The influence of various ecological factors on the distribution of gortigolous lichens, in Horsley Hope ravine, near Consett, Co. Durham

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IV. RESULTS

1. Lichen Distribution in the Study Area

The results of the survey of lichen species presence or absence in the study area showed quite clearly that there was an improvement in the lichen vegetation with distance from Consett in a S.W. direction.

This fact is brought out in TABLES XIII and XIV, in which the presence or absence data for individual trees at a certain distance from Consett is collated, in order to produce % frequency values of corticolous lichen species within kilometre sectors. Both the number of species per kilometre sector, and the total frequency value per kilometre sector, increase with distance from Consett.

The distribution of individual species does not necessarily follow this broad pattern. Thus while the % frequency of most lichens steadily increases S.W. of Consett, the occurence of certain species remains fairly constant (e.g. _Lecanora conizaeoides_) or increases at first and then declines over the 7 km. distance (e.g. _Chaenotheca ferruginea_, _Parmeliopsis ambigua_). These irregular spatial patterns of % frequency for some species are, however, masked by the overall trends of increasing species diversity and total frequency.

The distribution of lichens in relation to aspect on the tree trunk displayed a very marked E.-W. oriented pattern throughout the study area. The E. sides of trees

Lichen Species Recorded	Distance from Consett in Kms.					
	0-I	I-2	2-3	3-4	4-5	5-7
Lecanora conizaeoides	I00	I00	I00	I00	I00	I00
Lepraria incana	64	I00	I00	78	96	I00
Lecidea scalaris		50	64	2I	24	5I
Parmelia saxatilis		40	40	57	66	87
Parmeliopsis ambigua		20	I6	I8	6	6
Hypogymnia physodes		20	48	72	78	90
Evernia prunastri			8	39	24	54
Lecanora expallens			8	2I	52	75
Ochrolechia turneri				30	I0	30
Chaenotheca ferruginea				I5	22	9
Hypogymnia tubulosa				I2	28	54
Ochrolechia androgyna				3	26	33
Calicium viride					6	I8
Toninia caradocensis					22	27
Lecanora chlarona					I6	2I
Parmelia subaurifera					4	2I
Parmelia sulcata						6
Pertusaria amara						I8
Pertusaria pertusa						3
Species Totals	2	6	8	I2	I6	I9
Total Frequency	I64	330	384	469	580	805

TABLE XIII : % Frequency of Corticolous Lichens on the E. Sides of Oak Trees in the Study Area.

Lichen Species Recorded	Distance from Consett in kms.					
	0-1	1-2	2-3	3-4	4-5	5-7
Lecanora conizaeoides	100	100	100	100	100	100
Lepraria incana	72	100	100	78	98	100
Lecidea scalaris	56	50	72	36	48	54
Parmelia saxatilis	48	90	100	84	100	100
Parmeliopsis ambigua	8	60	32	54	22	12
Hypogymnia physodes		100	100	90	98	100
Evernia prunastri		20	72	75	90	84
Lecanora expallens		10	80	39	54	84
Hypogymnia tubulosa		20	24	56	78	100
Ochrolechia turneri			32	66	60	57
Chaenotheca ferruninea			24	24	10	6
Ochrolechia androgyna			40	42	58	69
Calicium viride			16	33	4	3
Toninia caradocensis			32	12	38	30
Pertusaria pertusa			8	18	42	51
Lecidea quernea				15	4	18
Catillaria griffithii				6	2	6
Parmelia sulcata				6	12	18
Parmelia subaurifera				12	46	57
Pertusaria amara				36	64	57
Lecanora chlarona				24	58	24
Pertusaria hemispherica				-	2	15
Cetraria glauca					8	-
Parmelia glabratula					26	27
Alectoria fuscescens					18	15
Pertusaria albescens						6
Usnea subfloridana						12
Species Totals	5	9	15	22	25	26
Total Frequency	284	550	832	907	1138	1204

TABLE XIV : % Frequency of Corticolous Lichens on the W. Sides of Oak Trees in the Study Area.

consistently scored lower lichen records than the respective W. sides. Thus, the collated species diversity and total frequency figures are much lower in TABLE XIII (E. sides of trees) than in TABLE XIV (W. sides of trees). For example, between 2 and 3 kms. S.W. of Consett, the W. sides of oak trees bear up to 15 species of corticolous lichens, with a total frequency value of 832; while the E. sides of oak trees support a maximum of only 8 species, with a total frequency value of 384.

The improvement in the corticolous lichen vegetation (as shown by the change in species diversity and total frequency values) of the E. and W. sides of oak trees S.W. of Consett, is shown diagrammatically in Figs. 11 and 12. It can be seen that there is a straight-line relationship between numbers of species and distance from Consett, and total frequency values and distance from Consett.

To examine the mathematical relationship between distance from Consett and the improvement in the corticolous lichen flora, correlation coefficients and regression equations were calculated from the species presence or absence data. For all the trees in the study area employed for sampling purposes, the following information had been obtained: position of tree (by grid reference), number of species on the E. side of the tree, and number of species on the W. side of the tree. These comprehensive data were able to be used to produce mathematical relationships quantifying the change in species numbers, with distance in kms. from Consett, on (a) the E. sides of trees (b) the W. sides of trees.

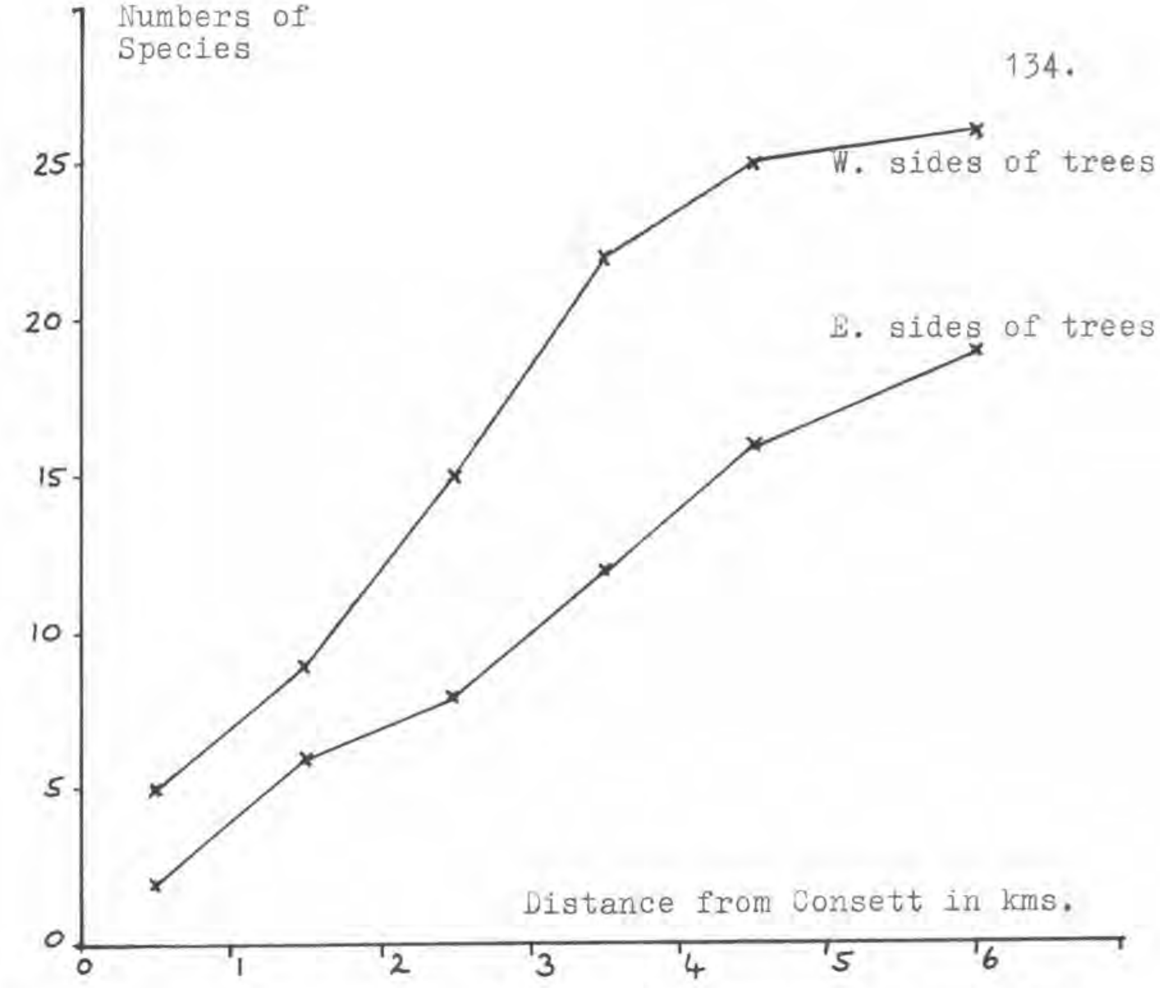


Fig. II : The Variation in Numbers of Species with Distance S.W. of Consett

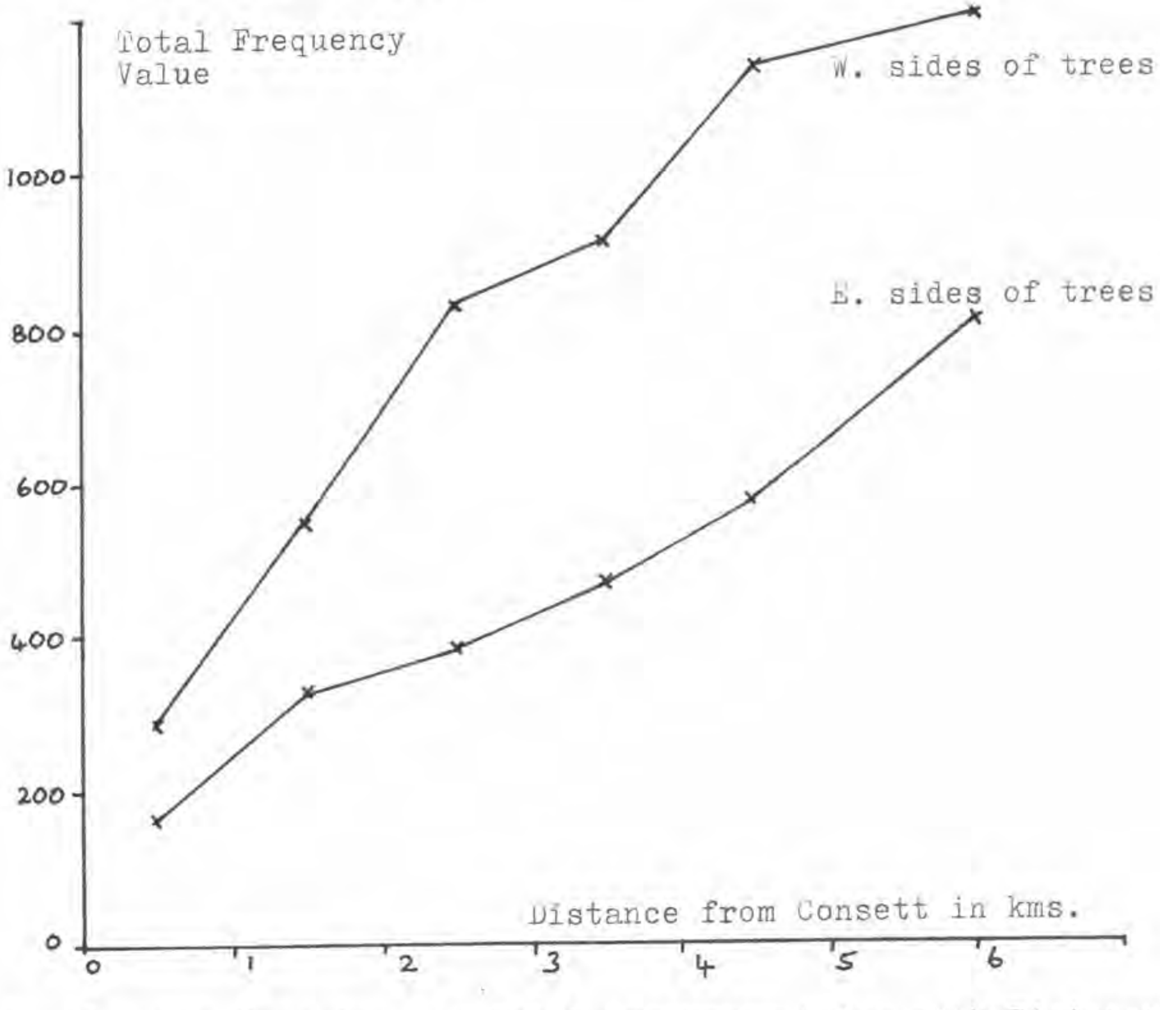


Fig. 12 : The Variation in Total Frequency Value with Distance S.W. of Consett

Correlation coefficients were obtained from the formula:-

$$r = \frac{\Sigma xy - \left(\Sigma x - \Sigma \frac{y}{n}\right)}{\sqrt{\left(\Sigma x^2 - \Sigma x . \Sigma \frac{x}{n}\right)\left(\Sigma y^2 - \Sigma y . \Sigma \frac{y}{n}\right)}}$$

where x = the number of lichen spp. recorded on the E. (or W.) side of an oak tree,

y = the distance in kms. of that tree from Consett.

