SULPHUR AND THE DISTRIBUTION OF BRITISH PLANTS

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Abstract

The extent of recent additions of sulphur from fertilizers and atmospheric pollution to British soils is pointed out. Gymnosperms are especially sensitive to sulphur pollution, while crucifers and some other plants are unusually tolerant. It is possible that the diminution of some species, such as *Juniperus communis*, in Britain is a result of atmospheric pollution, as is the spread of many crucifers such as *Cardaria draba*. The distribution maps of many alien crucifers can be correlated with a map of sulphur dioxide pollution. Many native crucifers restricted to coastal habitats may be so restricted because their requirement for sulphur is satisfied by sea-spray.

Sulphur is a common element in the soil which is essential for the growth of plants. During the present century the amount of sulphur in British soils and plants has increased, partly from the use of fertilizers, but more substantially from pollution of the atmosphere. The present note attempts to correlate some recent changes in the distribution of plants with sulphur pollution in Britain, and suggests that further studies of the problem should be made.

Sulphur in soils

Sulphur is universally present in British soils, largely as the sulphate anion, but there are no data from which a map of sulphur abundance could be drawn. In the north and west of Britain, on soils derived from igneous rocks, sulphur is four or five times more abundant in soils derived from basalt and other basic rocks than it is in granitic soils. It is also unusually abundant in regions where certain minerals are common, as in parts of Cornwall. South and east Britain are mostly covered by soils derived from sedimentary rocks. In these rocks the relative abundance of sulphur increases in the order sandstones, limestones, shales and coal deposits: sulphur deficiency is most likely to occur in sandy soils. Soils unusually rich in sulphur are found near open-cast coal mines and above clays containing the sulphide of iron (iron pyrites). Calcium sulphate or gypsum occurs in large amounts in triassic clays in a narrow band stretching from Watchet in Somerset to Hawton in Nottinghamshire, while strontium sulphate or celestine occurs in a small area near Bristol, including the Avon gorge. Barium sulphate or barytes is found very locally in several parts of Britain, for example, the Derbyshire dales and Ben Bulben in Sligo.

Sulphur constitutes 4 per cent of the solids in fresh water, and 2·5 per cent of the solids in sea water, so that it must be unusually abundant in salt marshes and on cliffs and beaches exposed to salt spray. Thomas *et al.* (1950) have shown that halophytes usually contain far more sulphur than do other plants.

Agricultural soils are subjected to a steady drain on their sulphur content, since a ton of crop usually contains between 1·5 and 10 kg of sulphur. During the present century most agricultural land in Britain has received heavy dressings of sulphur in fertilizers, either as ammonium sulphate, potassium sulphate or more often as superphosphate, which contains 12 per cent of sulphur from the sulphuric acid used to make it. The amount of sulphur applied to agricultural land in Britain each year is about 130,000 tons, corresponding to 10 kg/hectare. Some artificial soils, such as colliery dumps and railway cinder tracks, contain sufficient sulphur to restrict plant growth.

Sulphur in the air

The extent of atmospheric pollution in Britain has been described by Meetham (1956), and the world problem has been summarized by Junge (1963). The pollution arises largely

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from burning coal, and to a minor extent from smelting ores and making sulphuric acid. Coal contains from 0·5 to 4 per cent of sulphur, but much of this is oxidized to sulphates which remain in the ash after the coal is burnt. The remainder produces sulphur dioxide, and about five million tons of this gas are set free in Britain every year. As a result all big cities and industrial areas in Britain are surrounded by belts of air polluted with sulphur dioxide, as shown in Fig. 1. Polluted air may contain up to 200 μg sulphur dioxide per cubic metre, as against 1–3 μg in the purest air to be found on the earth today. The mean time each molecule of sulphur dioxide remains in the air before it is absorbed by plants or washed out by rain is 4 days. During this time the gas may be blown well out into the surrounding countryside. The ultimate effect of this pollution is to add between 5 and 400 kg of sulphur to each hectare of soil in Britain every year.

