow – its transplanting to an environmentally similar site nearby would be unlikely to invoke adverse comment. Needless to say, transplanting is likely to succeed only where a thorough understanding of lichen population dynamics exists.

Lichens as indicators of woodland age and continuity

The revised index of ecological continuity

There are a number of accepted ways of assessing the degree of historical continuity of woodlands. These include examining documentary evidence (the Nature Conservancy Council has now published an *Inventory of Ancient/Semi-Natural Woodlands* on a county basis), studying the soil structure, analysing the woodland flora and fauna, etc.

The most frequently used method involves an examination of the woodland vegetation in order to assess the occurrence of certain indicator plants. The extreme sensitivity of lichens to changing environmental conditions allowed Rose, after lengthy studies in many British woodlands, to compile a list of indicator lichens which were found to be largely restricted to woods where the environment had remained relatively stable over long periods. The original list of 20 species has been revised – it now contains 30 of these 'relic' lichen species – and their occurrence can be used in a simple formula to calculate a Revised Index of Ecological Continuity (RIEC). See Table 5.

The Revised Index of Ecological Continuity is calculated as follows:

$$\text{RIEC} = \frac{n}{20} \times 100$$

Table 5 Lichen species used to calculate the Revised Index of Ecological Continuity

Arthonia didyma	*Pannaria conoplea*
Arthopyrenia cinereopruinosa	*Parmelia crinita*
Biatorina atropurpurea	*P. reddenda*
Catillaria sphaeroides	*Parmeliella triptophylla*
Dimerella lutea	*Peltigera collina*
Enterographa crassa	*P. horizontalis*
Haematomma elatinum	*Porina leptalea*
Lecanactis premnea	*Pyrenula* species (any one)
L. lyncea	*Rinodina isidioides*
Lobaria amplissima	*Schismatomma quercicolum*
L. laetevirens	*Stenocybe septata*
L. pulmonaria	*Sticta limbata*
L. scrobiculata	*S. sylvatica*
Nephroma laevigatum	*Thelopsis rubella*
Pachyphiale cornea	*Thelotrema lepadinum*

where n is the number of species present (up to a maximum of 20) at the site out of the 30 species on the list. Occurrences at any one site of more than 20 of the species can be ignored or may be included to give a figure of over 100 per cent, thus indicating unusually outstanding sites.

Some typical examples of lowland broadleaved woodland sites and their RIEC values are given in Table 6.

Lichens characteristic of ancient woodland may persist on individual trees for many years, even when the rest of the wood has been felled. At Nettlecombe, Somerset, F. Rose and P. Wolseley (1984), supplemented documentary evidence by a survey of the oldest native trees and their epiphytic lichen communities and were able to recognise parkland and ancient woodland boundaries on the ground.

Lichen conservation

A considerable amount of survey work has been carried out in the last couple of decades, so that many of the nation's most important sites have now been identified. The British Lichen

Table 6 Typical examples of lowland broadleaved woodland sites and their RIEC values

1. Sites of old high forest of oak with glades: either medieval parklands or former Royal Forests or Chases (after Rose, 1976)	Species density per km^2	RIEC
Boconnoc Park, Cornwall (contained 29 out of the 30 species in the indicator list)	188	100
Holne Chase, Devon	106	100
Horner Combe, Somerset	176	100
Melbury Park, Dorset	215	100
Cranborne Chase, Dorset and Wilts	133	85
Savernake Forest, Wilts	112	60
New Forest, Hants	300	100
Nettlecombe, Somerset	150	75
St Leonards Forest, Sussex (a) 1974	107	65
(b) Pre-1805	143	100
Staverton Park, Suffolk	65	35
Wychwood Forest, Oxfordshire	65	35
Brampton Bryan Park, Herefordshire	131	60
Gwaun Valley, Dyfed	117	65
Coedmore Woods, Dyfed	120	70
Swallow Falls, Betws-y-coed, Gwynedd	103	100
Great Wood, Borrowdale, Cumbria	100	100
Shipley Wood, Durham (a) 1974	108	55
(b) 1805	114	80
2. Sites with naturally regenerated mature forest on former common grazing land		
Ebernoe Common, Sussex	112	45
The Mens, Sussex	75	40
3. Mature broadleaved plantations in the New Forest, Hants		
Pitts Wood Enclosure	54	40
Pond Head Enclosure	31	30
4. Mature high forest of oak, etc., known to have been clear felled and replanted within the last 200 years		
Dalegarth Woods, Eskdale, Cumberland	68	20
Nagshead Enclosure, Forest of Dean, Glos	16	0
Low Coppice Wood, Grizedale, Lancs	16	0
St Michael, Penkevil, Cornwall	54	20
Five Lords Wood, Quantocks, Somerset	29	10
Pamber Forest, Silchester, Hants	29	0
5. Old coppice woodlands with oak and ash standards		
Maplehurst Wood, Westfield, Sussex	54	10
Felsham Hall Wood, Suffolk	13	0
Foxley Wood, Norfolk	15	5
Brenchley Wood, Kent	45	5