The results were (a) $r = +0.58$

(b) $r = +0.71$

The significance of these results was examined by using the Students' 't' test, using the equation:-

$$t = \frac{r\sqrt{(n - 2)}}{\sqrt{1 - r}}$$

The results were (a) 5.76

(b) 8.18

Consulting the tables, this means that the correlation coefficients obtained are statistically significant at a level better than .05%. That is, there is less than one chance in two thousand that the correlation between distance from Consett and the change in species numbers is due to chance.

With such high correlation coefficients, it is clearly justified to proceed to the calculation of regression equations.

Regression equations were obtained from the formula:-

$x = a + by$ where x = the number of lichen spp. recorded on the E. (or W.) side of an oak tree

y = the distance in kms. of that tree from Consett

b is the regression coefficient and

$$= \frac{\Sigma xy - \frac{\Sigma x . \Sigma y}{n}}{\Sigma y^2 - \frac{(\Sigma y)^2}{n}}$$

a is the base constant and $= \bar{x} - b\bar{y}$.

The results were (a) $x = 1.49y - 0.78$

(b) $x = 2.59y - 0.16$

Values of x have been inserted to plot the regression lines shown in Fig 13 which diagrammatically expresses these regression equations.

The regression equations and the regression lines in Fig. 13 reveal that the lichen flora in the study area improves with distance from Consett. It is also apparent that the numbers of lichen species on the W. sides of oak trees rises at a faster rate with increasing distance from Consett than does the corresponding improvement in the lichen flora on the E. sides of oak trees.

For all trees in the study area, irrespective of distance from Consett, the mean number of species per tree is 10.2 for the W. sides of oak trees, and 5.2 for the E. sides. Again this shows that there is a distinct E-W. pattern in the distribution of corticolous lichens with regard to aspect.

Finally, concerning lichen distribution in the

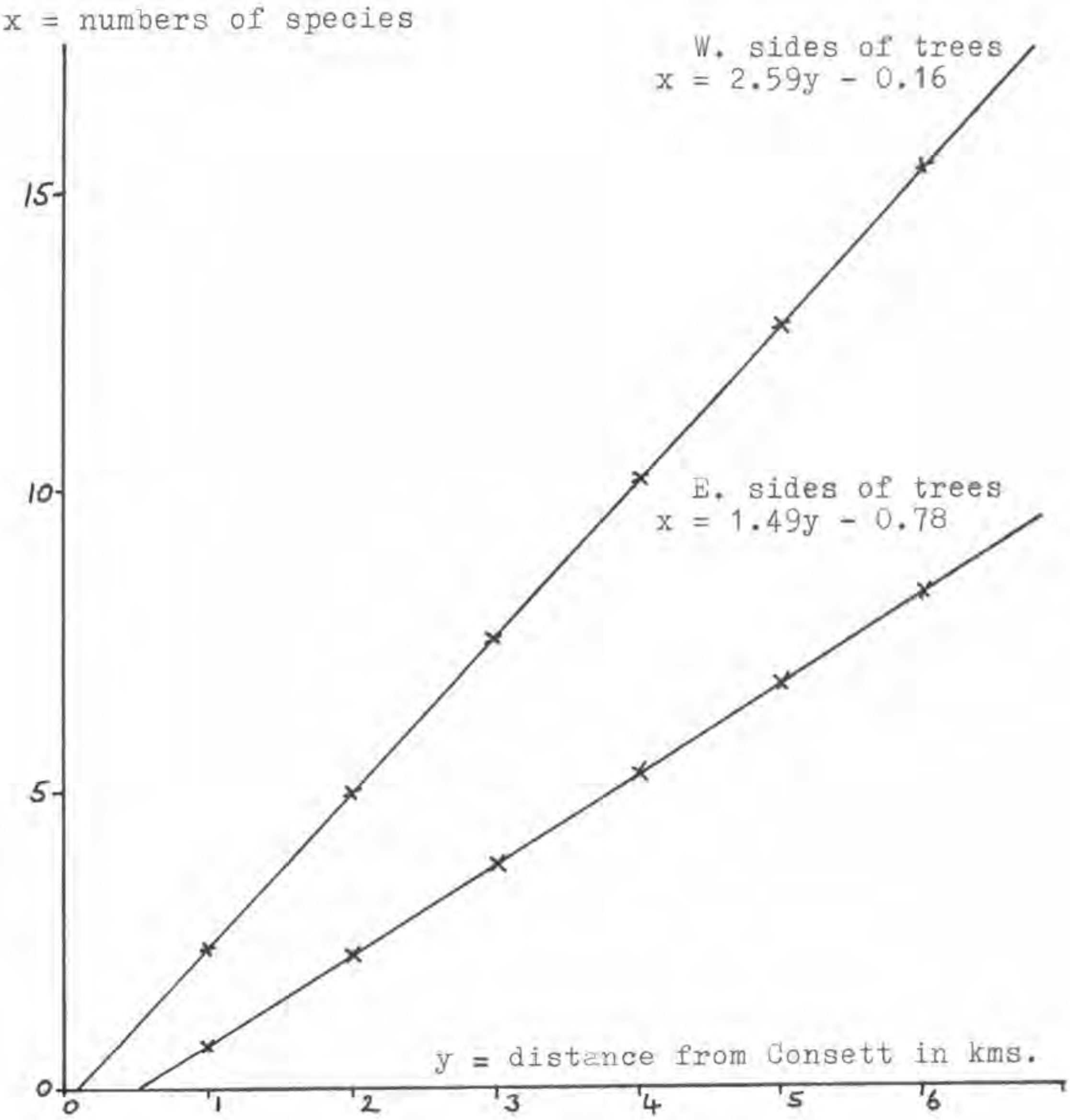


Fig 13 : Regression lines showing the mathematical relationship between species numbers and distance from Consett for the E. and W. sides of trees.

study area, the species presence or absence data was sorted into "lichen zones" as defined by Hawksworth and Rose[41] (see TABLE IX). These zones provide a scale by which SO2 pollution can be assessed through its effect on corticolous lichens. Hawksworth and Rose advise that in using their scale, only vertical, free-standing, mature trees should be used for sampling the lichen vegetation. The data used in devising the lichen zones was taken from trees conforming to this description. Having subjected the lichen flora of each tree to analysis in terms of the Hawksworth and Rose scale, it was possible to place each tree in a zone between 1 and 10. Again, considerable differences between the E. and W. sides of oak trees in the study area were noted, so the exercise has been carried out separately for the E. and W. sides of the trees. Thus, whilst the lichen flora of the W. side of a tree might be characteristic of zone 5, the E. side of the same tree might bear a lichen cover more representative of zone 3.

The position of each tree was plotted on a map, and the 2 zones (one zone value referring to the lichen flora on the E. side, one for the W. side) to which the tree had been allocated were marked alongside. Then, boundaries were drawn on the map between trees with different zone values (one set of boundaries delimiting zones for the E. sides of trees, one set for the W. sides). In this way, a zone map was produced (see Fig. 14), as described earlier, showing the shift in lichen zones with distance from Consett, and the differences in the location of the zones for the E. and the W. sides of trees. Once again, it is obvious that

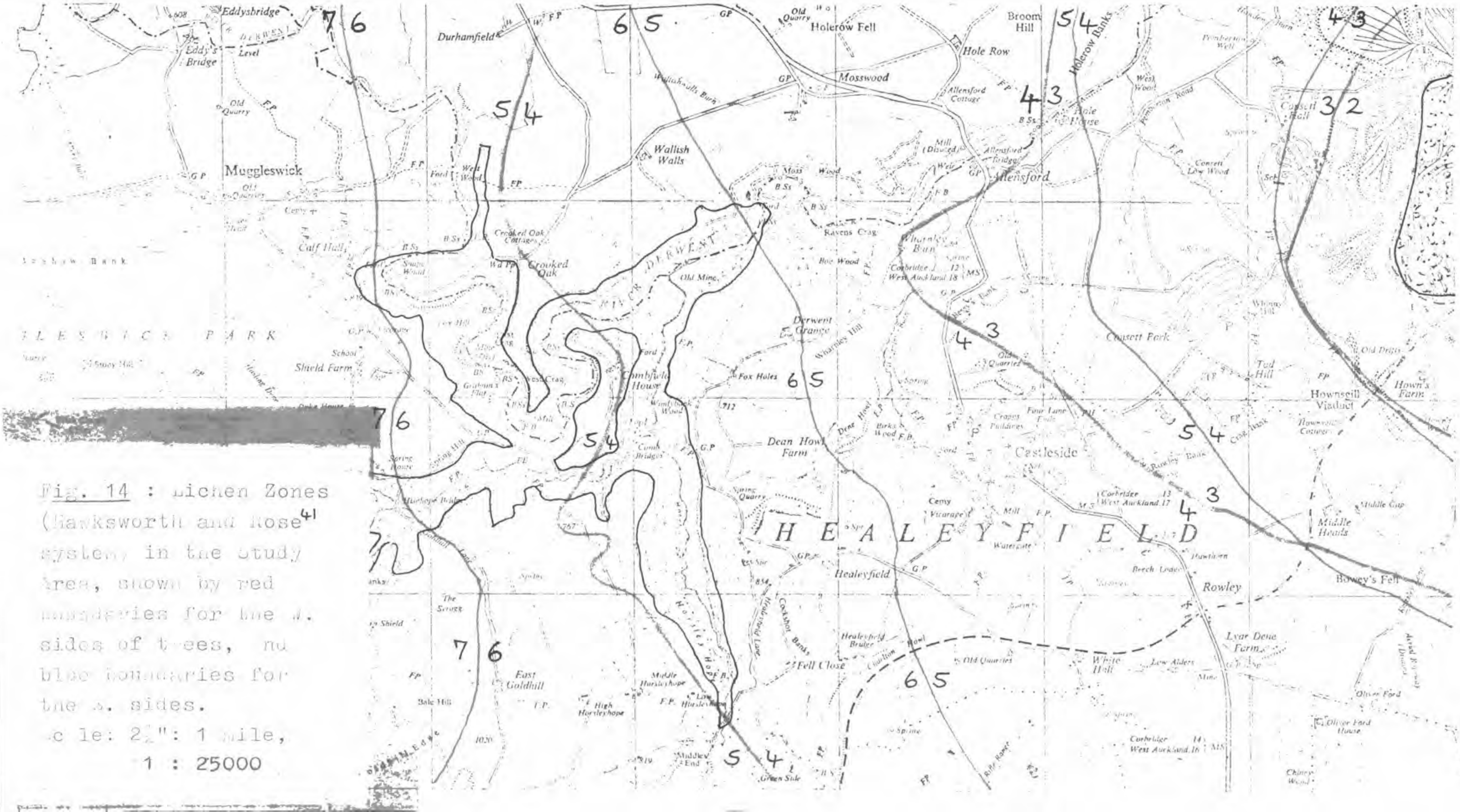


Fig. 14 : Lichen Zones (Hawksworth and Rose[41] system) in the study area, shown by red boundaries for the N. sides of trees, and blue boundaries for the S. sides.
Scale: 2½": 1 mile,
1 : 25000

the lichen vegetation improves S.W. of Consett with increasing distance from the town, and that the W. sides of trees bear a richer flora than the E. sides.

2. The Lichen Flora of Horsley Hope Ravine

The results of the 12 transects carried out in Horsley Hope Ravine are presented in TABLES XV - XXVI.