Sulphur in plants

Plants need sulphur for many aspects of growth, and absorb it either as the sulphate ion through the roots, or as gaseous sulphur dioxide from the air. Sulphur deficiency has never been reported in Britain, though it is known in Nyasaland and western North America (Wallace 1961): it gives rise to chlorosis of the younger leaves in the same way as a shortage of iron does. Plants suffering from excess of sulphur in the soil are seldom noticed. Excessive amounts of sulphur dioxide in the air are harmful to plants, and markedly reduce their growth rate. The gas causes leaf necrosis and accelerates leaf senescence, and may cause evergreen species such as *Ilex aquifolium* and *Ligustrum vulgare* to become deciduous (Scurfield 1960). There are wide variations in tolerance between different species.

Analytical data for sulphur in plants have been given for example by Beeson (1941), Thomas *et al.* (1950), and Spector (1956). Conifer leaves contain only about 0·1 per cent of the element, grasses contain 0·05–0·2 per cent, while most other Angiosperm leaves contain 0·2–0·4 per cent. Exceptionally large amounts of sulphur are found in species of Cruciferae and the genus *Allium* (0·5–1·5 per cent), halophytes such as *Salicornia* and *Suaeda* (2–3 per cent), and *Cuscuta europaea* (1 per cent); the last finding needs confirmation.

The biochemistry of sulphur compounds in plants has been reviewed by Kjaer (1963). He points out that all species of Cruciferae, together with members of the related families Resedaceae and Capparidaceae, contain thioglucosides (mustard oils), which are responsible for the pungent taste of such well-known condiment plants as radish, horseradish, cress, watercress and the mustards. Species of the genus *Allium* contain no thioglucosides, but instead have a wide range of unusual sulphur compounds, including the lachrymator propenyl-sulphenic acid. Other genera which have been shown to contain unusual sulphur derivatives include *Equisetum*, *Athyrium*, *Pteridium*, *Petroselinum*, *Lactuca*, *Petasites* and *Asparagus*. Much remains to be discovered in this field, but it is clear that the Cruciferae and the genus *Allium* need more sulphur than other plants and are adapted to high concentrations of the element. This implies that these groups may have evolved in regions rich in sulphur, but such speculations will not be followed up here.

Species abnormally sensitive to sulphur pollution

Sulphur dioxide is known to be absorbed almost entirely by the leaves, but very few studies of chronic exposure of plants have been made (Bleasdale 1959). Hence it is not possible to say which species are most sensitive to sulphur pollution, though it seems that Gymnosperms and grasses are more sensitive than other plants (Katz & Shore 1955, Scurfield 1955, 1960). Since pollution reaches its maximum levels in winter, its effects are usually most severe on evergreen trees, and on herbaceous plants which overwinter with functional leaves. Comparison of Fig. 1 with the distribution maps in the *Atlas of the British Flora* which show records before and after 1930 (Perring & Walters 1962) is suggestive. Unfortunately it is difficult to disentangle the effects of pollution from two other major factors responsible for recent changes in the distribution of British plants—

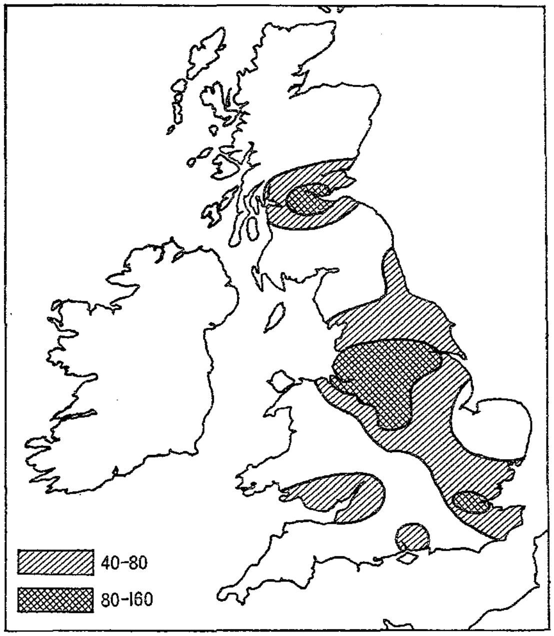

Fig. 1. Average amount of sulphur dioxide in the air in winter, in micrograms per cubic metre. After Meetham (1956).