Society set up a Conservation Committee in 1968 and this keeps an up-to-date record of sites worthy of protection and the Nature Conservancy Council is kept informed of the most important of these. It is fortunate that, as a result of coincidental interests with other aspects of nature conservation, many of these sites are to be found in National Nature Reserves and in County Naturalist Reserves. Others have been designated Sites of Special Scientific Interest in their own right, and a few of these, because of their exceptionally rich lichen flora, are recognised as being of international importance. Examples occur in the Forestry Commission's New Forest in Hampshire and in the National Trust's Horner Wood in Somerset. Unfortunately, not even these protected areas are safe from the far-reaching effects of atmospheric pollution, but perhaps at even greater risk are those sites which are yet to be surveyed and which might be harbouring noteworthy lichen communities. Old woodland sites, landscaped parklands, remnants of medieval deer forests, etc., are obvious candidates though many of these will already have been critically examined. Where doubt exists as to a woodland's lichenological status and some degree of felling is proposed an informal approach by the woodland manager to the appropriate

Regional Officer of the Nature Conservancy Council would be advisable. In the event of the discovery of a site of some significance the Nature Conservancy Council may request some modification to the felling proposals. In that case the possibility of entering into a management agreement should be explored.

In some lichenologically important areas the Forestry Commission is collaborating with other interested groups to maintain the botanical composition of important old woodlands and sometimes to preserve individual trees with a particularly rich lichen flora. In the Forest of Dean for example many of the older relic oak trees harbour rare lichens. Measures to protect these trees are included in the forest working plan, and the local staff are acquainted with their whereabouts. Routine forest operations are planned so that these trees are preserved and protected. If any tree becomes old and dangerous and has to be felled the rare lichen material may be transplanted on to neighbouring trees.

Active conservation policies have also been established in some woodlands in private ownership, for example at Longleat in Wiltshire and at Rushmore in Dorset where the owners are collaborating with the Nature Conservancy Council so that certain trees remain undisturbed.

Field studies

Studying and identifying lichens

Lichen courses for all ability levels from beginners to more advanced students are now widely available. These include university run weekend seminars; term-long evening classes run by local authorities and full residential courses at many Field Study Council centres.

A list of useful books for study will be found in the Bibliography section of this publication.

A small hand lens of ×10 or ×15 power (obtainable from any good photographic store), a sharp knife and a good field guide are all that is required to identify a large number of the more conspicuous lichens in the field. For some species identification is best confirmed by observing colour changes when small amounts of certain chemicals are applied to the medulla – the white layer of fungal hyphae exposed when the upper cortex is carefully scraped away. These tests can be carried out in the field. The main chemicals (which should be carried in small leak-proof glass bottles) and the letter codes commonly used are:

1. C : Calcium hypochlorite (common bleach)
2. K : Potassium hydroxide solution – about 20% strength
3. P : p-phenylenediamine – dissolved in alcohol or water

Note : P should be used with great care – the suppliers recommend rubber gloves. It should not be permitted to contaminate the skin.

A full account of lichen identification by this method is given in the Collins guide, *Ferns, mosses and lichens of Britain and northern and central Europe.*

A number of species can only be positively identified in the laboratory by microscopic examination of various parts of the fruiting structures and by other more elaborate tests.

Collecting lichens

Probably the best way to memorise lichen names is by frequent reference to a named collection. However, because of environmental pressures on rare and declining species indiscriminate collecting is discouraged. The Wildlife and Countryside Act (1981) makes it an offence intentionally to pick, uproot or destroy any wild plant on the Specially Protected Wild Plant list, and it is also an offence intentionally to uproot *any* wild plant without the permission of the owner or occupier. It is not illegal just to pick wild plants but you should always leave enough material to ensure the plant's survival. You should not,

Table 7 Species which have been designated by the British Lichen Society as rare and which should be photographed rather than collected

The whole of the British Isles	
Anaptychia spp. (except *A.fusca*)	*Rinodina isidioides*
Buellia epigaea	*Roccella* spp.
Cavernularia hultenii	*Solorina* spp.
Cornicularia normoerica	(except *S.saccata*)
Fulgensia spp.	*Squamarina lentigera*
Menegazzia terebrata	*Sticta* spp.
Nephroma spp.	*Teloschistes* spp.
Parmelia carporrhizans	*Umbilicaria crustulosa*
Parmelia quercina	*Umbilicaria grisea*
Peltigera venosa	*Umbilicaria hirsuta*
Pseudocyphellaria spp.	
Lowland Britain	
Lobaria spp.	*Ramalina* spp.
Pannaria spp.	*Sphaerophorus* spp.
Parmeliella spp.	

of course, pick any plants in a Nature Reserve. On professionally organised lichen courses a limited amount of collection of plentiful species is permitted. Species which have been designated by the British Lichen Society as rare and which should be photographed rather than collected are listed in Table 7.