Generally speaking, it is clear that species numbers and total frequency values are much higher in Horsley Hope Ravine than in the study area as a whole. This is shown in Figs. 15 and 16, in which values for total frequency and species numbers recorded at the bottom of the ravine (TABLES XV and XVI : 120m.-stream) are superimposed on Figs. 11 & 12. at the 4 km. mark - approximately the location of Horsley Hope Ravine in relation to the Consett Steelworks. The addition of these figures introduces a disjunct step into the smooth profiles of lichen luxuriance/distance from Consett obtained in Figs. 11 and 12. The lichen flora of Horsley Hope Ravine is thus richer - in terms of species numbers and total frequency - than the corticolous lichen vegetation of the surrounding countryside.

It may also be noted that the figures of species diversity and total frequency for the E. and W. sides of trees at the bottom of the ravine are approximately equal - in contrast to the situations pertaining outside Horsley Hope Ravine, where the lichen flora of the E. and W. sides of trees is markedly different. This detail is brought out in Fig. 17, which plots the changes in species numbers and

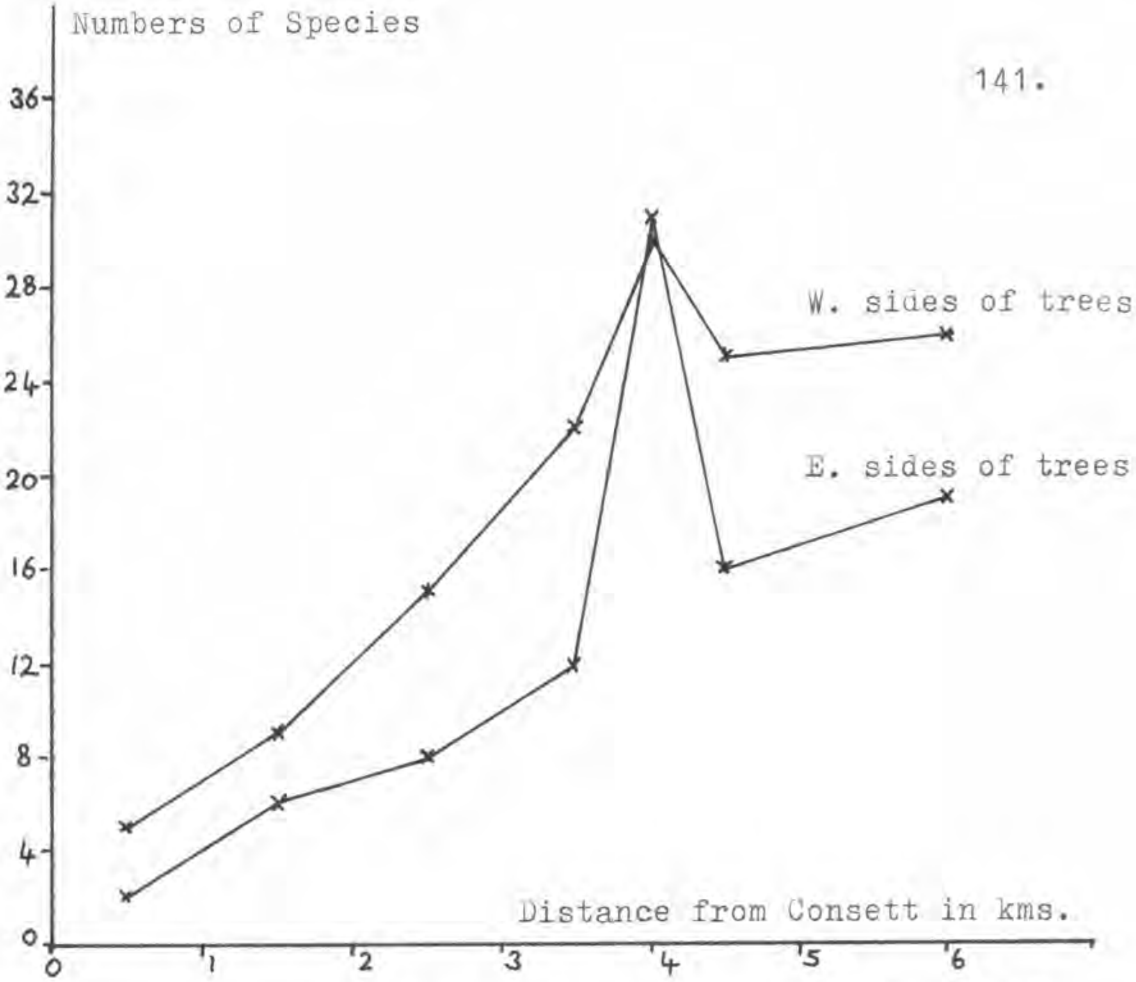


Fig. 15 : The Variation in Species Numbers S.W. of Consett, including figures for Horsley Hope Ravine

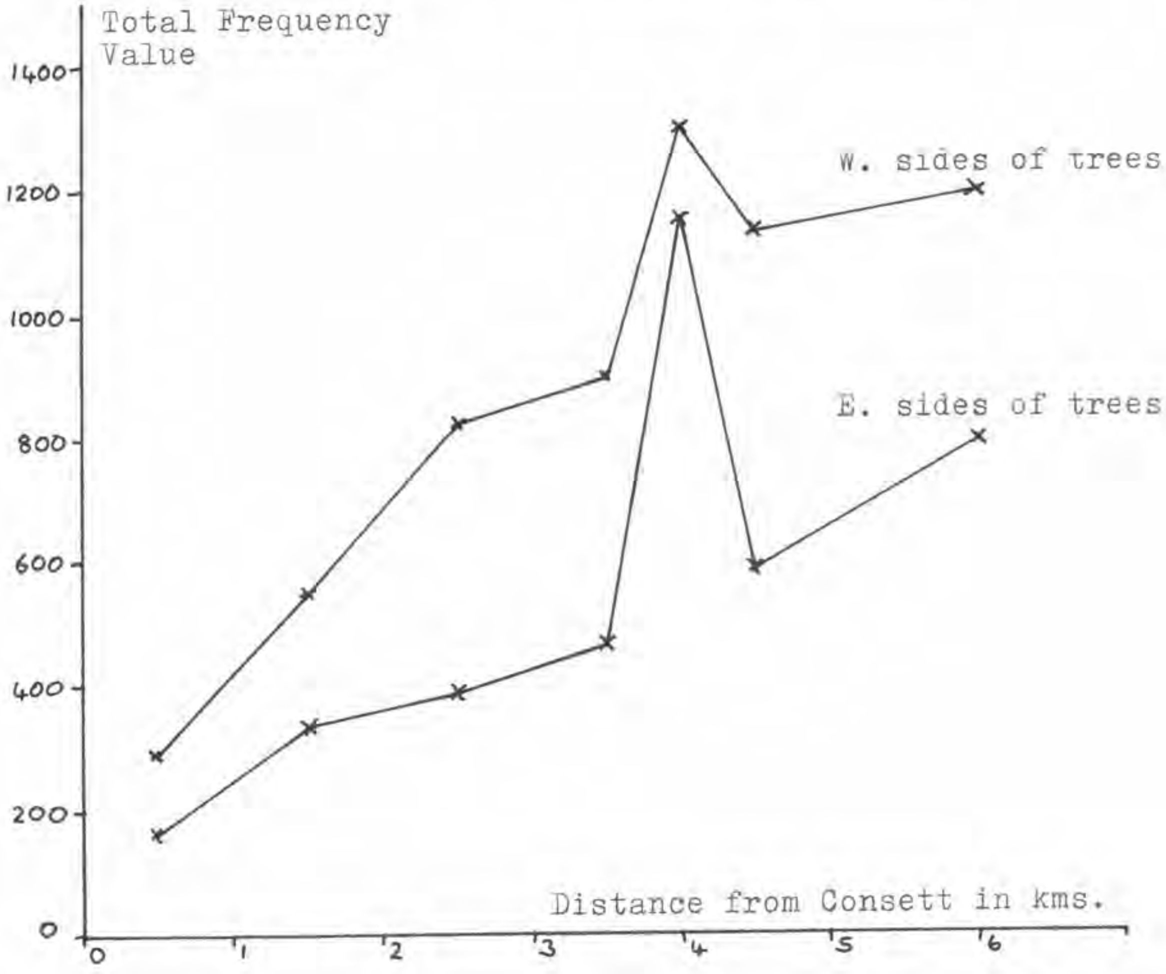


Fig 16 : The Variation in Total Frequency Values S.W. of Consett, including figures for Horsley Hope Ravine total species frequencies which occur between a point outside and to the east of the southern arm of Horsley Hope Ravine, and a point outside and to the west of this arm. The values for outside the ravine were computed from the results of the 20 trees nearest to each side of this part of the ravine. The values for within the ravine were taken from transects I - V. Fig. 17 shows that, in terms of both lichen indices, there is a dramatic improvement in the lichen flora of the E. sides of trees within the ravine, and a marked but lesser improvement in the vegetation of the W. side of trees. Thus, although there are considerable differences between the lichen vegetation of the E. and W. sides of trees outside Horsley Hope Ravine (as measured by species numbers and total frequency) - within the ravine, these values of lichen abundance are both higher and more constant with respect to aspect.

The corticolous lichen flora of Horsley Hope Ravine may also be seen to be richer than that of the study area by applying the Hawksworth and Rose scale. The presence of species such as Gyalecta flotowii, Usnea subfloridana and Pertusaria hemisphaerica within Horsley Hope Ravine suggests that the ravine should be placed in zones 7 or 8. The open countryside around Horsley Hope Ravine was classed as belonging to zones 5 or 6 (see Fig. 14), and thus the lichen vegetation of Horsley Hope Ravine is distinctly more luxuriant than that found on trees outside the ravine.

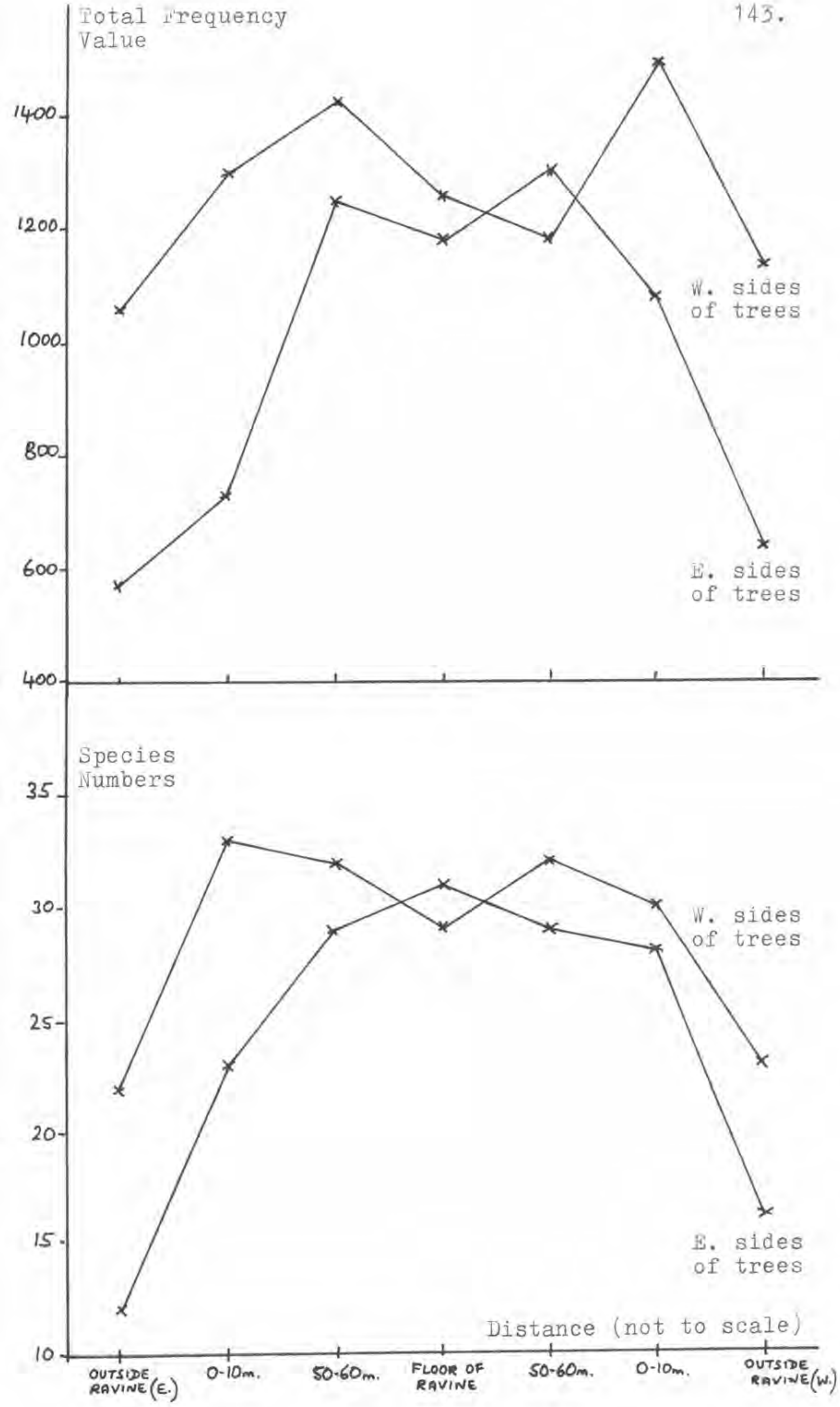


FIG. 17 : Transverse Section across S. Arm of Horsley Hope Ravine.

