Some aspects of the effect of atmospheric pollution on the Lichen Flora to the West of Consett Co. Durham

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Some Aspects of the Effect of Atmospheric Pollution on the Lichen Flora to the West of Consett Co. Durham.

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University of Durham

1966

Being a dissertation presented in candidature for the Degree of Master of Science in the Department of Botany at the University of Durham.

" No witchcraft, no enemy action had silenced the rebirth of new life in this stricken world. The people had done it themselves".

(R. Carson in Silent Spring)

Summary

The effect of atmospheric pollution on the growth of lichens has long been discussed. This work was aimed at obtaining data on the effect of such pollution, from the Iron and Steel works at Consett Co. Durham, on the lichen flora of the district.

The degree of pollution found to the west of Consett was evaluated by analysis of lichen thallus for sulphur and from bark washings for ammounts of deposited matter. These results were compared with standard pollution data at Consett, obtained from the D.S.I.R, and a pollution gradient passing west from Consett was plotted.

The distribution of corticolous, saxicolous and terricolous lichens in this area was mapped. The results from these distributions were applied to the pollution data and the control of lichens by pollution shown. The modification of the pollution effect by humidity factors is also discussed.

Contents.

Introduction

The phenomenon that lichens are rarely found in built-up and industrial areas is frequently observed, and attributed to a number of factors, chiefly effects of toxic pollution and of low humidity. Consett is a town with a residential population of 38.7 thousand and an Iron works producing some one million ingot tons of steel per annum. This work deals with the pollution from this source using data obtained from the D.S.I.R. and with the amounts of pollution found to the west of Consett as evaluated by bark washings and lichen thallus analysis. The distribution of lichens to the west of Consett was assessed and correlated with the pollution data.

Historical background to the study of atmospheric and humidity effects on lichens.

It has been clear to lichenologists and other investigators that lichens are practically absent from industrial and densely populated regions, and those present are often much reduced in quality. Such disappearance was noted in England by Nylander in the mid-nineteenth century, and more recently by Wheldon and Wilson in 1915. That this situation occurs throughout the world is shown by the accounts of Hansgja and Skye in Scandinavia, Tobler in Germany and noted by Lamb in North America.

A.L.Smith (1921) in her work on lichens indicates that the chief impurity in the air is coal smoke, produced not only from factories, but also from private dwellings. She notes that the effects are seen to reach far beyond the limits of settlement and that lichens are seen to deteriorate primarily due to the decomposition coal combustion products, especially sulphur compounds. Skye (1958) also asserts that toxicity, chiefly by sulphur dioxide, is the main cause for the scarcity of lichens in towns. In addition to these views of Smith and Skye there is the opinion, first expressed by Rydzak (1953) that low humidity and the virtually total absence of dew in towns is the prime factor controlling the degree of absence of lichens. Smith has little to say on the subject of humidity except to state that a high degree of humidity is of district advantage to the growth of the lichen thallus.

Wind, in itself, does little direct damage except as icy blasts in the circum-polar area, to crustose or foliose lichens as the substrate offers sufficient shelter. However wind does have a drying effect, reducing the humidity of the air layer over the thallus. Wind also acts as a transporting agent for abrasive sand and dust particles and also serves to disperse pollution from its source. Thus the limits of the effect of pollution are determined by the prevailing wind (Fig.1) and the centre of such an area is usually stated to be about one mile down-wind from the pollution source.

Barkman (1958) discusses the "drought or poisoning" problem very fully for situations in the Netherlands, giving both positive and negative arguments for both views, finally concluding that both factors are of importance. Jones (1952) indicates a number of ways in which lichens reflect such indirect effects of man. Barkman also shows how other effects of pollution are felt, by changing pH of substrate, blocking out of light by dust deposits as well as direct toxicity.

In Britain, at least, small particles of dust and smoke are attributed to the action of man; though in certain geographical areas volcanicity may contribute. To be of effect to the epiphgte these chemicals must achieve solution, either in precipitation or fog or in the moisture content of the substrate. Lichens have a remarkable capacity for absorbing vast quantities of water, and at very rapid rates (Smith 1961). In addition to this they have the ability to absorb a variety of minerals from solution, often against concentration gradients; and they may even absorb water from air that is not toally saturated. Large quantities of nutrients and other minerals are thus taken up, indiscriminately, during the short times when saturation and humidity is high. This is often quoted as an adaptation to a xerophytic mode of life but it also means that lichens are extremely susceptible to toxic substances. Tobler (1925) has shown in Germany that lichens are sufficiently xerophytic to withstand the drought

Wind Force and Direction.

Data from Durham Observatory (1964-5)

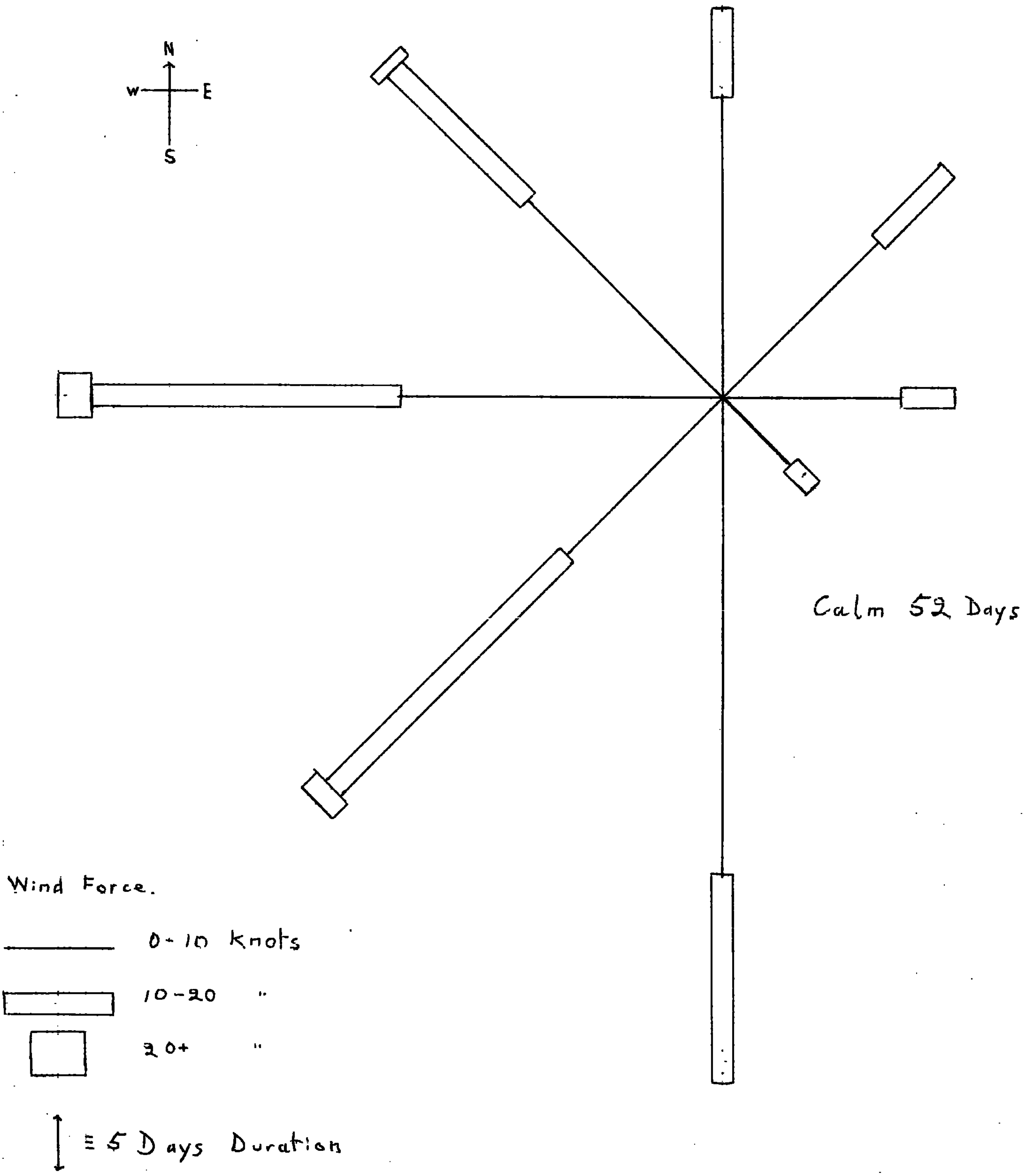


Fig 1

and absence of dew from towns, and as their assimilation and growth is so slow the "blocking out" is of no significance until it is virtually complete, when toxicity will have asserted its effect. Varying degrees of susceptibility of lichens to atmospheric pollution can thus be attributed to a less rapid rate of uptake of water, coupled with a higher selectivity for the absorbed ions; and the crustose and closely adpressed foliose growth form where more of the water and thus the nutrients are taken up by the rhizoids or by direct absorption from the bark. It is these latter forms and those with a rapid and indiscriminate uptake of moisture and ions that are found nearest to the centre of an area of pollution.

Many workers (e.g. Brightman 1962) have observed that along uphill stretches of trunk roads and roundabouts in rural areas lichens are found growing well, on stone walls and on tree bases, despite a covering of toxic exhaust gases, soot and dust, and thus discount the theory that lichens are absent from towns due to toxicity. However as Tobler suggests in such situations moisture content of the substrate is probably high enough for the lichens to avoid taking in water directly from the atmosphere and sufficient light would penetrate the dust film to allow the very slow metabolism and growth rate to take place unimpeded. Thus there may be a potential source of toxicity in such cases which, due to other factors of humidity and substrate moisture content, is not apparent.

Gilbert (1965) suggests, as does Borkman that it is toxicity that is of prime importance but that humidity is also relevant and that there is an interrelationship between the two. In "dry" areas (i.e. built-up areas) the bulk of water uptake comes directly from the atmosphere as rain, mist or fog and not from the substrate. In this way non-selective rapid absorption takes place and toxic substances are rapidly accumulated. In habitats of higher humidity not only do lichens tend to be more selective in their ionic uptake, but more is taken from the substrate and as the lichen remains in condition capable of carrying out metabolic conversion of sulphite to the less toxic form of sulphate for far longer the effect of pollution is less marked.

Country to the W. of Consett (showing line of transect)

Area of Study

The area just to the west of Consett lies in the north of County Durham (Vice County 66, M.R. 45/05 to 10, 48 to 51). It borders the eastern foothills of the north Pennines and is an area designated as of landscape, scientific and historic value. The river Derwent and it tributaries Hisehope and Wharnley burns, cut deep valleys into the Carboniferous Millstone Grit. West of this area is heath moorland of Calluna and Pteridium with some rough pasture. Wartime influences upon the pattern of agriculture were pronounced with a greatly increased anable acreage under corn and potatoes. By 1958 the natural factors of climate and terrain were reasserting themselves resulting in an increase of both temporary and permanent pasture for both cattle and sheep. The valley's of the river Derwent and its tributaries, Wharnley, Hisehope, Deneburn, carry dense mixed woodland, with a few small conifer plantations. (see map).

The Iron and Steel Works
at Consett.

Historical Background to Industry in the Area.

Records show that Consett grew from a small village during the 1820's to an urban industrial town by the mid-twentieth century. The nineteenth century industrial development was based on the utilisation of local iron ore from the millstone grit deposits. The mining villages of Leadgate and Knitsley grew up around Consett, producing the coal for the growing steel industry. The Fell coke works arose from the need to convert the coal to coke for use in the manufacture of Iron.

The Iron Works now (1966) produces about one million ingot tons of steel, mostly by the L.D. method, but also some by the Kaldo method. The approximate consumption of the principal raw materials is :-

1,315,000	tons Iron Ore
825,000	tons Coal
2,250	million cubic feet Oxygen.