the rise in mean winter temperatures which has caused many Northern species such as *Lycopodium selago* to retreat northwards or westwards, and the artificial drainage of wet habitats. However, there is sufficient correlation between areas of gross pollution and recent extinction to justify further studies on the following species: *Lycopodium inundatum*, *Juniperus communis*, *Hypericum elodes*, *Radiola linoides*, *Drosera* spp., *Gentiana pneumonanthe*, *Colchicum autumnale*, *Paris quadrifolia*, *Neottia nidus-avis* and *Rhynchospora alba*. The majority of these are plants of bogs or wet heaths, whose decrease may be largely due to drainage. Of the remainder, the Juniper (Fig. 2) has aroused interest because of its unexplained diminution on the Chilterns and in County Durham (Fitter 1964, Heslop-Harrison 1962). The decrease of the three monocotyledonous woodland species has been less spectacular and so has not been commented on. Studies of the chronic effects of sulphur dioxide on these species would be needed to establish whether the correlation is a true one.

Species tolerant of sulphur pollution

The maps given in the *Atlas of the British Flora* show that the distributions of the following species are fairly well correlated with regions of industrial pollution: *Artemisia absinthium*, *Barbarea stricta*, *Bunias orientalis*, *Cardaria draba* (Fig. 3), *Descurainia sophia*, *Erucastrum gallicum*, *Erysimum cheiranthoides*, *Lepidium ruderale*, *Rapistrum rugosum*, *Senecio squalidus*, *S. viscosus*, *Sisymbrium altissimum* and *S. orientale*. All of these are plants of waste ground and are commonly found growing on soils containing large amounts of coal-ash, such as railway tracks, yards and refuse-tips, though *Descurainia*, *Erysimum* and *Rapistrum* occur as weeds in arable land as well. All are introduced plants, and one, *Senecio squalidus*, is native to the sulphureous region of Sicily. Rarer plants confined to similar habitats in Britain include *Artemisia verlotorum*, *Astragalus cicer*, *A. odoratus*, *Hirschfeldia incana*, *Rorippa austriaca* and several other crucifers. Five other species (*Cerastium atrovirens*, *Cochlearia danica*, *Corrigiola litoralis*, *Diplotaxis muralis* and

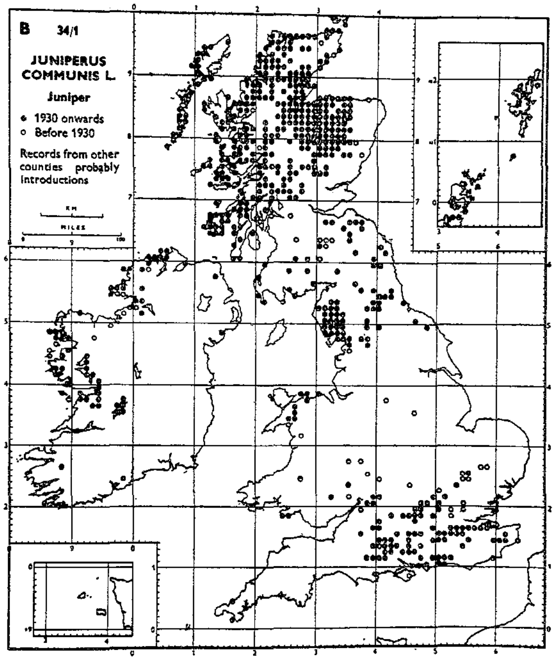

Fig. 2. Distribution map of *Juniperus communis* (Perring & Walters 1962). Note the disappearance since 1930 from polluted regions.