3. Lichen Distribution Within Horsley Hope Ravine

Although the overall picture of lichen abundance in Horsley Hope Ravine shows that the flora of the valley as a whole is considerably richer than that of the study area, the detailed distribution of lichen species within Horsley Hope Ravine is extremely variable. The patterns of lichen occurrence which may be picked out from the 12 transects are complicated, and possibly vary according to a number of factors. In order to simplify the situation, the 12 transects are first described, the results are presented in TABLES XV-XXVI, and then the results are analysed in such a way as to emphasise the two major patterns of lichen distribution within Horsley Hope Ravine.

A) The Transects

A general description of the methodology employed in sampling along transects down the valley-side was included in Chapter III, and the position of the transects is recorded in Fig. 8. A brief description of each transect is given below:-

(i) Transects I, II and V. These transects were all carried out on the same slope - a W. facing slope (aspect between 266° and 284° E. of N.) in the S. arm of the ravine woodlands. The outer edge of these transects was clearly demarcated by a break of slope, and a fence which separated the woods from permanent pasture. Between 0 and about 90 m. the measured slope angle was 20-25°, except for transect V which included a small 11 m. free-face element between 78 and 88 m. From about 90 m. to the stream, the slope flattened to an angle of 8-14°. Mature mixed deciduous woodlands (dominated by oak and ash) were present over the entire slope on which the transects were carried out. The lichen distribution pattern with respect to aspect was, without exception, distinctly E.-W. in orientation, and records were taken accordingly. Because these 3 transects were so similar in shape, length, aspect and vegetative cover, the results were amalgamated for ease of handling into two tables (see TABLES XV and XVI) - one combining the % frequencies of species on the E. sides of trees along the 3 transects; and the other showing the % frequencies of species on the W. sides of trees on transects I, II and V.

(ii) Transects III and IV. This pair of transects extended from the break of slope (and woodland/permanent pasture boundary) to the stream on the valley-floor, on the E. facing slope of the S. arm of Horsley Hope Ravine. The slope aspect was 81° E. of N. Between 0 and 70 m., the slope measured 21-22° and supported oak-ash woodland. From 70-94 m. the slope angle changed to about 3°, and in this flatter, wetter section alder was more prevalent and oak became scarcer. From 94 m. to the stream at 148 m., the slope angle increased again, averaging 12-15°, and mixed oak-ash woodland again occupied the valley-side. Lichen distribution in relation to aspect showed, as before, a markedly E.-W. pattern. Again, because of the similarity in physical and biological parameters, these transects were combined, and a single set of results presented for the E. sides of trees (TABLE XVII), and a single set for the W. sides (TABLE XVIII).

(iii) Transects VI and VII. These two transects were shorter than I-V, covering 48 m. and 56 m. respectively, and in each case extended from the road bounding the top edge of the S.-facing slope to the river at the bottom. Slope aspect was 186° E. of N. for transect VI, and 166° E. of N. for transect VII. In the heart of Horsley Hope Ravine, these mature mixed deciduous woodlands, within which the transects were taken, were very sheltered. From 0-19 m. the slope angle was 16°, from 0-38 m. it was 33-36° (including a 5 m. free-face element on transect VI), and at the break of slope at 38-40 m. marking the edge of the flood-plain, the slope flattened to 2°. Lichen distribution was very noticeably N.-S. in orientation. Only 2 trees out of the 200 sampled on these transects departed from this rigid pattern in relation to aspect. The results of transects VI and VII were amalgamated and TABLE XIX presents the results for the N. sides of trees, while TABLE XX shows the results for the S. sides of trees in the 2 transects.

(iv) Transects VIII and XII were undertaken on W.-facing slopes (slope aspects respectively 259° and 274° E. of N.) in the N. arm of Horsley Hope Ravine. Both transects again extended from the break of slope and woodland/agricultural land boundary to the valley-floor, and were fairly steep (18-27°) over their entire lengths. The woodlands were mature oak-ash woods, and the lichen distribution/aspect pattern was consistently E.-W. on nearly all the trees sampled. The similar nature of the results of these transects permitted their amalgamation into 2 sets of data - TABLE XI showing the % frequency of species on the E. sides of trees, and TABLE XXII showing the results for the W. sides of trees from transects VIII and XII.

(v). On the W. side of the S.arm of Horsley Hope Ravine, and just outside the ravine, there is a small tributary valley with a dense, mixed deciduous woodland cover (NZ 062478). Transects IX and X were taken across this small E.-W. oriented valley. Transect IX covers the S.-facing slope (aspect 155° E. of N) and is 22 m. in length; X covers the N.-facing slope (aspect 340° E. of N.) and extends for 28 m. The slope angles were 35° and 31° respectively. The recorded lichen pattern with respect to aspect was N.-S. for all trees sampled. It is interesting to note the existence of a N.-S. distribution pattern in this small valley, so close to transects III and IV which show a distinct E.-W. orientation of lichen distribution in relation to aspect. The results for the N. and S. sides of trees along transect IX are given in TABLE XXIII, and the results for transect X are set out in TABLE XXIV.

(vi) Transect XI. Finally, a transect was carried out along a slope which was non-conforming, in the sense that it was not covered with dense, mature, mixed deciduous woodlands, as were the other transects. Transect XI was taken down a W.-facing slope (292° E. of N.) in the N.E. arm of Horsley Hope Ravine. The slope angle was 24° between 0 and 76 m., and 9° between 76 m. and the river at 114 m. The valley-side in this part of Horsley Hope Ravine was covered by light, open woodland, comprising widely-dispersed, mature, deciduous trees with a poor ground flora, and little, if any, natural regeneration. In places, the tree cover was very thin, so that the landscape more closely resembled parkland than woodland, and in such parts, the requirement for sampling 20 trees per 10 m. length of valley-side was difficult to comply with. This ecological situation was the result of intensive grazing by cattle - a factor which had clearly been operative for some time (probably more than 50 years) judging by the age of the standing trees. The lichen flora was sampled by the same methods as were employed along other transects, and a clear E.-W. pattern of lichen distribution was revealed. TABLE XXV shows the results for the E. sides of trees on transect XI, and TABLE XXVI the results for the W. sides of trees.

B) Downslope Changes in the Lichen Flora

It can be seen from TABLES XV-XXVI that there are significant downslope changes within Horsley Hope Ravine in both the % frequency of individual lichen species, and in the summed figures of species numbers and total frequency. Moreover, these downslope changes vary considerably from transect to transect. Thus, along one transect a species may increase in frequency with distance downslope, along another transect its frequency may decrease downslope, and in a third transect the same species may become steadily more common up to a point 50 m. downslope, and then decrease in frequency from 50 m. to the valley-floor. Total figures of % frequency and species numbers show the same sort of variation in pattern.

For all transects, the downslope trends of species numbers and total frequency value (T.F.V.) resemble one

Species recorded	0-I0	I0-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-I00	I00-II0	II0-I20	I20-stream	r
Lecidea quernea	5	I0	40	60	60	50	75	80	75	I00	75	95	85	+0.973
Calicium viride	20	I5	5	-	I5	I5	20	20	30	30	50	35	30	+0.957
Catillaria griffithi	I0	40	45	70	70	80	80	90	80	85	80	95	90	+0.948
Arthonia spp.	-	-	-	-	5	5	5	20	30	30	35	25	25	+0.889
Pertusaria hemisphaerica	5	5	25	20	30	60	60	60	65	70	70	70	70	+0.858
Thelotrema lepadinum	-	-	-	-	-	-	20	-	25	30	35	60	55	+0.844
Phlyctis argena	-	I0	I0	45	40	45	50	45	60	50	60	60	55	+0.836
Pertusaria pertusa	I0	5	I5	35	50	40	50	60	55	55	45	55	60	+0.82I
Lecanactis abietina	5	I5	-	I5	30	30	50	40	30	50	40	40	40	+0.799
Pertusaria albescens	-	25	I0	40	45	45	55	50	70	55	50	45	65	+0.773
Usnea subfloridana	-	-	-	-	-	-	-	-	5	-	I5	I5	20	+0.753
Lepraria candelaris	-	-	-	-	-	-	-	I0	-	I0	I0	I0	5	+0.7I2
Chaenotheca ferruginea	5	30	I0	I5	30	30	30	45	45	20	35	30	25	+0.700
Opegrapha vermicellifera	-	-	I0	-	5	20	20	20	30	30	25	5	I5	+0.662
Parmelia glabratula	-	-	-	-	I5	I5	25	20	25	25	20	20	35	+0.649
Pertusaria amara	-	5	-	I5	I0	30	30	45	45	45	50	30	50	+0.639
Parmeliopsis ambigua	I0	I0	I0	I5	30	20	35	20	I5	20	I5	20	5	+0.62I
Parmelia subaurifera	I0	-	I0	I0	I5	30	30	30	25	30	30	20	30	+0.6I8
Gyalecta flotowii	-	-	-	-	-	-	-	5	5	-	-	-	5	+0.237
Lecanora expallens	85	80	I00	90	I00	85	I00	95	75	90	90	I00	95	+0.I85
Pertusaria hymenea	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Alectoria fuscescens	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Lepraria incana	I00	I00	I00	I00	I00	I00	I00	90	I00	I00	I00	I00	I00	-0.II8
Cetraria glauca	-	-	I0	I0	I0	20	I5	-	-	I0	-	-	-	-0.I50
Lecanora chlarona	20	-	I5	20	I0	-	I5	I0	-	-	I5	I5	I0	-0.I58
Ochrolechia androgyna	25	40	20	35	35	50	50	30	35	20	25	20	5	-0.345
Lecanora chlarotera	I0	I0	-	35	I0	5	I0	-	-	-	-	5	5	-0.44I
Parmelia saxatilis	60	50	90	60	55	70	80	50	30	45	50	60	50	-0.448
Evernia prunastri	I0	25	45	50	70	80	50	50	55	45	30	40	40	-0.529
Hypogymnia tubulosa	30	40	55	90	90	75	40	40	40	35	30	40	20	-0.537
Cetraria chlorophylla	-	5	I0	5	-	-	-	-	-	-	-	-	-	-0.546
Hypogymnia physodes	55	70	80	I00	I00	I00	80	60	55	55	40	35	40	-0.566
Parmelia sulcata	25	50	45	40	25	45	30	45	25	25	25	I0	I0	-0.580
Ochrolechia turneri	25	20	I0	25	-	I5	I0	I5	-	5	I0	5	-	-0.627
Toninia carodocensis	50	20	35	45	40	25	I5	-	-	20	5	-	-	-0.774
Lecidea scalaris	60	40	I5	25	20	I5	-	I0	I0	I5	I5	I0	5	-0.928
Lecanora conizaeoides	I00	I00	90	80	75	50	45	50	35	30	40	I5	I0	-0.932
Species totals	23	25	25	27	30	29	30	29	28	30	3I	3I	3I	
Total frequency	735	820	9I0	II50	I2I0	I250	I275	I205	II75	I230	I2I5	II85	II55	

TABLE XV:: % Frequency of lichens on the E. sides of trees in I0 m. lengths down the valley-side : Transects I,II,V.