The Urban population of Consett reached a density of 1,500 - 5,000 per square mile in 1949 and the present population of the Borough (which includes Leadgate, Knitsley and the newer estates of Moorside and the Crave) is 38.7 thousand and covers 10,042 acres. This represents a density of nearly 162 persons per square mile.

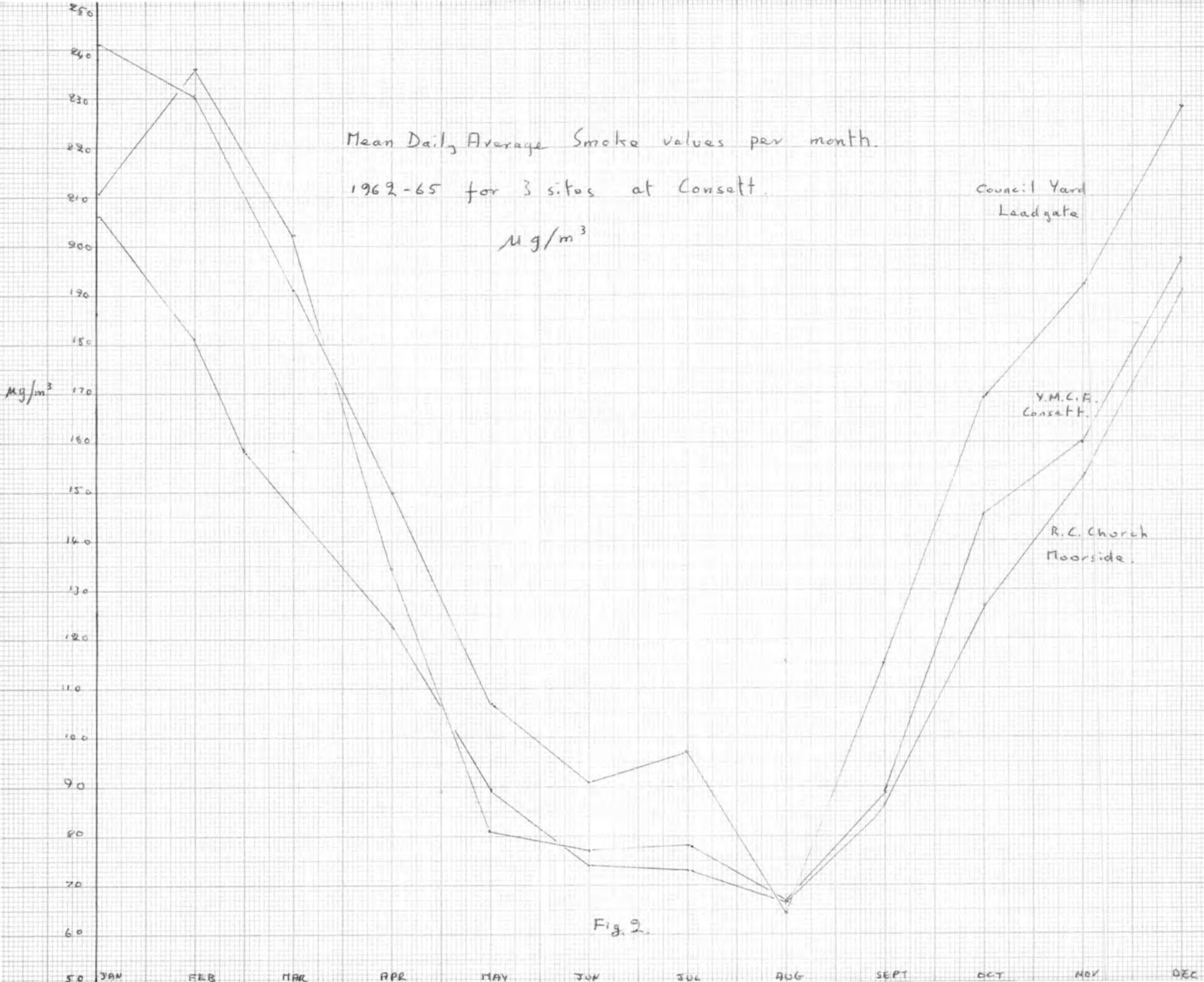
The atmospheric pollution influencing the lichen growth in this area thus comes from two main sources; from domestic fires, which have their main effect in winter, and from industrial smoke and dust which is of more or less equal effect throughout the year. (Fig.2,3).

Data of the amount of atmospheric pollution at Consett was obtained from the D.S.I.R., who, as part of a national monitoring scheme have three sites at which there is apparatus for the daily recording of smoke and sulphur dioxide, and also a deposit gauge which records the amounts of heavier particles such as fly ash and soot which settle quickly (details of these instruments will be found in the appendix). The smoke control meters are sited as follows :-

1. R.C.Church, Moorside (45/088494). This is in the middle of a medium-density housing estate with some industrial undertakings and surrounded by other built-up areas. It is about one mile S.W. of the main steel works, and is thus to the leeward during prevailing winds (Fig.1).
2. Y.M.C.A. (45/106510). This gauge is situated in a high density housing area within one eigth of a mile of the Consett Iron Company steel works and blast furnaces. It is to the N.E. and is thus in line of the prevailing winds.
3. Council Yard, Leadgate (45/128516). This is also in a high density housing area and is one mile N.E. of the Steel works.

The results show that pollution is heaviest at site (3) (Fig 2) thus bearing out the earlier statement that the centre of pollution is about one mile downwind of the source. The least pollution is at site (1) but the difference between the three sites is not very marked and does tend to be greater in the winter. This suggests that most of the smoke, especially in the winter months is produced from domestic fires and that industrial pollution is fairly evenly spread at about 75 ug/m^2/month of smoke. The greater values at site (2) (Fig 3) indicates that, as would be expected, the Iron works produces much more sulphur dioxide than domestic fires.

Results from the deposit gauge which is sited just outside the steel works to the N.E. give a mean of 33 tons/square mile/month of undissolved dust. (see Appendix).



Mean Daily Average Smoke values per month.

1962-65 for 3 sites at Consett.

μg/m³

Fig. 2.

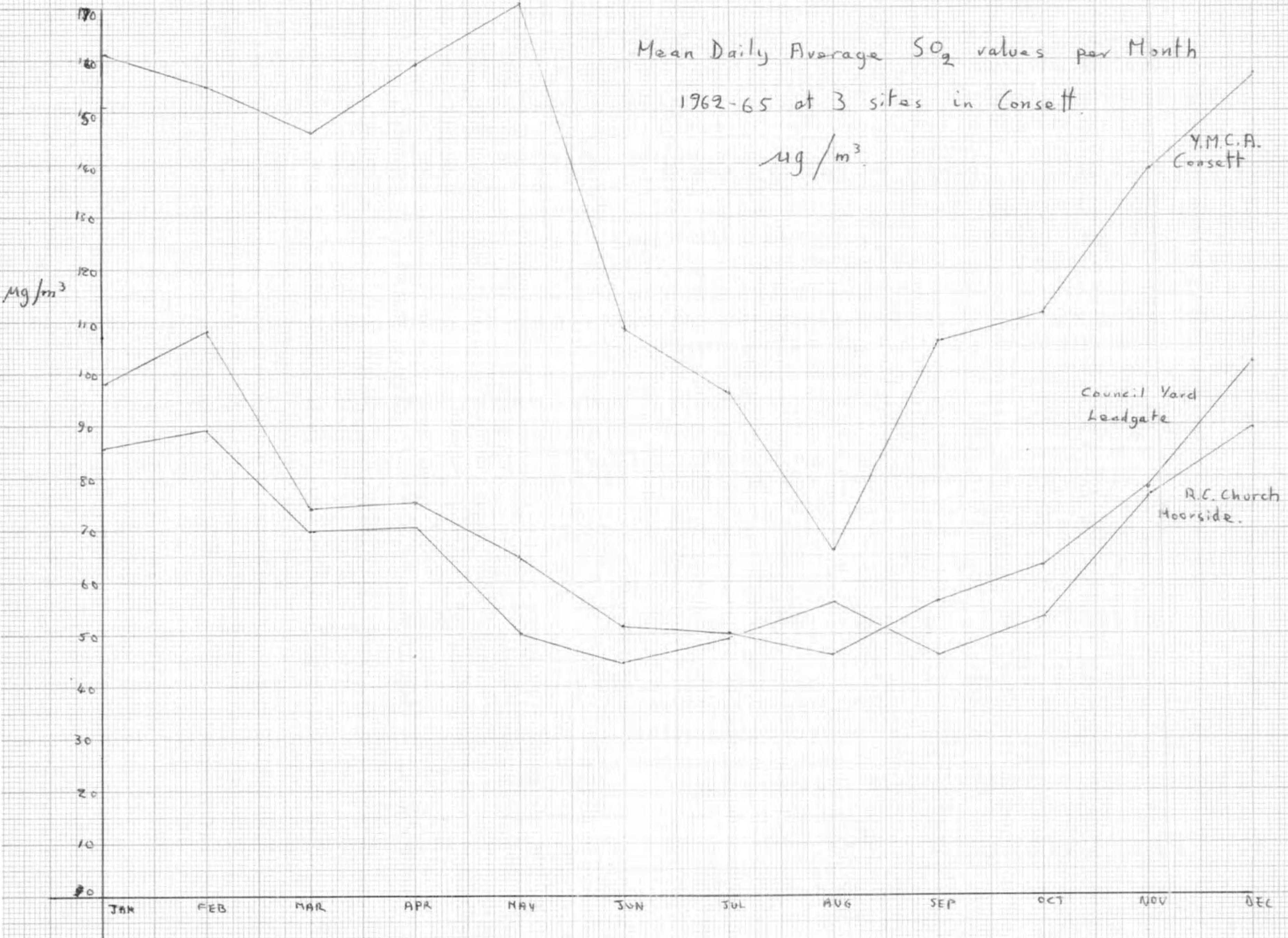

Mean Daily Average SO_2 values per Month
1962-65 at 3 sites in Consett
$\mu g/m^3$

Fig. 3.

Method of Investigation

In order to assess the distribution of lichens to the west of Consett a rough transect line was drawn. This followed Consett Lane and Pemberton Road to Allensford, a small section of the A68, Corbridge, Tow Law road and then followed minor roads from Wharnley Burn Bridge through Derwent Grange farm to Muggles wick (see Map, Photo p. 11). Apart from the small stretch of A68, these roads carry little traffic so that any effect of road dust or toxic exhaust fumes would be strictly limited and probably of insignificant nature.

Quercus robur was the tree species most intensively studied for epiphytic lichens as it was the commonest tree along the transect line. The corticolous species on Fagus silvatica, Fraxinus excelsior, and Betula alba were also studied as were saxicolous species on the millstone grit walls, and the terricolous species. The epiphytic lichen communities were studied only on trees which were without any obvious tendency to lean, which were free standing and not especially sheltered in any way from the east. Where possible examination was made of lichen communities for a single species stand of tree.

The lichen cover on the tree was measured with a point quadrat. This was found to be the most convenient method and gave consistent results with the cover expressed as a percentage. The quadrat (see photo p20) was placed between 1.5 and 2 metres from the ground on the trunk of the tree. The quadrat was placed 10 times on each trunk, roughly equally spaced round the circumference. Care was taken that the quadrat was not consciously placed in any particular position, but true random sampling in this situation was not thought to have any special merit. This is basically the method as used by Kershaw (1964).

The 10 cm. point quadrat - (10 pins inserted headfirst at 1 cm. spacing on a perspex strip). - in use on Oak covering Parmelia physodes and Pertusaria amara.