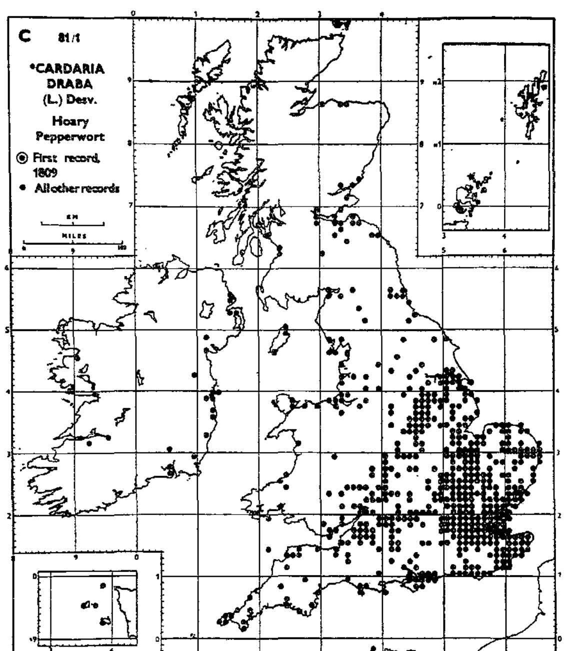

Fig. 3. Distribution map of *Cardaria draba* (Perring & Walters 1962). Most of the records outside polluted regions are from near the coast.

D. tenuifolia) should also be mentioned in this group. They are natives of the sea coast which have spread inland along railway tracks, but have not colonized unpolluted soils to any extent.

All these species can be said to be tolerant of sulphur pollution, and the high percentage of crucifers is noteworthy. As mentioned above, crucifers store much of their sulphur as thioglucosides, but the species of Caryophyllaceae, Papilionaceae and Compositae are believed not to do this. Biochemical examination of *Artemisia*, *Astragalus* and *Corrigiola* for sulphur compounds should be carried out.

Further peculiarities in the distribution of Cruciferae and Allieae

Sulphur may also be important in maintaining the abundance of some of the bad cruciferous weeds in Britain, such as *Brassica nigra*, *Sinapis arvensis*, *S. alba*, *Raphanus raphanistrum*, *Thlaspi arvense* and *Capsella bursa-pastoris*, as well as the crow garlic, *Allium vineale*. The large amounts of sulphur added to the soil in fertilizers may stimulate cruciferous weeds at the expense of others, and this should be tested experimentally.

In nature, coastal habitats are rich in sulphur and this may account for the high percentage of cruciferous species restricted to the sea-coast. If one compares the British representatives of other large herbaceous families in this respect, as in Table 1, one finds that only Allieae and Caryophyllaceae have a similar proportion of coastal species.

Table 1. Proportion of coastal species in various families of British plants.

Family	*No. of native species*	*% of coastal species*
Cruciferae	57	26·4
Allieae	8	25·0
Caryophyllaceae	71	18·3
Umbelliferae	53	11·3
Ranunculaceae	36	2·8
Scrophulariaceae	50	2·0
Labiatae	47	0

Coastal habitats are, of course, even richer in chlorine than they are in sulphur, but the two habitats of *Diplotaxis* suggest that the latter element is more important as far as crucifers are concerned.

The question arises as to whether some of our native crucifers and garlics are limited to soils relatively rich in sulphur. This is a difficult problem to which no definite answer can be given. A number of species of *Arabis*, *Cardaminopsis*, *Draba*, *Hornungia* and *Thlaspi*, together with *Allium oleraceum*, *A. schoenoprasum* and *A. sphaerocephalon*, are more or less localized to rocky soils in regions containing unusual minerals. The association of *Arabis stricta*, *Hornungia petraea* and *Allium sphaerocephalon* in the Avon gorge near Bristol may have arisen because of the sulphate minerals there, but there are other possible reasons. The area round Matlock in Derbyshire is noted for the occurrence of *Arabis hirsuta*, *Thlaspi alpestre*, *Draba muralis*, *D. incana*, *Hornungia petraea*, *Cardamine impatiens* and *Allium oleraceum*, as well as the mineral barytes or barium sulphate. However, it also yields minerals containing large amounts of fluorine, lead and zinc, among other elements, and the effects of specific minerals on these plants have not been tested. There is obviously a rich field here for future research.

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