	0- I0	I0- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80	80- 90	90- I00	I00- II0	II0- I20	I20- stream	r
Lecanactis abietina	I5	40	55	70	60	85	I00	95	I00	I00	90	I00	I00	+0.962
Chaenotheca ferruginea	I0	20	25	45	35	65	80	75	80	95	70	95	80	+0.947
Lepraria candelaris	-	-	-	5	-	-	I5	I5	35	30	20	45	70	+0.826
Usnea subfloridana	-	-	-	-	-	I5	-	5	I0	5	I0	I5	I0	+0.7I0
Pertusaria albescens	25	35	35	70	65	55	70	50	90	80	70	50	85	+0.692
Arthonia spp.	5	-	-	I0	-	20	25	25	25	35	20	I0	I5	+0.668
Calicium viride	35	35	55	55	45	90	I00	80	80	90	90	90	95	+0.666
Pertusaria pertusa	35	35	60	45	65	40	60	70	70	60	70	50	70	+0.626
Gyalecta flotowii	-	-	-	-	-	I0	-	5	5	5	-	I5	-	+0.596
Lecidea quernea	20	30	55	95	65	80	80	75	90	85	70	90	I00	+0.593
Pertusaria amara	20	30	60	55	30	50	45	40	55	70	65	40	50	+0.58I
P. hemisphaerica	I0	I0	45	30	60	55	50	40	50	40	35	50	50	+0.567
Catillaria griffithi	30	65	I00	I00	I00	I00	90	I00	95	90	95	I00	I00	+0.5I6
Thelatremum lepadinum	I0	I0	I5	I5	I0	-	20	I0	I0	20	-	40	55	+0.506
Opegrapha vermicellifera	I0	I5	I0	-	5	5	-	30	I0	20	25	5	5	+0.4I2
Lepraria incana	I00	I00	I00	I00	I00	I00	I00	I00	I00	95	I00	I00	I00	-0.I3I
Parmelia glabratula	I0	I0	I0	-	20	20	20	20	-	-	-	I5	5	-0.I53
Toninia carodocensis	60	20	-	I5	20	I0	I5	-	25	20	I5	30	5	-0.I98
Phlyctis argena	20	25	20	25	25	45	35	-	5	20	20	5	I5	-0.392
Lecanora expallens	I00	I00	I00	90	I00	I00	I00	95	80	I00	95	90	95	-0.482
Lecanora chlarona	20	5	35	20	5	-	20	I0	5	-	-	I5	-	-0.485
Parmelia subaurifera	20	I5	25	30	25	35	30	I0	I0	I5	-	I5	I5	-0.493
Ochrolechia turneri	20	I5	5	I5	20	5	I0	-	-	-	5	I0	5	-0.559
Lecanora chlarona	20	I5	I0	I0	5	I0	I5	-	I0	5	I0	-	-	-0.569
Alectoria fuscescens	-	I5	I0	5	-	-	-	-	-	-	-	-	-	-0.580
Cetraria chlorophylla	I0	20	-	I0	-	-	5	-	-	-	-	-	-	-0.656
Pertusaria hymenea	I0	5	5	-	-	5	-	-	-	-	-	-	-	-0.730
Cetraria glauca	20	30	20	5	20	I0	-	-	-	-	-	-	-	-0.732
Ochrolechia androgyna	60	95	45	65	35	20	20	-	I5	I0	I0	I5	-	-0.826
Parmelia sulcata	70	90	75	50	40	40	25	5	-	20	20	20	20	-0.840
Parmeliopsis ambigua	45	35	55	45	55	40	20	I5	20	I5	-	5	20	-0.866
Parmelia saxatilis	80	85	90	80	75	60	40	30	30	35	35	20	I5	-0.874
Evernia prunastri	70	85	65	80	65	50	50	35	45	30	40	30	30	-0.889
Hypogymnia physodes	I00	95	I00	I00	I00	80	60	55	45	40	40	30	40	-0.903
Lecidea scalaris	65	50	45	35	30	I5	25	20	25	20	20	30	I0	-0.9I9
Hypogymnia tubulosa	85	65	65	90	85	75	30	30	20	I5	20	20	25	-0.93I
Lecanora conizaeoides	I00	85	65	65	60	35	30	30	20	I5	20	30	I0	-0.976
Species totals	33	33	3I	32	30	32	3I	28	30	30	27	3I	30	
Total frequency	I300	I385	I460	I520	I425	I425	I345	II75	I260	I280	II80	I275	I300	

<u>TABLE XVI</u> : % Frequency of lichens on the W. sides of trees in I0 m. lengths down the valley-side : Transects I,II,V.

	0-IO	IO-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-I00	I00-II0	II0-I20	I20-I30	I30-stream	r
Lecidea quernea	-	I5	35	60	80	75	95	I00	85	80	95	85	70	90	+0.930
Lepraria candelaris	-	-	-	25	25	30	20	50	45	50	60	40	50	55	+0.880
Catillaria griffithi	20	45	55	80	85	Io0	90	I00	80	90	I00	I00	I00	95	+0.85I
Arthonia spp.	-	5	-	-	25	30	20	I5	I5	20	35	30	25	20	+0.844
Chaenotheca ferruginea	45	50	65	80	95	I00	I00	I00	I00	I00	I00	I00	I00	I00	+0.78I
Calicium viride	30	70	90	I00	I00	85	85	I00	I00	I00	I00	90	I00	95	+0.749
Lecanactis abietina	40	45	75	I00	I00	I00	I00	I00	I00	95	I00	I00	I00	I00	+0.749
Phlyctis argena	-	-	5	I5	25	30	I5	20	25	20	25	30	25	25	+0.676
Thelotrema lepadinum	-	I0	20	I5	-	25	35	30	20	25	20	20	25	30	+0.593
Pertusaria albescens	20	30	35	40	50	55	70	50	60	60	55	40	40	30	+0.592
Gyalecta flotowii	-	-	-	-	-	-	-	-	5	-	I5	I0	-	5	+0.542
Pertusaria pertusa	20	30	60	45	60	50	45	45	55	50	50	50	45	45	+0.530
Opegrapha vermicellifera	I0	I5	I5	I5	20	-	I0	30	I5	40	20	25	20	25	+0.525
Parmelia glabratula	5	20	30	I5	20	30	25	I0	30	I5	25	30	20	20	+0.428
Parmelia subaurifera	5	I5	25	25	I0	20	20	20	I5	25	20	I5	I5	20	+0.277
Pertusaria amara	45	55	50	50	60	45	55	45	50	60	55	40	55	60	+0.I77
Usnea subfloridana	5	I0	-	5	5	I0	I0	-	I0	5	I0	-	5	5	+0.I55
Pertusaria hemisphaerica	25	30	40	40	55	50	40	40	35	45	35	30	20	25	+0.07I
P. Hymenea	-	-	-	-	I0	-	-	-	-	-	-	-	-	-	-0.I22
Lecanora expallens	70	80	I00	95	80	I00	85	95	70	I00	I00	80	85	95	-0.I46
Lecanora chlarotera	25	I5	-	5	5	I5	I0	-	20	5	5	I0	I0	I0	-0.265
Toninia caradocensis	I5	I5	5	I0	5	20	I0	-	5	-	20	5	30	I0	-0.269
Lepraria incana	I00	95	I00	I00	I00	I00	85	I00	90	90	I00	I00	I00	I00	-0.297
Cetraria chlorophylla	-	-	I5	5	-	-	-	-	-	-	-	-	-	-	-0.368
Alectoria fuscescens	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-0.397
Ochrolechia turneri	20	5	I0	-	-	-	-	-	-	5	5	-	I0	-	-0.59I
Parmelia sulcata	65	60	60	50	40	60	20	35	40	45	I5	25	25	25	-0.632
Ochrolechia androgyna	40	25	35	35	I5	5	I0	20	I5	-	5	-	20	I£	-0.637
Cetraria glauca	I5	I5	5	-	-	-	I0	-	-	-	-	-	-	-	-0.674
Parmeliopsis ambigua	30	25	25	5	I5	-	I0	20	5	5	I0	5	-	-	-0.707
Parmelia saxatilis	60	80	80	60	65	45	40	45	40	45	30	55	40	30	-0.76I
Lecanora chlarona	30	-	I5	I0	-	5	-	-	-	-	-	5	-	-	-0.762
Hypogymnia tubulosa	50	55	50	60	30	40	I5	25	30	20	25	20	30	25	-0.80I
Lecidea scalaris	45	55	45	30	30	I0	30	I0	I0	5	5	-	-	-	-0.826
Evernia prunastri	90	80	60	65	50	30	25	35	35	40	25	40	25	25	-0.865
Hypogymnia physodes	85	70	85	60	65	30	40	30	20	25	20	30	40	20	-0.882
Lecanora conizaeoides	70	60	55	40	25	I0	I0	20	20	-	I0	5	5	I0	-0.939
Species totals	28	3I	30	3I	30	29	3I	27	3I	28	32	28	30	30	
Total frequency	I080	II85	I365	I340	I350	I305	I235	I290	I245	I275	I295	I2I0	I245	I2I5	

TABLE XVII : % Frequency of lichens on E. sides of trees in IO m. lengths down the valley-side : Transects III,IV.

	0-I0	I0-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-I00	I00-II0	II0-I20	I20-I30	I30-stream	r
Lecidea quernea	I5	30	45	65	80	80	90	75	80	70	I00	95	I00	85	+0.9I9
Catillaria griffithi	20	35	55	60	70	65	60	60	75	65	90	80	80	90	+0.903
Phlyctis argena	-	-	20	20	30	35	35	45	70	55	30	25	45	60	+0.89I
Lecanactis abietina	-	5	20	I5	35	25	40	40	45	45	40	30	35	60	+0.832
Parmelia subaurifera	20	20	I5	25	40	35	50	30	50	60	35	50	50	45	+0.797
Pertusaria hemisphaerica	40	40	40	60	50	45	45	50	45	70	60	80	75	75	+0.692
Thelotrema lepadinum	-	I5	25	20	40	35	35	35	30	30	50	30	45	40	+0.652
Lepraria candelaris	-	-	-	-	-	5	-	I0	5	I5	-	I0	I0	I0	+0.603
Pertusaria pertusa	40	40	45	65	65	60	55	65	30	65	55	60	50	65	+0.593
Opegrapha vermicellifera	5	5	5	45	45	45	40	40	40	40	45	30	35	35	+0.569
Gyalecta flotowii	-	-	5	-	5	I0	-	I5	-	-	-	-	I0	20	+0.54I
Pertusaria albescens	20	30	40	60	55	45	50	55	25	30	35	40	30	35	+0.53I
Parmelia glabratula	30	25	20	40	40	40	35	45	45	50	40	30	40	40	+0.5I0
Arthonia spp.	-	-	35	25	25	40	40	35	40	30	45	30	I5	30	+0.502
Calicium viride	20	70	45	25	30	30	20	30	35	40	35	40	45	30	+0.350
Lecanora expallens	85	75	80	60	80	90	I00	75	I00	I00	95	90	75	65	+0.I72
Chaenotheca ferruginea	25	25	40	45	50	40	30	60	30	35	35	40	30	30	+0.II7
Pertusaria hymenea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Lepraria incana	I00	I00	I00	I00	I00	I00	I00	I00	I00	I00	I00	95	I00	I00	-0.II2
Pertusaria amara	70	70	65	50	85	60	50	55	60	75	50	60	55	55	-0.386
Cetraria chlorophylla	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.440
Toninia carodocensis	I0	I5	-	5	I0	-	I0	5	I0	I0	-	-	5	-	-0.532
Parmeliopsis ambigua	45	35	-	I5	I0	I0	I0	-	-	20	-	I0	-	-	-0.558
Lecanora chlarona	40	20	30	-	-	I0	5	-	I5	I0	-	5	-	I5	-0.6I6
Cetraria glauca	50	30	30	I5	5	5	I0	I0	5	-	-	-	-	-	-0.640
Ochrolechia turneri	30	25	I0	20	I0	-	5	I0	5	-	I5	-	I5	5	-0.706
Alectoria fuscescens	35	30	5	-	-	-	-	-	-	-	-	-	-	-	-0.7I2
Usnea subfloridana	25	25	5	5	-	I0	I0	-	-	-	-	-	I0	-	-0.756
Lecanora chlarotera	30	-	-	I5	-	5	-	-	-	5	5	-	-	-	-0.760
Parmelia sulcata	I00	85	60	60	40	40	45	45	40	30	45	50	45	50	-0.850
P. saxatilis	I00	I00	95	55	60	50	55	70	45	45	55	50	50	40	-0.862
Hypogymnia tubulosa	80	85	85	60	40	35	35	25	35	40	25	30	40	30	-0.873
Evernia prunastri	I00	I00	80	35	40	40	30	40	35	35	25	25	30	45	-0.888
Lecidea scalaris	90	I00	45	40	I5	25	20	30	35	5	I5	5	-	-	-0.906
Hypogymnia physodes	I00	I00	80	40	50	40	35	55	35	40	35	25	30	45	-0.9I7
Ochrolechia androgyna	80	45	35	25	25	20	25	25	I5	20	I5	I5	I5	5	-0.94I
Lecanora conizaeoides	80	65	60	40	I0	I0	I0	I5	I0	I0	-	5	I0	I5	-0.954
Species totals	30	30	3I	3I	30	32	3I	30	30	30	26	28	29	28	
Total frequency	I505	I445	I320	I2I0	I240	II85	I200	I250	II90	I235	II65	II35	II65	I220	

TABLE XVIII : % Frequency of lichens on W. side of trees in I0 m. lengths down the valley-side : Transects III,IV.