It was noted that lichens tended to form vertical distributions on one side of the trunk. If the trunk was leaning they tended to prefer the upper side and the various species obviously formed a pattern related to variations of water regime of the bark. (Fig.4). Even on vertical trunks it was often noted that similar distributions were found. In such cases there was no apparent relationship to prevailing wind direction, direction of insolation or even to the direction of the source of pollution. Perhaps even in these cases rain tracks down the trunk and other factors associated with shelter provided by cracks in the bark and local high humidity are of prime importance for determining the distribution of lichens on the tree. The total number of lichen species, including those at the base, was also noted.

For many of the trees and sites studied a circle of bark was cut from the east side of the trunk. These were washed and the surface dust collected and weighed to give an indication of the dust settling out on the tree and lichens. The discs were also used to give pH measurements, to see if the pollution affected the pH of the bark and thus indirectly the lichen assemblage.

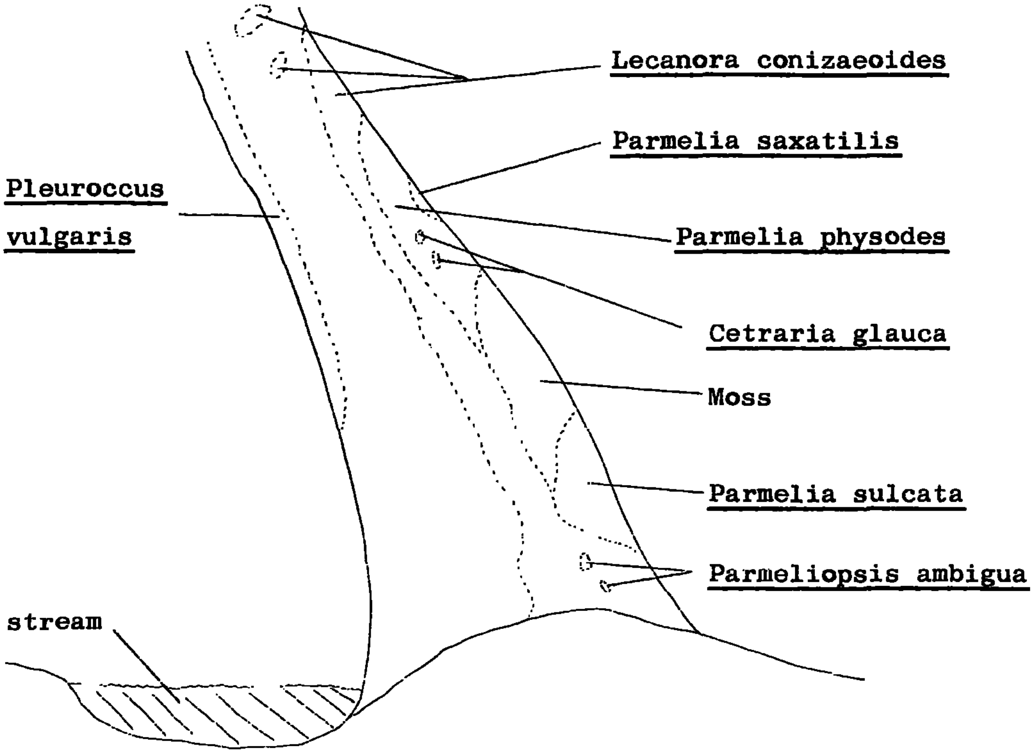
Leaning Betula alba. (1.85 km from Consett).

to illustrate

1) Lichen zonation on leaning trunk

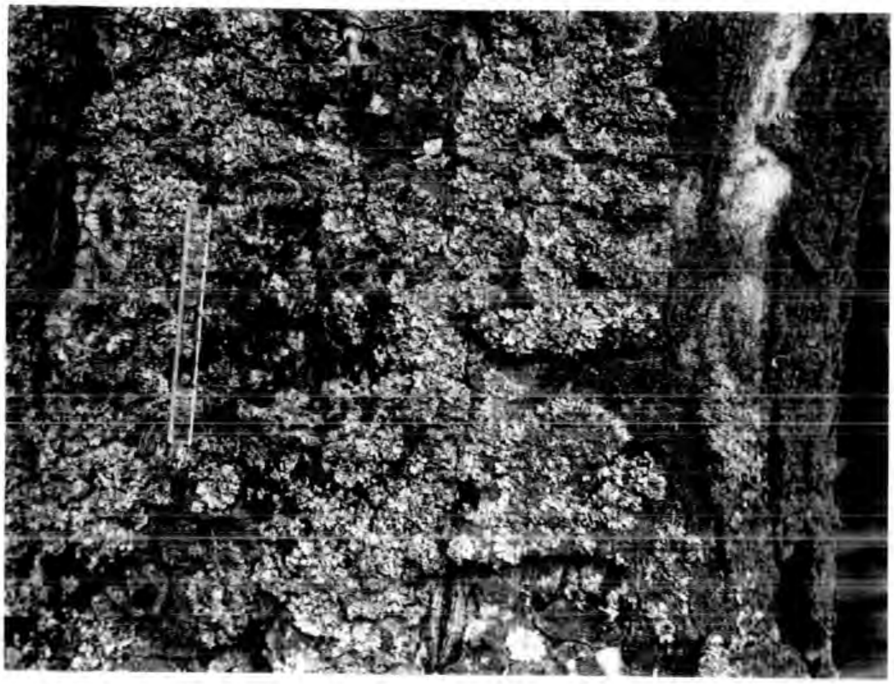
2) Increasing richness of Lichen flora at base

3) Effect of local high humidity



This Birch, though only 1.85 km out was in a sheltered position with high humidity at its base. This lichen assemblage was not found at a height of 1-1.5 metres on birch anywhere in the area studied. This emphasises the great moderation of pollution toxicity by a high humidity level.

Fig.4.



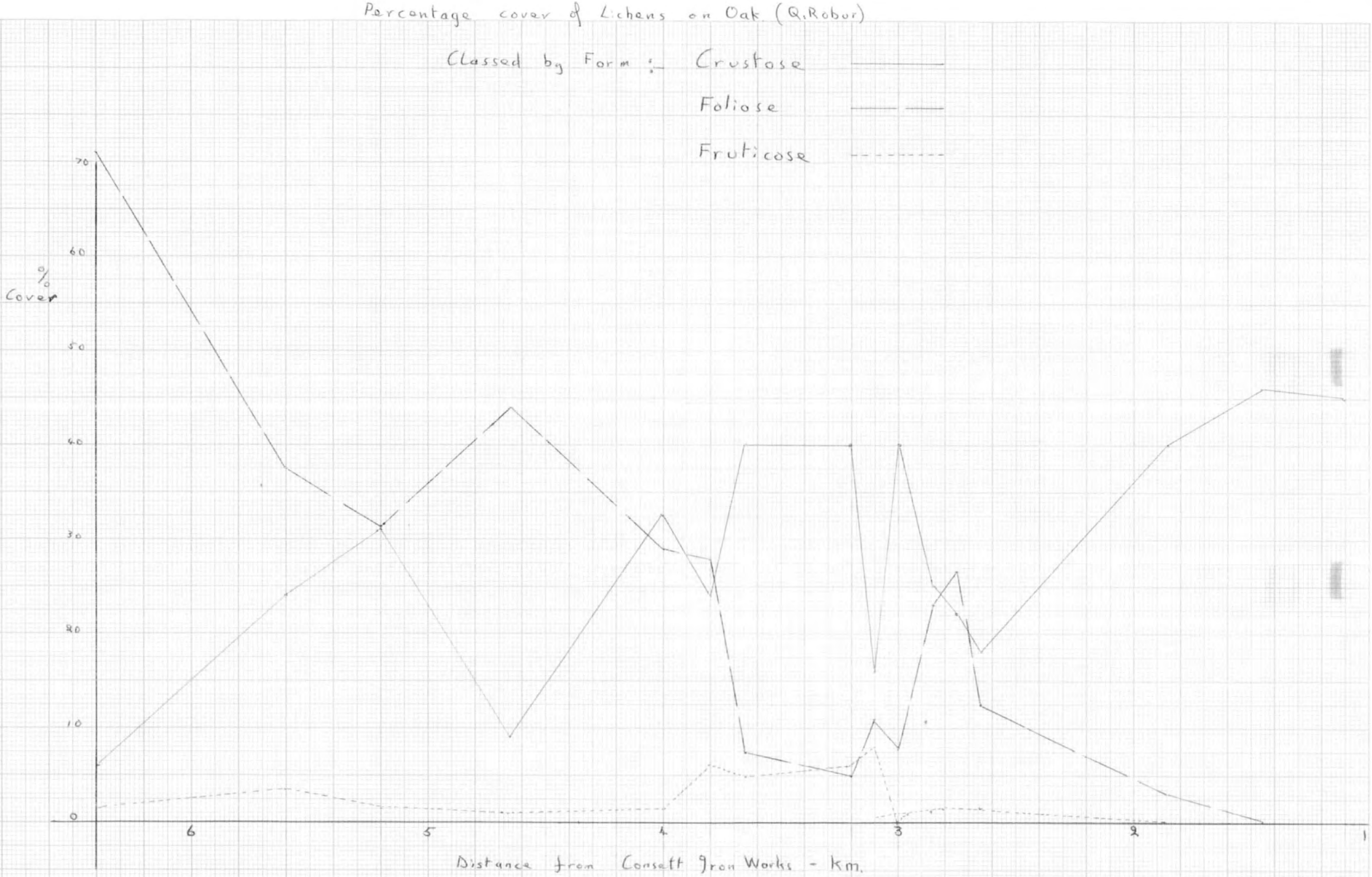
Point quadrat covering Parmelia physodes
and Cetraria glauca on
(6 km from Consett)

Observations of Epiphytic Lichens.

By measuring percentage cover in the manner described there is shown an evident decrease in both numbers and coverage of most lichens (Fig.5,9). The chief exception to this is *Lecanora conizaeoides* (Fig.6,7). This lichen exhibits a high degree of toxitolerance and may even be called toxicolous. *Parmelia physodes* and *P. saxatilis* also show a similar tendency to be able to exist well into the polluted area, although they do decrease in coverage (Fig.6).

Usnea, a genus that is characteristic of pure air regions was not represented within 4.6 km of the Iron works. Even this near only a few small specimens were observed in sheltered positions in the cracks of rough bark of old *Quercus robur.*

Oak was the commonest tree species encountered and was thus the most intensively studied. It carried a lichen flora which was rather richer than expected, as *Quercus robur* is usually among the "poorer" species. *Betula alba* had, as expected the poorest lichen assemblage encountered, only *Lecanora conizaeoides* being found above one meter within 4 km of the Iron works (see data in appendix). The paucity of lichens growing on *Betula alba* has often been noted and I think this may be due to some inhibitive agent in the phellem, as when lichens are found (e.g. *Lecanora conizaeoides*) they are seen initially to appear where the outer bark layer has peeled off, or where transverse splits have occurred in it. The lack of lichen colonisation of *Betula alba* was quite marked. At 3.8 km out it still had only *Lecanora conizaeoides* whilst *Quercus robur* had 9 species, *Fagus silvatica* 8, *Fraxinus* excelsior 7. (Fig.8). Although the percentage coverage of most species tends to be shown as being rather variable, the increases in bare bark and Lecanora conizaeoides with the concommitent decrease in the majority of fruticose and foliose lichens is demonstrated (Fig.5). It is also shown that crustose species are carried further in to the centre of pollution than the foliose species (Fig.5). The decrease in richness of the lichen flora as the Iron works is approached is also shown (Fig.9).