Many species can be easily lifted off the substrate by hand. Others grow closely appressed to the substrate and need to be prised from their anchorage with the blade of a knife. Some cannot be taken without also removing some of the substrate (but care should be taken to avoid cutting into live wood). A sharp knife will be needed for this, while for rocks and masonry a 1lb hammer and a small cold chisel should be carried.

Specimens should be put into paper packets or envelopes on to which the following information should be written:

1 date
2 location (with Grid Reference number)
3 substrate (species of tree – type of rock)
4 name of collector

Specimens should be dried out slowly near a radiator or a sunny windowsill and after identification can be stored in their envelopes, displayed in trays or attached to stiff card. Treated thus, specimens should last indefinitely.

Useful addresses

British Lichen Society
c/o Department of Botany
British Museum (Natural History)
Cromwell Road
London SW7 5BD

An international society which seeks to stimulate and advance interest in all aspects of lichenology. Anyone interested in lichens may become a member.

Nature Conservancy Council
Northminster House
Peterborough
PE1 1UA Telephone : Peterborough (0733) 40345

Information Office
Field Studies Council
Preston Montford
Montford Bridge
Shrewsbury
SY4 1DX Telephone: Shrewsbury (0743) 850380

Forestry Commission
231 Corstophine Road
Edinburgh
EH12 7AT Telephone: Edinburgh 031-334 0303

An excellent wall chart (Plate 30) and information booklet *Lichens and air pollution* are published by:
British Museum (Natural History) and BP Educational Service
and are available from
The Natural History Museum Shop
Cromwell Road
London
SW7 5BD

Glossary

Apothecia – disc-like, cup shaped or elongated fruiting structures

Cladoniiform – a growth form with both vertical and horizontal structures as in the *Cladonia* genus

Cortex – the outermost layer of a lichen thallus

Corticolous – found growing on bark

Crustose – an encrusting growth form, the thallus usually penetrating the substrate

Endophloeodal – growing immersed in bark

Epiphytic – a plant growing on another without being parasitic on it

Foliose – a leafy growth form

Fruticose – a shrubby growth form

Hyphae – a fungal tissue

Isidia – minute coralloid outgrowths on the thallus composed of algal cells and fungal tissues and capable on becoming detached of reproducing the plant vegetatively

Medulla – the layer of fungal tissue beneath the cortex

Perithecia – globular fruiting structures often immersed in the thallus each opening by minute pores at the top

Podetia – stalk-like structures peculiar to the *Cladonia* genus

Saxicolous – found growing on stone

Soredia – a powdery combination of algal cells and fungal tissues and capable on becoming detached of reproducing the plant vegetatively

Substrate – the rock, bark, wood, soil, etc., on which a plant grows

Taxa (pl.) – the recognisable unit on which a species is based (taxon, s.)

Terricolous – found growing on soil

Thallus – the plant body

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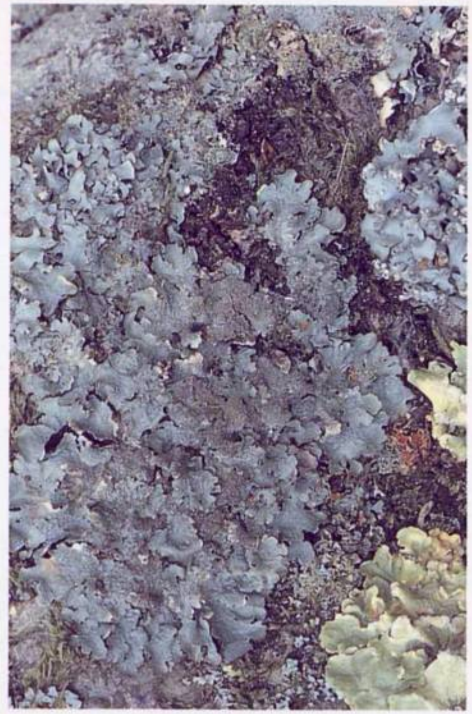

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