	0-10	10-20	20-30	30-40	40-stream	r
Opegrapha vermicellifera	-	5	15	35	30	+0.940
Phlyctis argena	20	45	55	60	70	+0.926
Arthonia spp.	10	35	30	55	60	+0.903
Thelotrema lepadinum	10	20	70	70	75	+0.902
Chaenotheca ferruginea	20	25	30	30	45	+0.846
Catillaria griffithi	30	80	100	85	85	+0.842
Lecidea quernea	50	60	100	95	90	+0.809
Gyalecta flotowii	-	-	5	10	10	+0.773
Lecanactis abietina	10	45	40	40	50	+0.756
Parmelia subaurifera	20	10	25	25	25	+0.609
Calicium viride	20	35	30	30	35	+0.587
Parmelia glabratula	25	30	40	35	30	+0.416
Lecanora chlarotera	-	5	-	-	10	+0.357
Pertusaria hemisphaerica	40	15	70	55	50	+0.348
Lepraria incana	100	100	100	95	100	-0.142
Lepraria candelaris	-	20	-	-	5	-0.213
Parmelia saxatilis	100	100	100	45	65	-0.370
Pertusaria albescens	90	60	30	65	50	-0.541
Ochrolechia turneri	-	10	-	-	-	-0.562
Cetraria chlorophylla	5	-	-	-	-	-0.714
Alectoria fuscescens	15	25	-	-	-	-0.759
Parmelia sulcata	70	50	55	50	35	-0.792
Pertusaria pertusa	70	60	55	55	55	-0.811
Usnea subfloridana	25	15	5	10	5	-0.849
Parmeliopsis ambigua	10	-	5	5	-	-0.888
Hypogymnia physodes	100	100	75	40	40	-0.926
Lecanora conizaeoides	100	85	45	30	30	-0.927
Pertusaria amara	60	60	30	45	30	-0.932
Toninia caradocensis	60	45	10	-	-	-0.940
Lecanora expallens	100	90	75	70	70	-0.943
Lecanora chlarona	10	5	5	-	-	-0.947
Hypogymnia tubulosa	100	100	70	20	30	-0.948
Ochrolechia androgyna	90	95	20	-	5	-0.951
Cetraria glauca	45	30	-	-	-	-0.961
Pertusaria hymenea	15	5	-	-	-	-0.962
Lecidea scalaris	80	60	35	-	-	-0.975
Evernia prunastri	100	100	40	15	20	-0.983
Species totals	32	34	30	26	28	
Total frequency	1600	1625	1365	1170	1195	

TABLE XIX : % Frequency of lichens on N. sides of trees in 10 m. lengths down the valley-sides : Transects VI & VII.

	0- 10	10- 20	20- 30	30- 40	40- stream	r
Arthonia spp.	5	35	40	55	55	+0.871
Lepraria candelaris	40	50	60	60	100	+0.808
Lecanactis abietina	70	100	100	100	100	+0.805
Chaenotheca ferruginea	80	70	100	100	100	+0.786
Lecidea quernea	40	70	80	80	75	+0.758
Gyalecta flotowii	-	-	-	10	10	+0.757
Opegrapha vermicellifera	-	15	30	20	25	+0.754
Thelotrema lepadinum	20	15	15	30	30	+0.728
Catillaria griffithi	80	100	100	80	95	+0.720
Calicium viride	75	100	95	100	100	+0.671
Lepraria incana	100	90	100	100	100	+0.116
Lecanora chlarotera	-	-	-	-	-	0
Parmelia subaurifera	25	20	10	20	20	-0.339
Lecanora expallens	100	90	100	85	90	-0.366
Pertusaria pertusa	70	60	80	55	60	-0.460
Cetraria chlorophylla	-	10	-	-	-	-0.562
Phlyctis argena	30	40	25	20	25	-0.619
Parmelia glabratula	20	5	-	5	5	-0.625
Pertusaria hemisphaerica	50	75	40	20	25	-0.626
Lecanora chlarona	10	-	10	5	-	-0.687
Pertusaria hymenea	5	-	-	-	-	-0.714
Ochrolechia turneri	5	-	-	-	-	-0.714
Usnea subfloridana	15	-	5	5	-	-0.724
Alectoria fuscescens	10	-	10	5	-	-0.687
Parmelia saxatilis	100	60	30	40	40	-0.797
Parmeliopsis ambigua	15	5	-	-	-	-0.874
Cetraria glauca	35	15	10	-	5	-0.902
Parmelia albescens	70	40	50	45	30	-0.909
Toninia caradocensis	65	40	15	-	-	-0.930
Pertusaria amara	60	60	45	30	25	-0.942
Parmelia sulcata	95	60	25	10	5	-0.948
Lecidea scalaris	80	55	40	5	-	-0.952
Hypogymnia tubulosa	100	75	35	25	25	-0.953
Hypygymnia physodes	100	85	30	20	10	-0.962
Ochrolechia androgyna	80	45	20	-	5	-0.964
Evernia prunastri	85	35	15	10	10	-0.972
Lecanora conizaeoides	100	70	30	10	10	-0.977
Species totals	33	30	29	28	27	
Total frequency	1835	1540	1435	1145	1180	

TABLE XX : % Frequency of lichens on S. sides of trees in 10 m. lengths down the valley sides : Transects VI & VII.

	<u>0- I0</u>	<u>I0- 20</u>	<u>20- 30</u>	<u>30- 40</u>	<u>40- stream</u>	<u>r</u>
Pertusaria hemisphaerica	-	I5	45	50	50	+0.987
Lecanactis abietina	-	I0	25	35	40	+0.978
Phlyctis argena	-	I5	30	35	55	+0.959
Opegrapha vermicellifera	5	-	I5	25	35	+0.947
Pertusaria albescens	-	5	5	25	40	+0.940
* Arthonia spp.	-	I0	I0	I5	I5	+0.905
Pertusaria pertusa	30	25	40	40	60	+0.873
Calicium viride	20	25	45	40	40	+0.826
Lecanora expallens	65	I00	85	I00	95	+0.826
L. chlarotera	-	-	20	30	20	+0.826
Chaenotheca ferruginea	20	30	50	40	40	+0.79I
Parmelia glabratula	I0	I5	25	20	35	+0.780
Lepraria candelaris	-	-	-	I0	I0	+0.757
Pertusaria amara	I0	55	40	45	30	+0.736
Parmelia saxatilis	70	I00	I00	90	95	+0.735
P. subaurifera	5	-	I5	20	45	+0.729
Usnea subfloridana	-	-	-	-	I0	+0.709
Catillaria griffithi	5	50	40	45	65	+0.683
Cetraria glauca	-	-	I0	-	I5	+0.67I
Thelotrema lepadinum	-	-	-	I5	-	+0.354
Parmelia sulcata	20	I00	I00	60	50	+0.083
Evernia prunastri	25	75	75	60	35	+0.034
Pertusaria hymenea	-	-	-	-	-	0
Cetraria chlorophylla	-	-	I0	-	-	0
Alectoria fuscescens	-	-	-	-	-	0
Gyalecta flotowii	-	-	-	-	-	0
Lepraria incana	I00	I00	I00	95	I00	-0.I42
Lecanora chlarona	35	20	40	I5	I5	-0.607
Ochrolechia androgyna	50	45	20	20	I0	-0.6I4
Hypogymnia physodes	80	I00	85	65	50	-0.668
Hypogymnia tubulosa	75	90	90	35	35	-0.756
Lecidea scalaris	65	60	40	35	20	-0.830
Ochrolechia turneri	I5	5	-	-	-	-0.874
Toninia caradocensis	60	45	30	-	I0	-0.942
Parmeliopsis ambigua	55	35	20	5	5	-0.964
Lecanora conizaeoides	I00	I00	60	25	-	-0.974
* Lecidea quernea	20	10	50	60	75	+0.888
<u>Species totals</u>	23	26	30	29	30	
<u>Total frequency</u>	940	I240	I350	II55	I200	

<u>TABLE XXI</u> : % Frequency of lichens on E. sides of trees in I0 m. lengths down the valley-side : Transects VIII & XII.

	0-I0	I0-20	20-30	30-40	40-stream	r
Lepraria candelaris	-	I0	40	50	60	+0.985
Opegrapha vermicellifera	5	25	20	40	55	+0.948
Catillaria griffithi	30	50	65	70	70	+0.944
Lecanactis abietina	I0	20	80	I00	I00	+0.939
Calicium viride	I5	40	70	85	80	+0.93I
Phlyctis argena	-	I0	20	20	20	+0.888
Chaenotheca ferruginea	35	30	80	85	I00	+0.8I8
Pertusaria hemisphaerica	-	20	I0	30	25	+0.733
Lecidea quernea	I5	85	I00	85	95	+0.696
Arthonia spp.	-	20	35	I5	30	+0.690
Pertusaria albescens	25	50	50	50	45	+0.687
Parmelia subaurifera	25	25	35	50	40	+0.4I6
P. glabratula	I0	-	30	25	30	+0.I04
Gyalecta flotowii	-	-	-	-	-	0
Lepraria incana	I00	I00	I00	I00	I00	0
Thelotrema lepadinum	-	-	-	-	-	0
Lecanora expallens	95	I00	I00	90	I00	-0.095
Usnea subfloridana	-	30	I0	5	5	-0.203
Pertusaria amara	65	60	60	70	55	-0.237
P. pertusa	80	95	60	45	60	-0.44I
P. hymenea	-	I0	-	-	-	-0.562
Lecanora chlarona	20	5	-	5	5	-0.625
Ochrolechia androgyna	60	65	50	20	-	-0.702
Cetraria chlorophylla	I5	25	-	-	-	-0.759
Parmelia sulcata	70	50	55	50	35	-0.792
Parmeliopsis ambigua	45	25	I0	I0	I5	-0.804
Parmelia saxatilis	I00	I00	90	45	65	-0.870
Cetraria glauca	30	20	5	I0	5	-0.902
Lecanora chlarotera	30	20	20	-	5	-0.903
Ochrolechia androgyna	60	65	50	20	-	-0.905
Toninia caradocensis	55	40	20	-	5	-0.92I
Hypogymnia tubulosa	90	95	60	30	40	-0.928
Lecidea scalaris	65	50	30	35	I0	-0.933
Lecanora conizaeoides	I00	85	20	25	I0	-0.94I
Alectoria fuscescens	25	5	-	-	-	-0.949
Hypogymnia physodes	I00	I00	65	55	50	-0.967
Evernia prunastri	95	80	70	60	25	-0.989
<u>Species totals</u>	29	34	30	29	30	
<u>Total frequency</u>	I435	I565	I460	I350	i240	

TABLE XXII : % Frequency of lichens on W. sides of trees in I0 m. lengths down the valley-side : Transects VIII & XII.

	(a)		(b)	
	0-I0	I0-stream	0-I0	I0-stream
Lecanora conizaeoides	I00	70	95	50
Lepraria incana	I00	I00	I00	I00
Lecanora expallens	I00	I00	I00	I00
Lecidea scalaris	55	40	60	-
Ochrolechia androgyna	85	I0	I5	-
Ochrolechia turneri	5	-	-	-
Lecidea quernea	60	60	60	I00
Catillaria griffithi	45	70	I00	I00
Cetraria glauca	85	40	40	I0
Hypogymnia physodes	I00	60	70	I0
H. tubulosa	I00	85	45	30
Evernia prunastri	I00	55	85	I5
Parmelia saxatilis	90	70	I00	55
P. sulcata	80	I0	25	-
P. glabratula	20	20	20	I0
P. subaurifera	30	35	I5	40
Toninia caradocensis	I0	I0	I5	I0
Pertusaria amara	40	45	I0	25
P. albescens	20	-	-	I0
P. pertusa	I0	55	35	45
P. hemisphaerica	45	65	60	60
Lecanactis abietina	I0	45	65	I00
Calicium viride	I5	25	70	I00
Chaenotheca ferruginea	25	60	80	I00
Lepraria candelaris	-	I0	-	60
Parmelia ambigua	70	25	75	25
Lecanora chlarona	I5	-	5	-
Arthonia spp.	20	45	I5	55
Phlyctis argena	20	45	I5	25
Thelotrema lepadinum	-	I0	-	I5
Usnea subfloridana	25	5	-	-
Opegrapha vermicellifera	-	45	-	65
Alectoria fuscescens	I0	-	-	-
Lecanora chlarotera	-	-	-	-
Pertusaria hymenea	-	-	-	-
Cetraria chlorophylla	-	-	-	-
Gyalects flotowii	-	-	-	-
Species totals	30	29	26	26
Total frequency	I490	I3I5	I375	I3I5

TABLE XXIII : % Frequency of lichens on (a) N. side, and (b) S. side of trees in I0 m. lengths down the valley side. Transect IX.