Percentage cover of Lichens on Oak (Q.Robur)

Fig. 5

Percentage Cover on Oak (Q. Robur) of the principal Lichen species

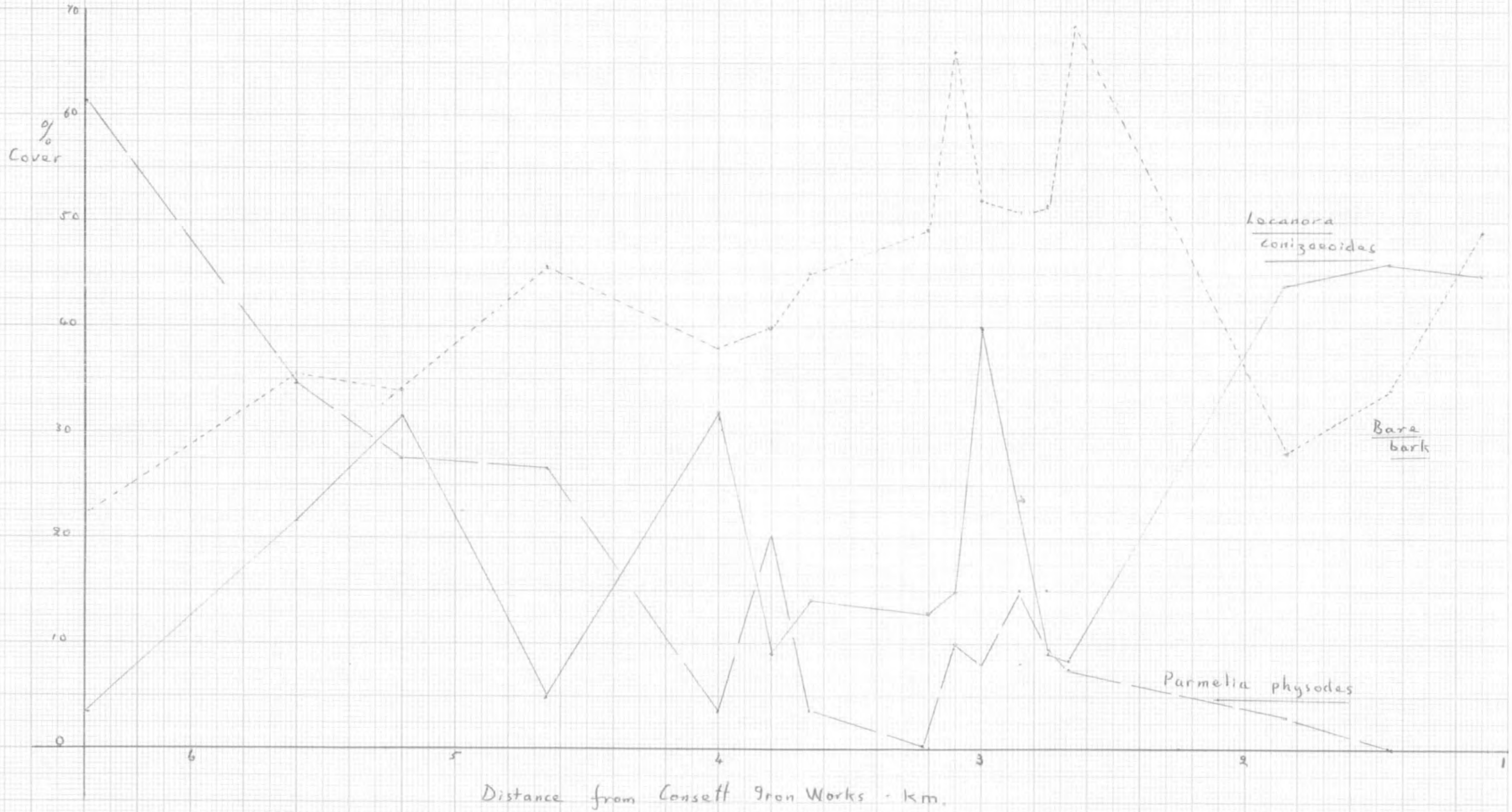


Fig. 6.

Percentage Cover on Ash (Fraxinus excelsior) of the principal Lichen species

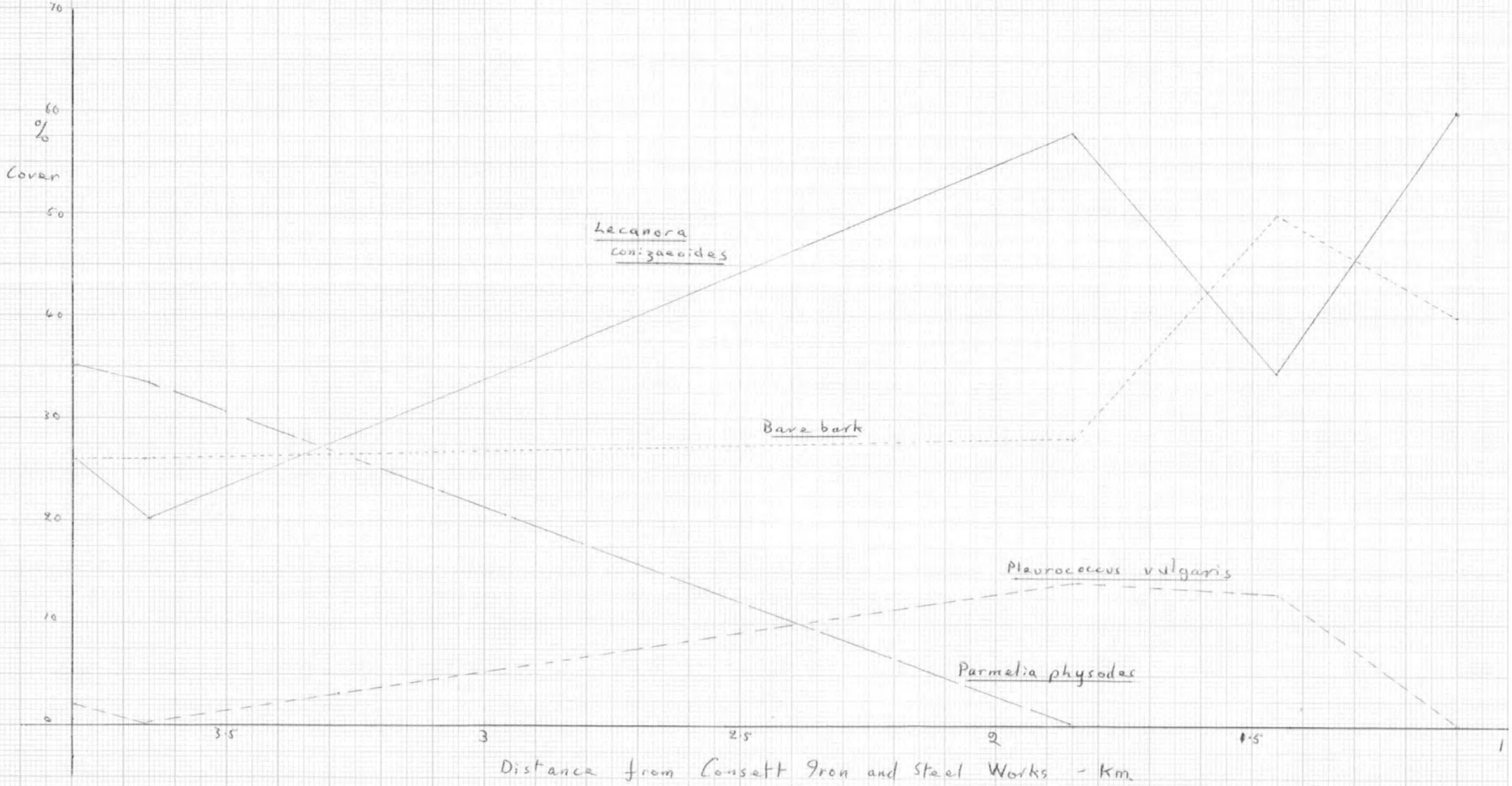
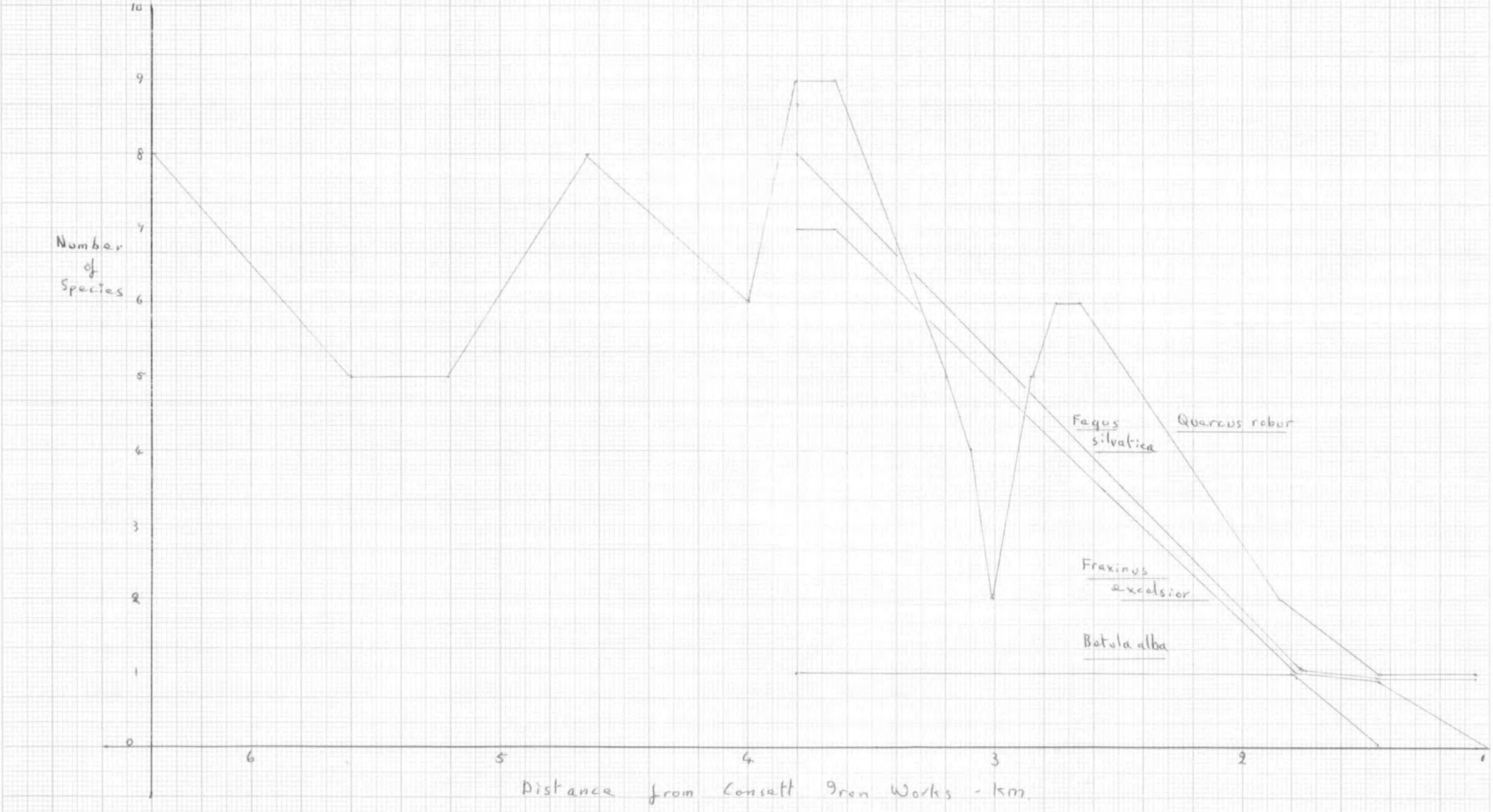


Fig 7.



Total numbers of Lichen species at 1-1.5 m. high on various Trees

Fig. 8

Saxicolous species of low toxitolerance.

Rhizocarpon geographicum on Millstone Grit (5 km from Consett)

Parmelia furfuracea (+ P. saxatilis) on Millstone Grit.
(4.5 km from Consett).

Observations of Saxicolous lichens

On the millstone grit walls *Lecanora conizaeoides* and *Candelariella vitellina* occur to within 0.8 km of the Iron works. *Parmelia saxatilis*, *P. physodes* and *Xanthoria parietina* are found outside a 1.6 km limit and *Parmelia glabratula*, *Lecidea macrocarpa* and *Physcia orbiculoris* occur no nearer than 2.8 km. Outside a 4 km limit various *Lecanora* species occur. e.g. *L. gangaleoides*, *L. badia*, *L. intricata*, *L. polytropa*, *L. soralifera*, also *Lecidea tumida* and *Parmelia furfuracea*. The nearest occurrence of *Rhizocarpon geographicum* was 4.8 km.

Saxicolous species of Moderate Toxitolerance

Xanthoria parietina on Millstone grit and Mortar (3 km from Consett)

Parmelia saxatilis on Millstone grit (2 km from Consett)

Observations of Terricolous Lichens

It was noticed that the lichens growing amongst grass and moss on the ground show a tendency to penetrate nearer to the centre of pollution than might otherwise be expected. This may be observed at Consett, where in areas of permanent meadow *Cladonia pyxidata*, *C.papilloria*, *C.furcata*, *C.fimbriata*, and *Peltigera polydactyla* were found to within 3.5 km of the Iron works. *Cladonia conio craea* was found, growing chiefly around tree bases to within 1.85 km. The tree bases in general supported a greater diversity and quantity of lichens than the rest of the trunk and species otherwise regarded as absent at a height of 1-1.5 m were often found to be present at the base of the tree (Fig.4). The first occurrence of a species as you progress away from the Iron works was also often noted to be at the base of the tree, For example *Parmelia sulcata* and *Evernia prunastri* were found at the base of Quercus robur 1.85 km out but did not appear at a height of 1-1.5 m until 2.65 km from the Iron works. This richer lichen growth amongst the ground flora and on tree bases is attributed to the consistently higher lands of relative humidity found there.

Increasing species diversity of Lichens, on differing substrates with increasing distance from the source of Pollution.

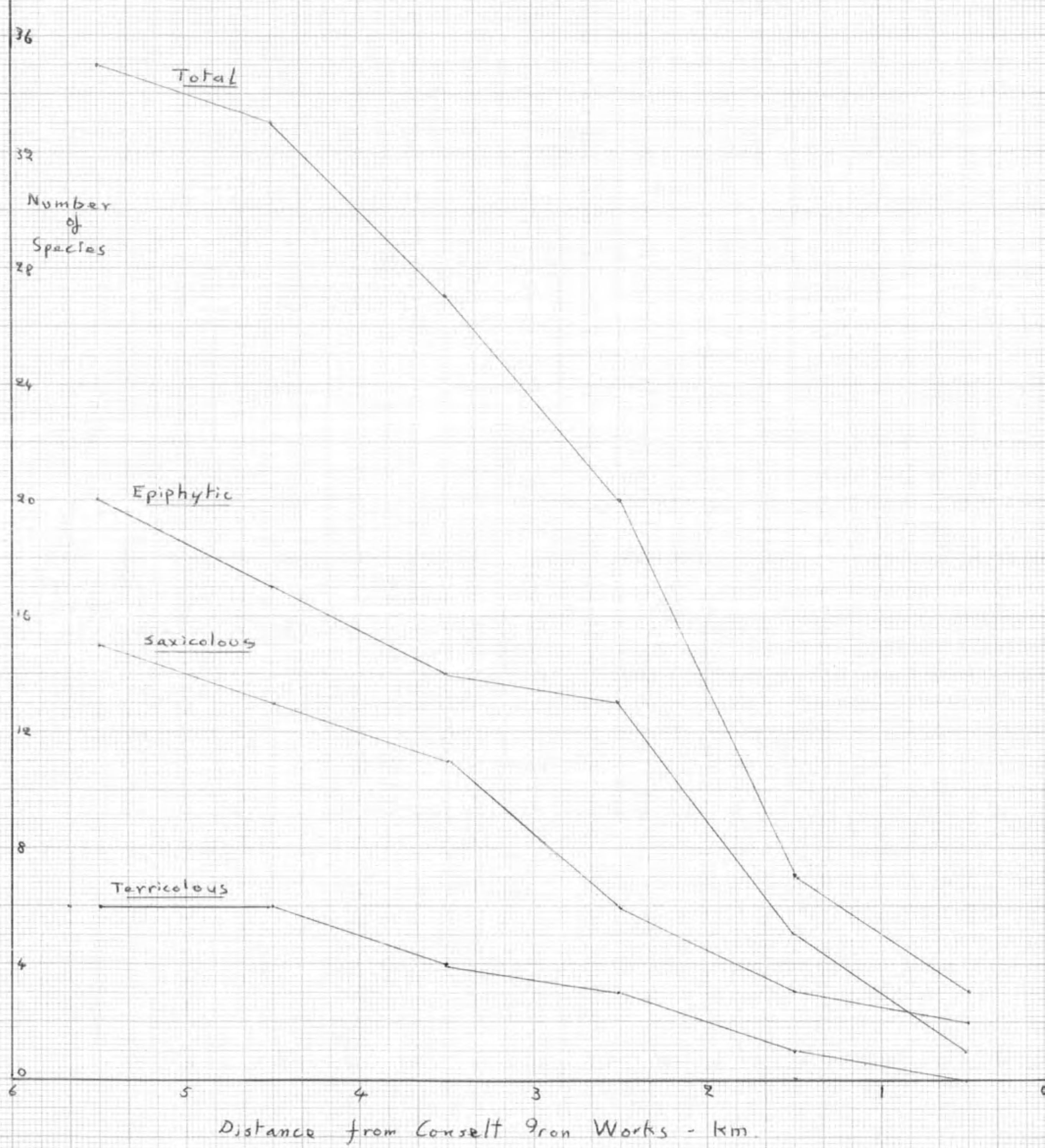


Fig. 9.

Correlation of Pollution effects on Lichens

In order to try and account for this observed distribution of lichens on trees three possible effects of pollution were studied. The direct effects of toxicity and "blacking out" and the indirect effect of altering the pH of the substrate.

pH

The main components of atmospheric pollution tend to give it an acidic nature and it is thought that dust and smoke settling on dead bark can influence or modify the pH. This may in turn have an inhibitory effect on the establishment of lichen colonies. Only the so called "toxicolous" species having a sufficiently wide range of pH tolerance to withstand this effect, Barkman (1958) gives pH values for dead bark of trees in areas of the Netherlands free from pollution and shows that the pH is reduced when atmospheric pollution is high. Gilbert (1965) gives a similar illustration for Newcastle (England) though here pH rises again slightly due to soot (which is only slightly acid). My readings for Consett show that no consistent decrease in pH occurred towards the Iron works, though in some cases there is a slight trend in lowering the pH to 1.5 km from the source of pollution and then an increase in pH, perhaps due to domestic pollution, such as soot, becoming more apparent.

Distance from Consett in km.	*	2.3	1.8	1.45	1.1
Quercus robur	3.7-5.0		4.881±.227	4.657±.152	5.344±.067
Fraxinus excelsior	5.2-5.8	5.867±.172	4.581±.084	6.050±.124	5.720±.058
Fagus silvatica	5.1-5.8		5.725±.144		5.883±.061
Betula alba	3.7-4.9	5.947±.073	4.613±.124	6.036±.083	
Acer pseudoplatanus	6.1-6.9	6.047±.098		6.157±.078	5.947±.067
Aesculus hippocastanum	6.0-6.1	6.114±.127			
Ulmus compestris	5.1-5.8			6.343±.112	

* Average range from pollution
free bark - J.J.Barkman (1958)

Sulphur content

Evaluation of the effect of the main component of industrial pollution, that of sulphur dioxide on the lichen thallus was achieved by assuming that the substance was absorbed by the lichen in amounts consistent with its occurrence in the atmosphere. During short periods of high humidity, such as occur during rain showers or fog, in otherwise physiologically "dry" areas the lichen thallus absorbs rapidly and indiscriminately, so obtaining sufficient minerals for its metabolic processes. Where humidity is continually high the thallus remains in a condition amenable to nutrient uptake for far longer as it is not subjected to long periods of partial dessication. Thus the lichens found in habitats with consistent high humidity values are seem to have a slower and more selective mechanism for the uptake of mineral ions from the atmosphere. Where humidity is continually high therefore the amounts of sulphur dioxide absorbed may not reflect the amounts present in the atmosphere. *Parmelia physodes*, which was used for the sulphur extraction was taken between 1 and 1.5 metres from the ground on tree trunks. Being a lichen with less contact with the bark than crustose or the more closely adpressed foliose lichens and must receive the bulk of its nutrients from the atmosphere, being dependent on spasmodic periods of high humidity for its nutrient uptake. *Parmelia physodes* was also easy to collect and occurred more commonly than the other foliose lichens in the sampling area.

The sulphur dioxide absorbed can be analysed as amounts of elemental sulphu present, by quantitative miro-chemical methods (Gilbert 1965, method given in appendix). Results from this show a consistent decrease away from the centre of pollution (Fig.10). To check the accuracy of this method of extraction for sulphur most of the experiments were duplicated.

Even allowing for the fact that pollution is lower from Consett than in Newcastle *Parmelia physodes* shows a lower sulphur content than *Parmelia saxatilis* (Gilbert 1965). This may be partly explained by the fact that *Parmelia saxatilis* was growing on sandstone around Newcastle and probably acquired its nutrients from the atmosphere. Further *P. saxatilis* tends to be most frequent on horizontal surfaces such as the tops of walls and sheds where dust settling out will accumulate more rapidly than on vertical surfaces. Thus *P. saxatilis* will be subjected to much higher local accumulations of sulphurous compounds than *P. physodes*.

Distance from Consett in km.	6.4	5.6	4.65	4.0	3.8	1.85	
Sulphur content of area dried P. physodes thallus in p.p.m.	102.8	212.6	274.2	325.6	446.0	610.0	

Dust Washings

For an organism with such a slow rate of metabolism and growth as a lichen it may not seem immediately obvious that the "blocking out" of light, or interference with carbon dioxide absorption will have any marked effect until it is virtually complete, by which time toxicity of the dust deposit will have had its effect. This may in fact be so for lichens that are well established and obtaining their nutrients from the bark, but the deposit may also have the effect of modifying the bark pH, so limiting or preventing further spread or new colonisation by the lichen and thus reducing percentage cover of the epiphyte. By influencing such conditions as pH, dust will also effect the numbers of species present, as already mentioned.

It is obvious that dust settling out from the atmosphere will be graded; greater quantity and size of particles being found nearer the source of pollution (Fig.10). The effect of dust may thus vary away from the centre of pollution, as smaller particles may be of different material from larger particles. This has already been noted where the effect of soot is seen to modify somewhat the general acidyfing effect of pollution (see chapter on pH). The bulk of the industrial pollution as dust is flyash and coky matter. The ratio of fly ash: coky matter increasing away from the centre of pollution.

Washings of discs of bark were made, the deposit centrifuged out, dried and weighed. The results are expressed as milligrams per square centimetre and tons per square mile.

Km.from Consett	4.65	4.0	2.3	1.85	1.45	1.1	0.8
Dust in mg/cm^2.	0.66	0.8	0.42	1.19	2.22	2.93	4.9
tons/sq ml.	1.68	2.04	1.08	3.04	5.65	7.48	12.1

This compares with a mean monthly deposit just to the windward of the Iron works of 33 tons per square mile.

Decreasing amounts of Industrial pollutants passing West from Consett.