	(a)		(b)	
	0- IO	IO- stream	0- IO	IO- stream
Lecanora conizaeoides	I00	30	90	60
Lepraria incana	I00	I00	I00	45
Lecanora expallens	90	90	I00	85
Lecidea scalaris	40	-	I5	IO
Ochrolechia androgyna	40	I5	30	20
O. turneri	IO	-	-	-
Lecidea quernea	IO	55	20	I00
Catillaria griffithi	60	85	70	80
Cetraria glauca	60	20	20	20
Hypogymnia physodes	I00	35	90	25
H. tubulosa	85	40	60	I5
Evernia prunastri	90	25	60	I5
Parmelia saxatilis	I00	65	65	65
P. sulcata	40	20	-	5
P. glabratula	20	30	30	20
P. subaurifera	30	30	45	30
Toninia caradocensis	35	-	30	-
Pertusaria amara	60	40	35	30
P. albescens	50	50	30	60
P. pertusa	40	55	20	50
P. hemisphaerica	20	65	30	I5
Lecanactis abietina	I5	60	85	I00
Calicium viride	20	55	60	85
Chaenotheca ferruginea	40	75	90	I00
Lepraria candelaris	-	20	25	65
Parmeliopsis ambigua	65	45	80	I5
Lecanora chlarona	30	-	-	-
Arthonia spp.	IO	35	20	45
Phlyctis argena	IO	70	20	20
Thelotrema lepadinum	-	I5	-	20
Usnea subfloridana	IO	-	IO	-
Opegrapha vermicellifera	IO	35	20	35
Alectoria fuscescens	20	-	-	-
Lecanora chlarotera	-	-	-	-
Pertusaria hymenea	-	-	-	-
Cetraria chlorophylla	-	-	-	-
Gyalecta flotowii	-	-	-	5
Species totals	3I	27	28	29
Total frequency	I4I0	I250	I350	I290

TABLE XXIV : % Frequency of lichens on (a) S. side, and (b) N. side of trees in IO m. lengths down the valley-side. Transect X.

	0- I0	I0- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80	80- 90	90- stream	r
Pertusaria amara	-	5	-	35	40	50	50	80	75	70	+0.955
Cetraria glauca	-	-	-	5	20	20	40	45	50	55	+0.943
Evernia prunastri	I5	50	60	I00	95	I00	I00	I00	75	90	+0.94I
Parmelia sulcata	-	20	40	65	40	60	65	60	65	65	+0.925
Alectoria fuscescens	-	-	-	-	-	I0	-	20	25	I5	+0.907
Hypogymnia tubulosa	30	70	55	80	80	I00	I00	90	80	75	+0.897
Usnea subfloridana	-	-	-	I0	5	25	35	40	45	35	+0.896
Parmelia saxatilis	70	80	85	90	I00	I00	I00	I00	I00	I00	+0.887
Pertusar albescens	-	-	I0	20	60	60	40	60	55	40	+0.863
Lecanora chlarotera	-	-	I0	20	30	I5	45	30	35	50	+0.84I
Hypogymnia physodes	70	80	80	85	I00	I00	I00	90	I00	I00	+0.82I
Parmelia subaurifera	-	-	20	25	50	30	35	60	45	40	+0.8I3
Calicium viride	I0	20	50	45	50	45	40	50	35	30	+0.750
Catillaria griffithi	-	20	20	20	25	25	25	25	20	25	+0.742
Cetraria chlorophylla	-	-	-	-	20	25	25	I0	25	5	+0.726
Pertusaria pertusa	20	I0	20	60	75	45	80	80	80	80	+0.7I5
Chaenotheca ferruginea	5	45	30	25	50	45	40	40	35	35	+0.7I3
Arthonia spp.	-	-	-	-	5	5	I5	-	-	I5	+0.682
Parmelia glabratula	-	-	I0	-	30	-	-	I5	I0	20	+0.633
Lecanora chlarona	-	-	-	35	I0	50	55	40	40	I5	+0.620
Ledanactis abietina	-	I0	30	25	20	45	30	25	25	25	+0.6I8
Pertusaria hymenea	-	-	-	-	30	40	I5	20	25	I5	+0.509
Lecanora expallens	60	75	I00	85	I00	I00	95	I00	85	90	+0.498
Phlyctis argena	-	-	I0	5	I0	-	I5	5	20	I0	+0.409
Opegrapha vermicellifera	-	-	20	-	-	I5	-	-	20	I5	+0.350
Lecidea quernea	I5	-	40	60	30	40	35	20	30	30	+0.344
Lepraria candelaris	-	-	-	-	-	-	20	-	I6	-	+0.339
Pertusaria hemisphaerica	-	I5	20	-	20	I5	I5	I5	-	25	+0.299
Lepraria incana	90	I00	I00	I00	I00	I00	I00	I00	95	95	+0.I7I
Thelotrema lepadinum	-	-	-	-	-	-	-	-	-	-	0
Gyalecta flotowii	-	-	-	-	-	-	-	-	-	-	0
Ochrolechia androgyna	I0	90	50	45	55	40	35	40	50	35	-0.I63
Lecidea scalaris	30	45	30	5	-	I0	20	-	30	35	-0.3I9
Parmeliopsis ambigua	25	20	35	30	-	20	25	I5	-	-	-0.575
Ochrolechia turneri	30	20	-	-	20	-	I0	-	5	-	-0.672
Toninia caradocensis	50	60	75	50	45	30	I5	I5	-	20	-0.825
Lecanora conizaeoides	I00	I00	90	80	80	60	35	40	30	30	-0.923
Species totals	I6	20	25	26	30	3I	32	30	3I	32	
Total frequency	630	935	I090	I205	I375	I425	I455	I460	I505	I420	

TABLE XXV : % Frequency of lichens on E. sides of trees in I0 m. lengths down the valley side : Transect XI.

	0- I0	I0- 20	20- 30	30- 40	40- 50	50- 60	60- 70	70- 80	80- 90	90- stream	r
Pertusaria albescens	I0	20	35	50	80	95	70	I00	90	85	+0.904
P. pertusa	35	70	80	65	65	85	75	80	70	80	+0.840
Evernia prunastri	50	90	I00	I00	I00	I00	95	90	85	I00	+0.863
Cetraria chlorophylla	-	I0	I5	40	40	35	40	60	40	40	+0.854
Parmelia subaurifera	-	I5	60	45	50	35	45	60	60	55	+0.840
Pertusaria hymenea	-	I0	-	20	I5	40	35	30	20	25	+0.840
Cetraria glauca	5	20	50	40	65	45	45	55	60	60	+0.839
Catillaria griffithi	-	20	30	35	40	45	30	50	35	35	+0.833
Pertusaria amara	40	45	60	65	80	70	80	75	75	80	+0.737
Alectoria fuscescens	-	I0	I0	30	20	I5	20	I5	30	I0	+0.72I
Chaenotheca ferruginea	20	20	20	5	20	40	30	40	40	35	+0.703
Lecidea guernea	I0	I5	30	80	I00	70	45	80	85	75	+0.698
Usnea subfloridana	-	-	20	35	60	50	35	25	50	50	+0.667
Lecanactis abietina	I0	20	35	40	40	25	50	35	35	35	+0.648
Calicium viride	25	30	30	I5	25	40	35	30	35	35	+0.506
Phlyctis argena	-	-	-	25	-	25	-	20	I5	20	+0.502
Lepraria candelaris	-	-	-	-	-	I5	-	-	I0	-	+0.432
Parmelia sulcata	45	25	60	50	75	50	65	60	60	60	+0.4I4
Lecanora chlarona	20	-	20	35	30	30	25	20	I5	30	+0.408
Parmelia glabratula	-	20	I0	35	30	45	25	30	30	25	+0.374
Lecanora expallens	70	90	I00	I00	85	I00	I00	95	95	95	+0.236
Pertusaria hemisphaerica	-	20	30	25	20	30	20	I0	20	25	+0.20I
Arthonia app.	-	-	I5	I5	-	20	-	5	I0	5	+0.I50
Lepraria incana	I00	I00	I00	95	I00	I00	I00	I00	I00	I00	+0.I27
Thelotrema lepadinum	-	-	-	-	-	-	-	-	-	-	0.
Gyalecta flotowii	-	-	-	-	-	-	-	-	-	-	0
Lecanora chlarotera	20	40	35	25	40	35	20	I5	30	35	-0.049
Opegrapha vermicellifera	I0	5	30	-	I0	I0	I0	-	I5	20	-0.I2I
Parmelia saxatilis	I00	I00	85	I00	I00	65	I00	I00	I00	95	-0.207
Hypogymnia tubulosa	85	95	I00	75	80	80	90	I00	95	90	-0.228
H. physodes	I00	I00	80	I00	85	95	I00	I00	I00	95	-0.275
Ochrolechia turneri	30	-	20	I0	-	I5	I0	-	-	-	-0.497
Parmeliopsis ambigua	40	25	30	20	I5	I5	20	I0	I5	20	-0.5I5
Lecidea scalaris	60	30	45	I0	20	-	20	25	30	20	-0.62I
Toninia caradocensis	60	40	20	20	I5	I0	-	30	30	25	-0.69I
Ochrolechia androgyna	70	95	60	60	20	55	40	35	30	25	-0.749
Lecanora conizaeoides	90	75	60	60	35	30	40	35	25	40	-0.752
Species totals	24	29	32	33	3I	34	3I	32	34	33	
Total frequency	II05	I255	I475	I525	I560	I595	I5I5	I6I5	I605	I625	

TABLE XXVI : % Frequency of lichens on W. sides of trees in I0 m. lengths down the valley side : Transect XI.

another. This is to be expected, as total frequency is, in part, a measure of species numbers. However, the T.F.V. also incorporates information on the 'commonness' of the lichen species which are present, and is therefore a more comprehensive and sensitive statistic than numbers of species. This is apparent from studying Fig. 18, and Figs. 19-21, in which it can be seen that the downslope changes in species numbers and T.F.V. are very similar. However, the figures for species numbers are more uniform (few values outside the range 27-33 were recorded); and the variations which do occur tend to be irregular, and lacking in pattern. T.F.V.s, by comparison, vary significantly and rationally, and as they include an additional factor which measures the frequency of lichen species, the changes in T.F.V. are thought to provide a more useful guide to overall downslope changes in the lichen flora than figures on species numbers.

Fig. 19 plots the changes in T.F.V. for transects I-V (E. and W. sides). As outlined previously, T.F.V.s - are fairly constant towards the floor of the ravine - and this is particularly well seen in Fig. 19. For all 5 transects, and regardless of distribution/aspect phenomena, between 50-60 m. and the bottom of the valley T.F.V.s occur rarely outside the range 1150-1300. From 0 m. to 50-60 m., there is considerable variation in the T.F.V.s of the 4 sets of amalgamated results. Transects I, II and V (E.) show a steep rise from a figure of 735 at 0 m., until the graph flattens out to the "constant level" of 1150-1300 at about 40-50 m. Transects III and IV (W.)