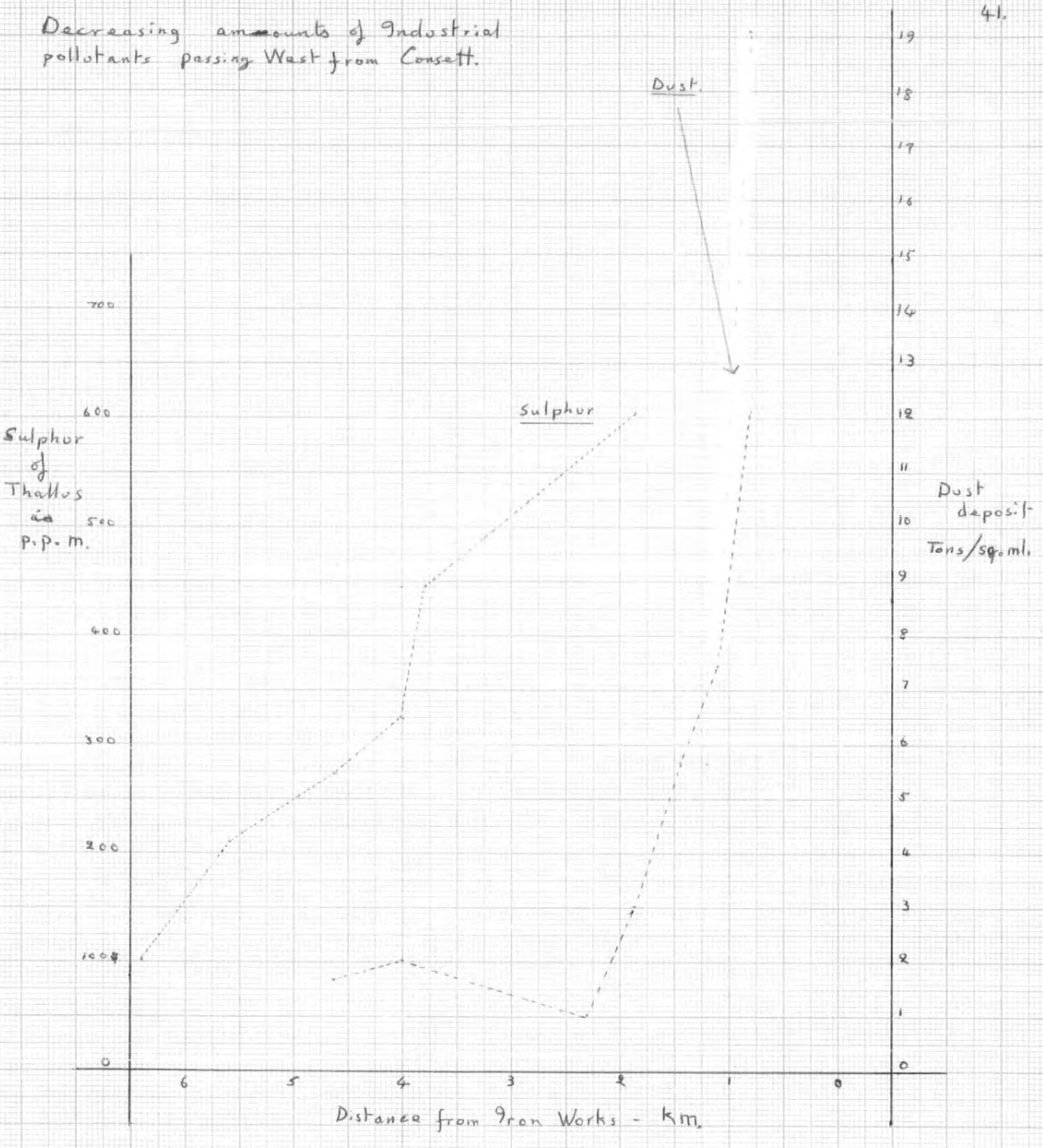


Fig. 10.

Discussion.

Lichens are generally associated with undisturbed areas. This is a reflection of their slow growth and establishment rate. The paucity of lichens around towns and industrial areas is however not merely due to physical disturbance but is also due to indirect effects brought about by civilisation, such as modification of the microclimate and the production and accumulation of pollution in amounts that are harmful to the balance of nature. The county to the west of Consett has been subjected to relatively little physical disturbance and a moderate development of lichens is seen. 5 km.west of Consett there is a total of nearly 35 species, all of which are commonly encountered. Within 2 km.of Consett this number has been more than halved (Fig.9) and the species are less frequently found. Besides this reduction in numbers there is also an overall reduction in both quality and percentage cover, Lecanora conizaeoides being the exception. As the denser polluted area is approached the individual lichens become stunted, and the patches of colonisation on trees less confluent and more isolated. The stunted form of lichens near to their pollution tolerance limit is best seen in the fruticose species. The species of Usnea 4.65 km. out from Consett had a growth of only 1 cm in length; Evernia prunastri became reduced from well branched healthy specimens of 5 cm. long at a distance of 6.4 km. out, to smaller less branched forms only 1.5 cm. long at a distance of 2.65 km. out.

To account for this distribution in both quantity and quality of lichens the pollution data was applied. From the dust washings it seems unlikely that fruticose species such as Evernia prunastri can stand more than a deposit equivalent to 0.8 mg/cm^2 , whilst Usnea may have a much lower limit. Foliose and crustose species appear in general to be able to tolerate a dust covering of up to about 1.2 mg/cm^2 , though species such as Parmelia physodes and P. saxatilis may be able to tolerate amounts of the order 2.5 mg/cm^2 . It is difficult to give an indication of the dust tolerance for Lecanora conizaeoides but it was found growing well in areas with a 5 mg/cm deposit.

These deposits are too small to have an effect on the lichen thallus by "blocking out" thus preventing light and carbon dioxide absorption. Though these may be some small degree of interference in this way this will probably be negligible when related to the very slow growth and assimilation rates (Smith 1961). If dust is a major cause of lichen control it is most likely to have its effect via the toxic substances it contains which will be concentrated and rapidly absorbed during periods of high humidity. The work also shows that good lichen growth can be found in pockets of high humidity in an otherwise poor locality (Fig.4). This further tends to suggest that a continually high humidity can madify to a great degree the delebrious effect of pollution. Without further investigation it is not possible to say with conviction that humidity can totally nullify the effect of pollution and that it is humidity not pollution which controls lichen growth in industrial areas. There are indications that this is not the case, as the sitings of the sampling areas were made with the aim of having, as near as possible, similar levels of humidity. It is suggested that the main value of high humidity in highly polluted areas is that the lichen thallus remains in an actively metabolic condition for long periods and is able to convert such toxic substances to less toxic forms. (e.g. oxidation of sulphite to the less toxic sulphate - Thomas 1961).

Smith (1962) has correlated physiological activity with thallus water content. Further physiological work will help to clarify this theory. Where pollution reaches a low value (below 0.5 mg/cm^2 and less than c.165 p.p.m. of S) then perhaps humidity may be the chief environmental factor, though there will also tend to be some degree of overlap between humidity and pollution as overriding factors, as the individual lichen species will have slightly different pollution tolerance limits and varying degrees of susceptibility to the low humidity values which are usually associated with high pollution and industrialisation.

The results obtained from this analysis of the lichen flora to the west of Consett agree favourably with other work along similar lines carried out in other areas by previous workers. (Jones 1952, Barkman 1958, Gilbert 1965). Basically it has been shown that, with certain exceptions of lichens which can be described as being toxicolous (Lecanora conizaeoides), both the total cover and species diversity of lichens decrease as pollution increases (cf Fig.9 and 10). It is also shown that crustose species in general penetrate farthest in towards the polluted area (Fig.5). The fruticose species are least toxitolerant, Usnea being especially so. There are some crustose species which are also very toxiphorbic, Rhizocarpon geographicum being an example. It is thus difficult to generalise and if it is wished to map lichen zones and accurately relate these to pollution values then the complexes of lichens chosen for determination of the various zone boundaries must be very carefully chosen. The effect of pollution is also extensively modified by humidity values and these must also be taken into account.

The study of lichens has been much less intensively developed than other fields of botanical or ecological research. Early work was mainly descrptive and physiological work is now chiefly based on interpreting lichen chemistry. Work on basic physiology is still lacking, though work of this nature has been done on Peltigera polydactyla by D.C.Smith (1961).

When results of such work are available perhaps a fuller understanding of the symbiotic nature of the thallus and why many of the species are so sensitive to pollution will be possible.

A closer study of the lichen associations and their correlation with microenvironments such as "rain tracks" in tree bark would also lead to a better understanding of how pollution effects are modified and so give a clearer explanation of the overall picture.

Conclusion

This investigation has demonstrated both quantitavely and qualitatively the relative paucity of the lichen flora of polluted areas when compared with surrounding localities where pollution is low or absent. The total number of lichens increases steadily from the centre of pollution until it begins to stabilise at 4.5 km (Fig. 9). This increase represents numerical increases of species and cover for corticolous, saxicolous and terricolous groups of lichens as well as a qualitative increase. This stabilisation takes place where the sulphur content of over dried *Parmelia physodes* is below c. 325 p.p.m. and where dust deposits are below 0.8 mg/cm^2. These may be taken as levels of pollution above which a natural expression of lichen distribution will not be found. With levels of pollution in excess of this limit the performance of lichens is shown to be affected, though there is also a moderating effect brought about by high levels of humidity.

Acknowledgements.

My thanks are due to the D.S.I.R. and Consett Urban District Council for providing standard pollution data and to the Consett Iron and Steel works for information on their history and production. I am also grateful to Mr J.R. Laundon and Mr O.L. Gilbert for help with the identification of specimens.

Bibliography.

Barkman J.J. (1958) Phytosociology and Ecology of Cryptogamic Epiphytes. Assen Netherlands.

Brightman F.H.(1962) Some Factors Influencing lichen growth in towns. Lichenologist Vol.1 pp. 104 - 108.

Gilbert O.L. (1965) Lichens as Indicators of Air Pollution in the Tyne Valley. 5th Br.Ecol.Soc. Symp. Blackwell.

Haynes F.N. (1964) Lichens Viewpoints in Biology Vol.3 pp.64-153. Butterworths.

Jones E.W. (1952) Some observations on the Lichen Flora of tree boles with special reference to the effect of smoke. Rev.Bryol et Lichen. Vol.21 pp.96-115.

Kershaw K.A. (1964) Epiphytic Lichens. Lichenologist Vol.2. pp.263-276.

Smith A.L. (1921) Lichens Cambridge.

Smith D.C. (1961) Physiology of Peltigera. Lichenologist Vol.1 pp.219-225.

" " (1962) The Biology of Lichen Thall: Biol.Rev. Vol.37 pp.537-570

Thomas M.D. (1964) Air Pollution W.H.O. Geneva.

Wheldon and Travis (1915) Atmospheric influences on lichen vegetation. J.Linn. Soc. Vol XLIII pp.87-136.

Appendix.

Appendix A

Monitoring of smoke and Sulphur Dioxide

(1) Principle of Operation of Pollution Guage.

When air is drawn through the filter paper the smoke present in the air is retained and forms a stain on the paper. "Smoke" is taken to include particles of 10 (1/2500) or less in diameter. Such particles do not fall noticeably under their own weight and can thus be regarded as being suspended in the air. The darkness of the stain depends on the amount of smoke collected and also, to some extent, on the nature of the smoke. The darkness of the stain is measured with a reflectometer. The weight of smoke on the filter paper can thus be inferred in terms of a standard smoke for which the calibration of the reflectometer has been calculated. Hence the equivalent concentration per unit volume of air can be determined.

After passing through the filter the air is bubbled through H_2O_2 which is later titrated with a standard alkali solution and the amount of So_2 present can be evaluated. Other strong acids or alkalis in the air may effect this estimation but under all normal circumstances the concentration of such substances is negligible compared with that of SO .

After passing through the filter paper and dreschel bottle, which are changed every day (as daily readings are made), the air passes through the meter which accurately measures the volume of air drawn through the apparatus.

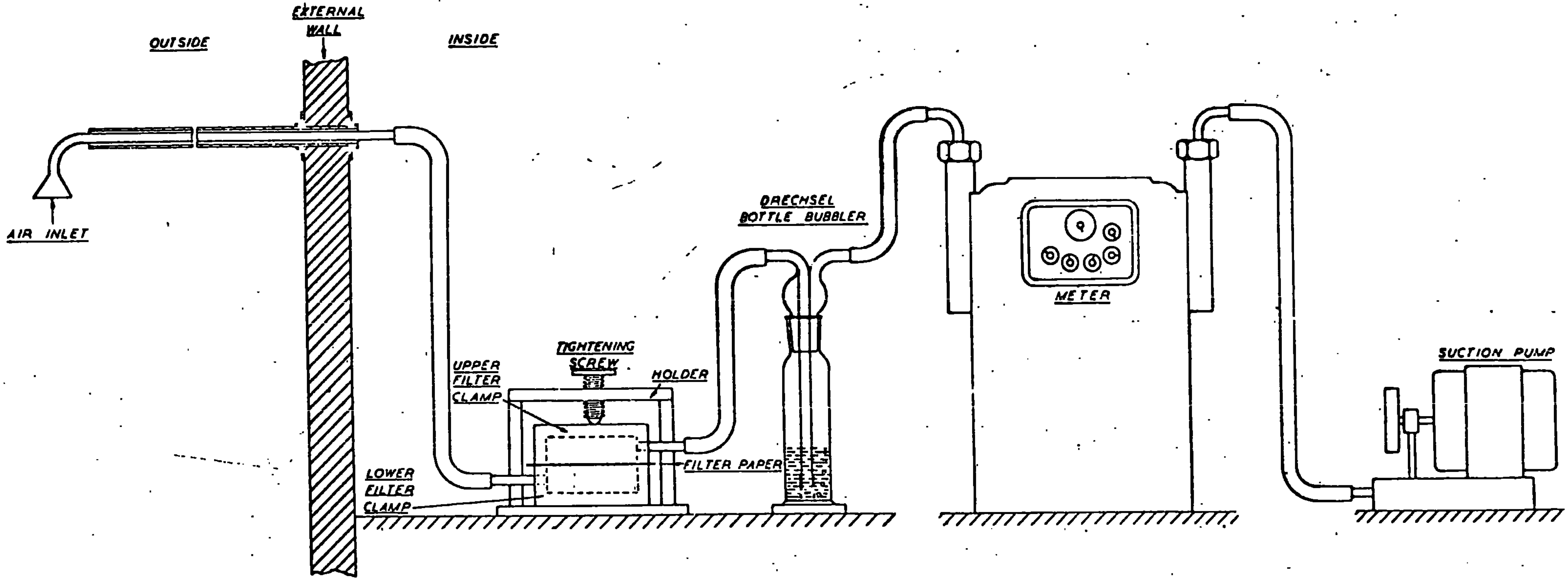


FIG.1 APPARATUS FOR THE DETERMINATION OF SMOKE AND SULPHUR DIOXIDE IN THE AIR

D. S. I. R.	WARREN SPRING LABORATORY. STEVENAGE	CROWN COPYRIGHT RESERVED	DATE 12·4·61	P 1311452

Mean Daily Average SO_2 values per Month. ($\mu g/m^3$)

Council Yard Leadgate.

	1962.	1963.	1964.	1965.	Mean.
J		123	112	60	98.3
F		165	108	52	108.3
M		90	93	40	74.3
A		71	80		75.5
M		60	70		65.0
J	48	51	55		51.3
J	42	58	52		50.7
A	37	62	39		46.0
S	44	67	59		56.7
O	60	75	54		63.0
N	89	94	52		78.3
D	109	134	64		102.3

Y.M.C.A.

	1962.	1963.	1964.	1965.	Mean.
J		162	195	126	161.7
F		228	173	63	154.7
M		178	167	93	146.0
A		126	192		159.0
M		180	162		171.0
J	135	75	115		108.3
J	80	122	86		96.0
A	57	88	53		66.0
S	97	115	106		106.0
O	131	126	78		111.7
N	152	172	93		139.0
D	150	234	88		157.3

Moorside.

	1962.	1963.	1964.	1965.	Mean.
J		129	86	42	85.7
F		146	78	43	89.0
M		76	83	52	70.3
A		90	51		70.5
M		47	53		50.0
J	35	62	37		44.7
J	52	59	37		49.3
A	28	49	91		56.0
S	39	80	39		46.0
O	55	66	39		53.3
N	100	98	30		76.0
D	91	131	47		89.7

Mean Daily Average Smoke Values. ($\mu g/m^3$)

Council Yard, Leadgate.

	1962.	1963.	1964.	1965.	Mean.
J		264	253	207	241.3
F		293	234	164	230.3
M		192	185	197	191.3
A		153	148		150.5
M		117	97		107.0
J	84	90	100		91.3
J	111	93	87		97.0
A	86	92	16		64.7
S	123	112	111		115.3
O	149	134	226		169.7
N	188	199	190		192.3
D	191	253	241		228.3

Y.M.C.A. Consett.

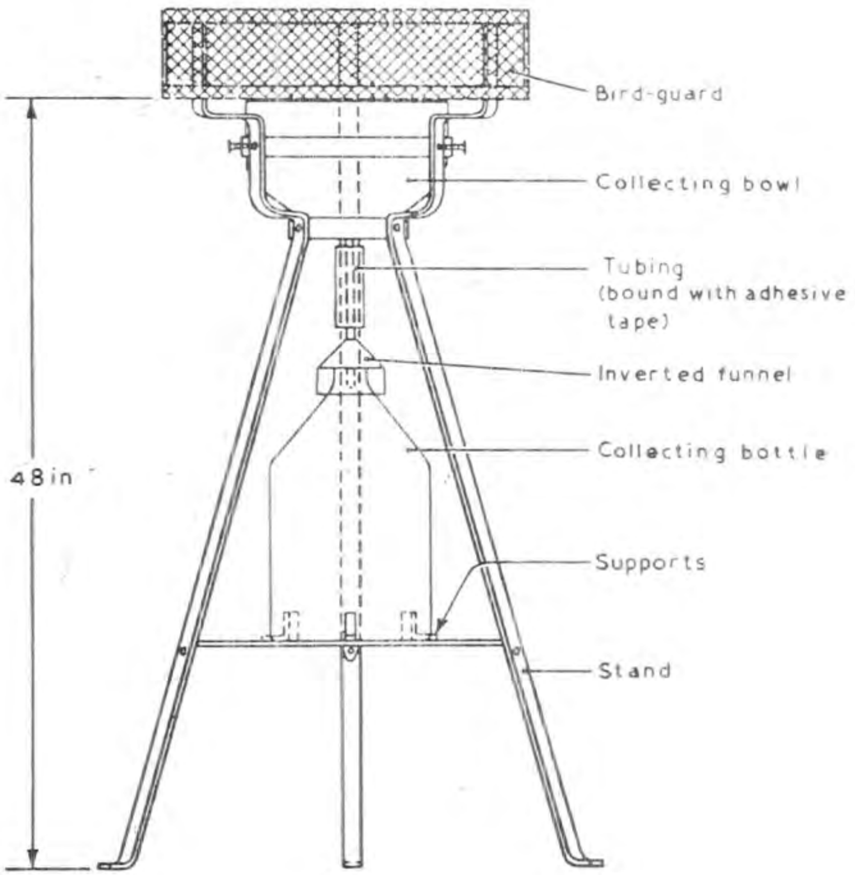
	1962.	1963.	1964.	1965.	Mean.
J		227	187	218	210.7
F		314	242	154	236.6
M		174	258	175	202.3
A		159	110		134.5
M		85	78		81.5
J	60	82	91		77.7
J	92	79	65		78.7
A	41	67	90		66.0
S	93	81	94		89.3
O	114	77	185		145.3
N	159	170	152		160.3
D	136	249	206		197.0

R.C. Church Moorside.

	1962.	1963.	1964.	1965.	Mean.
J		215	211	193	206.3
F		221	158	164	181.0
M		146	175	155	158.7
A		141	104		122.5
M		93	85		89.0
J	63	79	81		74.3
J	89	70	60		73.0
A	59	66	74		66.3
S	93	90	77		86.7
O	119	103	160		127.3
N	161	148	151		153.3
D	152	221	201		191.3

(ii) Deposit Guage.

This is designed to trap the denser particles falling through the atmosphere. They fall into the collecting bowl where they settle until washed by rain water into the collecting bottle. This method has the disadvantage of depending upon rain for collection of the dust and is thus liable to inaccuracies during dry months as the dust is blown about in the collecting bowl by high winds and much may be lost. As the area of the top of the collecting bowl is known the deposit can be evaluated as a weight per unit area per month.


Bird-guard
Collecting bowl
Tubing
(bound with adhesive
tape)
Inverted funnel
Collecting bottle
Supports
Stand
48 in

Appendix B

Percentage Cover of Epiphytic Lichens on Quercus Robur.

Distance from Consett (Km).	6.4	5.6	5.2	4.65	4	3.8	3.65	3.2	3.1	3.0	2.85	2.75	2.65	1.85	1.45	1.1
Bare Bark	22.4	35.4	33.8	45.6	38	40	47.5	49	66	52	51	51.5	68.5	28	34	49
Pleurococcus vulgaris	-	-	-	-	-	2	-	-	-	-	-	-	-	25	20	6
Lecanora conizaeoides	3.6	21.4	31.6	2.6	31.8	9	14	13	15	40	24	9	8.5	44	46	45
Parmelia physodes	61.2	34.8	27.6	26.6	3.4	20	3.5	-	10	8	15	9.5	7.5	3	-	-
Pertusaria hymenea	-	-	-	-	-	-	2.5	18	-	-	1	-	1.5	-	-	-
Pertusaria amara	-	-	1	-	2	-	5.5	-	-	-	-	7.5	-	-	-	-
Pertusaria pertusa	2.2	2.5	0.2	5.4	0.6	-	-	-	-	-	-	-	-	-	-	-
Pertusaria albescens	-	-	-	-	-	4	4	9	-	-	-	-	-	-	-	-
Calicium viride	-	-	-	-	-	2	12	-	-	-	-	2.5	7.5	-	-	-
Chaenotheca ferruginea	-	-	-	-	-	5	-	-	-	-	-	3	-	-	-	-
Ochrelechia turneri	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Parmelia sulcata	2.2	-	-	-	-	3	4	5	1	-	8	17	5	-	-	-
Parmelia saxatilis	0.6	-	-	0.8	24	-	-	-	-	-	-	-	-	-	-	-
Parmelia omphalodes	6.6	2.5	5.2	16.8	0.6	-	-	-	-	-	-	-	-	-	-	-
Evernia prunastri	0.6	3.4	1.6	0.6	1.6	9	5	6	8	-	1	-	1.5	-	-	-
Cetraria glauca	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Usnea sp.	0.6	-	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-

Percentage Cover of Epiphytic Lichens on Fraxinus excelsior.

Distance from Consett (km)	3.8	3.65	1.85	1.45	1.1
Bare bark	26	26	28	50	40
Pleurococcus vulgaris	2	-	14	13	-
Lecanora conizaeoides	26	20	58	37	60
Parmelia physodes	35	32.5	-	-	-
Pertusaria hymenea	2	1.5	-	-	-
Pertusaria amara	3	2.5	-	-	-
Calicium viride	2	4.5	-	-	-
Parmelia sulcata	2	8	-	-	-
Evernia prunastri	-	3.5	-	-	-
Cetraria glauca	2	1.5	-	-	-

Percentage cover of Epiphytic Lichens on Fagus silvatica.

Distance from Consett (km)	3.8	1.85	1.1
Bare bark	23	19	46
Pleurococcus vulgaris	1	36	9
Lecanora conizaeoides	10	45	47
Parmelia physodes	40	-	-
Pertusaria hymenea	6	-	-
Pertusaria albescens	8	-	-
Calicium viride	1	-	-
Chaenotheca ferruginea	3	-	-
Parmelia sulcata	7	-	-

Percentage cover of Epiphytic Lichens on Acer pseudoplatanus.

Distance from Consett (km)	1.45	1.1
Bare bark	20	49
Pleurococcus vulgaris	29	-
Lecanora conizaeoides	51	51

Percentage cover of Epiphytic Lichens on Betula alba.

Distance from Consett (km)	3.8	1.85	1.45	1.1
Bare bark	40	50	95	-
Pleurococcus vulgaris	5	13	-	-
Lecanora conizaeoides	55	37	5	-

Appendix C

Total Number of Lichen species per sampling area.

Corticolous species.	5-7	4-5	3-4	2-3	1-2	0-1	km from Steel Works.
Lecanora conizaeoides	-	-	-	-	-	-	
" expellans	-			-			
" dispersa	-	-					
Parmelia physodes	-	-	-	-	-		
" sulcata	-	-	-	-			
" saxatilis	-	-		-	-		
" omphalodes	-	-					
" glabratula	-	-					
Parmeliopsis ambigua	-	-	-	-	-		
Pertusaria albescens	-	-	-	-			
" amara	-	-	-	-			
" pertusa	-	-					
" hymenae			-	-			
Cetraria glauca	-		-		-		
Evernia prunastri	-	-	-	-			
Buellia punctata	-	-	-	-			
Pyrenula nitida	-						
Coniocybe pallida		-					
Graphis elegans		-					
Calicium viride			-	-			
Cladonia coniocraea	-	-	-				
" fimbriata	-						
" pyxidata	-						
Ochrelechia turneri			-				
Chaenotheca ferruginea			-	-			
Usnea	-	-					

Total Numbers of Lichen species per sampling area.

Distance in km from Iron Works.	5-7	4-5	3-4	2-3	1-2	0-1
saxicolous						
Cetraria glauca	-					
Parmelia furfuracea	-					
" glabratula				-		
" physodes	-	-	-	-	-	
" saxatilis	-	-	-	-	-	
Physcia orbicularis	-	-	-	-		
Xanthoria parietina	-	-				
Candellariella vitellina	-	-	-	-	-	-
Lecanora badia	-	-	-			
Lecanora conizaeoides						-
" gangaleoides	-	-	-			
" intricata	-	-	-			
" polytropa	-	-	-			
" soralifera	-	-	-			
Lecidea macrocarpa	-	-	-	-		
" tumida	-	-	-			
Rhizocarpon geographicum	-	-				
Terricolous						
Cladonia coniocraea	-	-	-	-	-	
" fimbriata	-	-	-	-		
" glauca	-	-				
" pitraea	-	-				
" pyxidata	-	-	-	-		
Peltigera polydactyla	-	-	-			

Appendix D.

(i) pH Estimation.

Circles of bark, 3.6 sq.cm. in area (in actuality those used for dust washings were used for pH after being washed) were obtained from between 1 and 1.5 m from the ground and any surface dust washed off. The discs were then crushed in a pestle with a mortar and added to 100 ml. D.W. The mixture was allowed to settle for one hour and the pH measured with a glass electrode.

Results at 1.1 km									**Mean**	**Variance**
Oak	5.45	5.25	5.4	5.31	5.3	5.3	5.4		5.344	.067
Ash	5.75	5.70	5.75	5.6	5.71	5.8	5.73		5.72	.058
Beech	5.9	5.95	5.85	5.92	5.91	5.9	5.78		5.883	.061
Sycamore	5.95	6.1	5.95	5.92	5.9	5.88	5.93		5.947	.067
at 1.45 km										
Oak	4.85	4.4	4.5	4.75	4.8	4.7	4.6		4.657	.152
Ash	5.95	6.1	5.8	6.15	6.05	6.1	6.2		6.05	.124
Silver Birch	5.95	5.9	6.1	6.15	6.0	6.05	6.1		6.036	.083
Sycamore	6.2	6.3	6.05	6.1	6.15	6.1	6.2		6.157	.078
Elm	6.55	6.45	6.30	6.25	6.35	6.3	6.2		6.343	.112
at 1.85 km										
Oak	5.2	4.8	5.15	4.9	4.6	4.7	4.75	4.95	4.881	.227
Ash	4.65	4.7	4.6	4.55	4.6	4.5	4.55	4.5	4.581	.084
Beech	5.6	5.55	5.95	5.6	5.9	5.7	5.65	5.85	5.725	.144
Birch	4.4	4.7	4.75	4.5	4.6	4.8	4.6	4.55	4.613	.124
at 2.3 km										
Ash	6.1	6.05	5.62	5.65	5.95	5.9	5.8		5.867	.172
Silver Birch	6.1	5.95	5.9	6.0	5.88	5.91	5.89		5.947	.073
Sycamore	5.93	6.2	6.17	6.0	6.0	6.08	5.95		6.047	.098
Horse Chestnut	6.1	6.4	6.0	6.1	6.15	6.0	6.05		6.114	.127

(ii) Sulphur Estimation.

A 2 gm sample of washed oven dried thallus was heated with 250 c.c. conc. HNO_3 at 80-85°C until the solution turned from a dark brown to a pale straw colour (3-5 days). The insoluble residue was spun off and 2 gm $Ba\ Cl_2$ added to the supernatant. The solution was then left for a further 2 days when the resultant precipitate was centrifuged off. This p.p.t. was then washed to remove any $Ba\ NO_3$, thus leaving only $Ba\ So_4$ which was centrifuged out, oven dried and weighed. By using atomic weights the amount of elemental Sulphur in p.p.m. of oven dried P.physodes thallus could be evaluated.

Results.

Km.	6.4	5.6	4.65	4	3.8	1.85
Wt. tube + Ba So_4	13.0365	12.4588	12.5415	12.4605	12.5440	12.5415
" "	13.0350	12.4556	12.5375	12.4556	12.5375	12.5320
∴ wt Ba So_4	.0015	.0032	.0040	.0049	.0065	.0095
∴ S. in p.p.m.	102 .8	219.4	274.2	335.9	445.6	651.24
Wt. tube + p.p.t.		12.4586		12.4602	12.4622	13.0397
Wt. tube		12.4556		12.4556	12.4556	13.0314
p.p.t.		.0030		.0046	.0066	.0083
S. in p.p.m.		205.7		315.3	446.5	568.9

(iii) Bark Washings for Dust

From each site five discs of bare bark, each 3.6 sq.cm. in area, were collected at a height of 1.0 to 1.5 metres from the ground. The discs were shaken with water for 30 minutes. After the first 10 minutes the surface of the discs were brushed with a stiff brush to loosen any closely adhering particles or tarry matter. The discs were then used for the pH measurements. The dust was centrifuged out, oven dried and weighed.

Distance from Iron Works (km)							
Centrifuge tube + dust	12.4635	12.5521	13.0390	12.6084	12.5769	12.5869	12.6851
Centrifuge tube	12.4556	12.5375	13.0314	12.5869	12.5360	12.5341	12.5969
Dust in gm/18 sq.cm.	0.0119	0.0146	0.0076	0.0215	0.0399	0.0528	0.0882
Dust in mg/cm^2	0.66	0.80	0.422	1.194	2.22	2.933	4.9
Dust in tons/sq.ml.	1.68	2.039	1.076	3.044	5.65	7.477	12.098

<u>D.S.I.R. Deposit Guage Data</u> (Tons/sq.ml.)

1964	Oct.	20.08
	Nov.	23.09
	Dec.	59.70
1965	Jan.	34.57
	Feb.	6.71
	Mar.	48.43
	April.	13.69
	May.	27.42
	Jun.	47.49
	July.	12.48
	Aug.	52.62
	Sep.	33.59
	Oct.	44.42
	Nov.	-
	Dec.	26.75

Mean = 33.0 Tons/sq.ml./month of total undissolved matter.
= 12.936 mg/cm^2/month.


CONSETT
Consett Iron Works
BLACK HILL
BRIDGE HILL
Buxton Cottages
Shotley Grove
Shotley Grove High Mill (Disused)
Suspension Bridge
The Forge
Sandypath Cottages
Reservoir
Brownsbog Wood
Brown's Hill
Sodfine Reservoir
Sodfine Wood
Buildings Farm (Quarry)
Howden Cottage
Howden Wood
Howden Burn
Bulbeck Cottage
Broom Hill
Hole Row
Holerow Haughs
Holerow Burn
Pemberton Well
Pemberton Road
Consett Plantation
Consett Hall
Beech Grove
Hall Road
Selby Lodge
Consett Grove
Reservoir
Pumping Station
Consett North Junction
THE GROVE
Consett Low Wood
Sewage Farm (Consett UDC)
Stanefordham
Moorside
Sheepfold
Consett Park
Park Cottage
Consett Park Terrace
Consett High Wood
Old Drift
Consett South Junction
Hownsgill Junction
Hown's Farm
Hownsgill Viaduct
Hownsgill Cottages
Hown's Quarry (Disused)
Hown's Wood
Hown's Gill
Dene Burn
Todd Hill
Whinny Allotment
Howards Buildings
Park Terrace
Maudville Institute
Four Lane Ends
Crag Bank
Middle Gap
Middle Heads
Middles Dene
Gantry
Drovers Road
Rowley Cottage
Rowley Farm
Beech Lodge
Hawthorns
The Sycamores
Corbridge 13
West Auckland 17
Castleside
St John's Ch
Craggs Buildings
Fleece Inn
Castle Hill
Birks Well
Birks Wood
Sewage Works (Lanchester R D Council)
Old Quarries
Allensford Bank
Wharnley Burn Bridge
Wharnley Burn
Corbridge 12
West Auckland 18
West Fines Wood
Allensford House
Allensford
Allensford Bridge
Allensford Mill (Disused)
Allensford Cottage
Hole House
Deneburn Wood
West Wood
Temperley's Wood
Dene Burn
Mosswood Cottages
Mosswood
Mosswood Farm
Wallish Walls Road
Wallish Walls
Wallishwalls Burn
Moss Wood
River Derwent
Ravenscrag Wood
Bog Wood
Old Mine (Lead)
Derwent Grange
Fox Holes
Sand Pit
Whaupley Hill
Dean Howl Farm
Old Shafts
Old Quarry
Healeyfield Quarry (Disused)
Healeyfield
Healeyfield Lane
Healeyfield Smelting Mill
Watergate
Vicarage
War Memorial
Sun Sch
Spring Well
Windybank Wood
Combfield House
Comb Bridges
Narrow Comb Wood
Black Pool
Leadmill Bridge (Foot)
Lead Mill
Hisehope Grove (Disused)
Old Shaft
Graham's Flat
Silvertongue Lead Mine (Disused)
Silver Tongue
West Crag
East Crag
Fox Hill
Crooked Oak
Crooked Oak Cottages
Windpump
Snape Wood
Ford
West Wood
Stepping Stones
H E A L E Y F I E L D
Co Const & R D Bdy
Co Const & U D Bdy
Co Const & F P Bdy
400
500
600
700
800
52
51
50
49
06
07
08
09
NZ 05 SE
10 Metres
1°55'W
54'
53'
52'
1°51'W
LAT 54°50'
CONSETT PH.