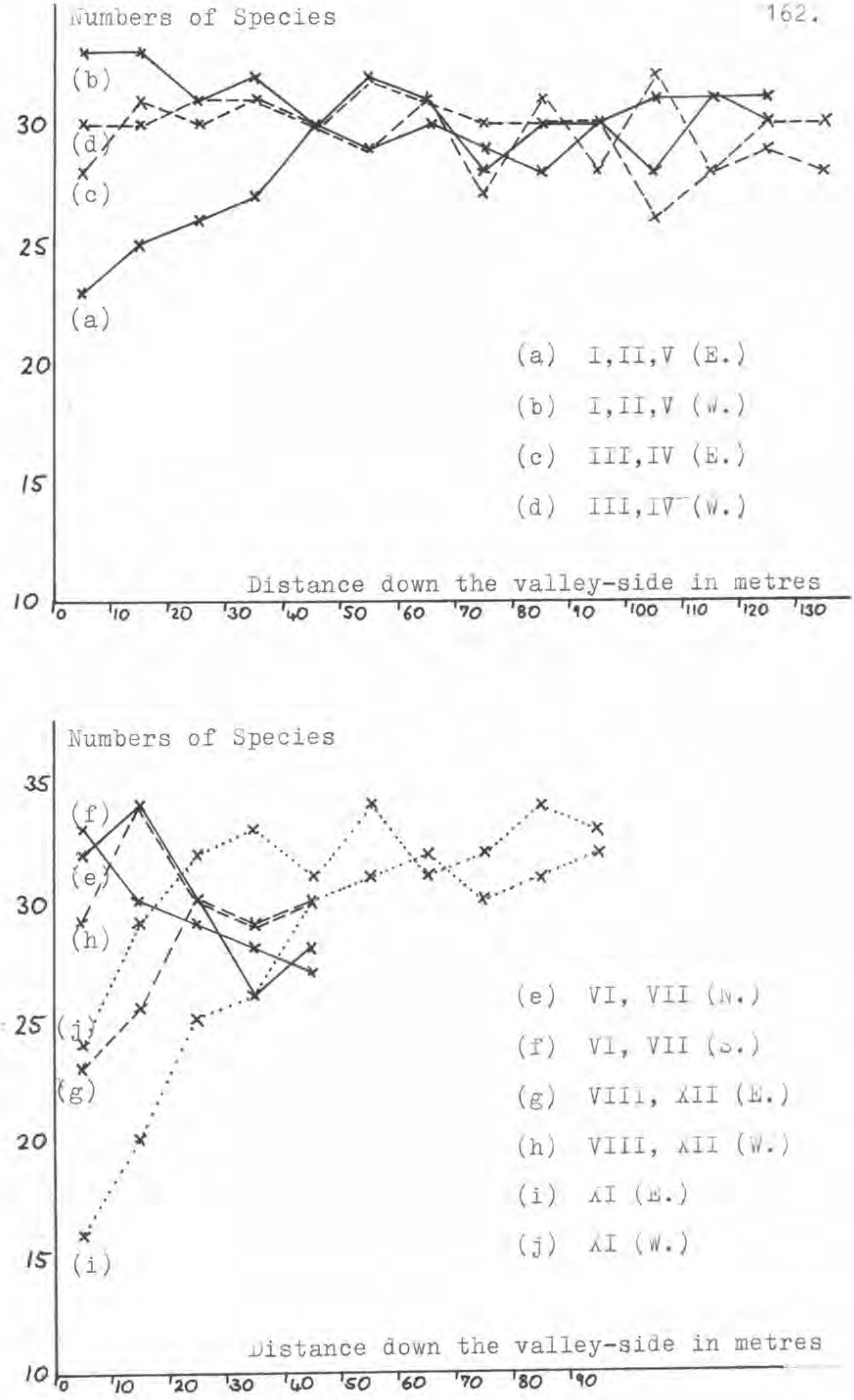


Fig 18 : The Variation in Numbers of Species along all the Transects.

display the opposite pattern, with the T.F.V. falling steadily from 1505 at 0 m. to 1210 at 30-40 m., and then remaining steady at the constant level. The first part of transects I, II, V (W.) and III, IV (E.) are fairly similar: the T.F.V.s of both increase initially between 0 m. and about 30 m., and then fall between about 40 m. and 60-70 m. before attaining the constant level.

Fig. 20 shows the variation in T.F.V.s for the 4 short transects: VI, VII, VIII, and XII. Again, a constant level of 1150-1300 may be recognised: between 40 and 50 m. all 4 values on the graph lie between 1150 and 1250, despite the fact that the T.F.V.s for the first (0-10 m.) section of slope are as different as 940 in the case of VIII and XII (E.) and 1835 for transects VI and VII (S.). As before, there is considerable variation in the slopes of the T.F.V. curves between 0 and 40-50 m. Transects VI and VII (N.) and VI and VII (S.) both decline from high values (1600 and 1835 respectively) and flatten out at about the 40-50 mark. Transects VIII and XII (E.) have a T.F.V. of 940 at 0-10 m., which increases to 1350 at 20-30 m., and then drops to the constant level. Transects VIII and XII (W.) start at 1435, rise to 1565, and then decrease steadily to 1240 at 40-50 m.

Fig. 21 presents the T.F.V curves for transect XI. Both sets of results begin at low levels at 0 m. (1105 for XI W., 630 for XI E.), and then increase steadily until 50-60 m., at which point the T.F.V.s are more nearly equal (1595 for XI W., 1425 for XI E.). Then the T.F.V.s become approximately constant and the curves flatten - varying

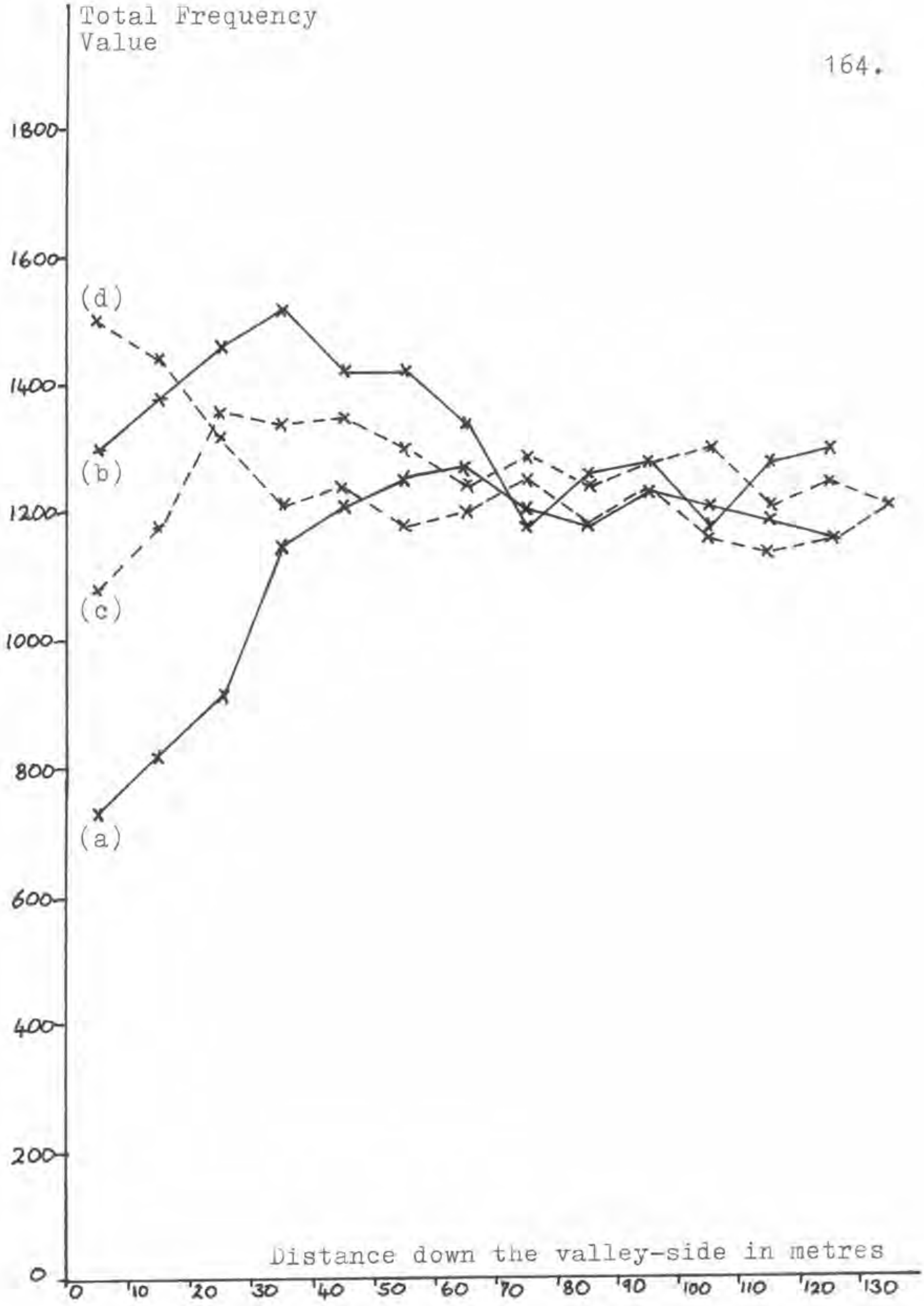


Fig 19 : The Variation in T.F.V.s along :-

(a) I, II, V (E.)

(b) I, II, V (W.)

(c) III, IV (E.)

(d) III, IV (W.)

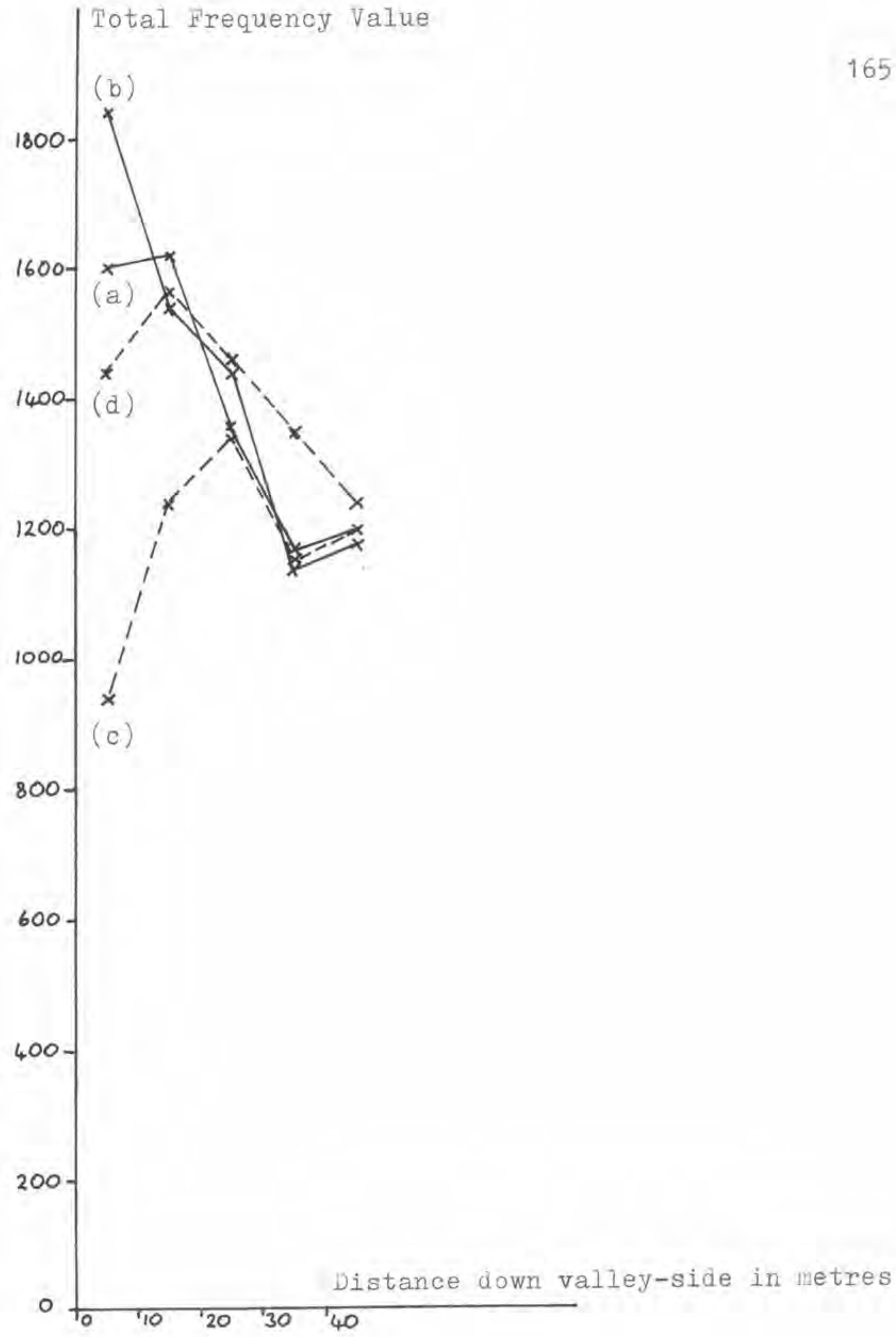


Fig. 20 : The Variation in T.F.V.s along :-

(a) VI, VII (N.)

(b) VI, VII, (S.)

(c) VIII, XII (E.)

(d) VIII, XII (W.)

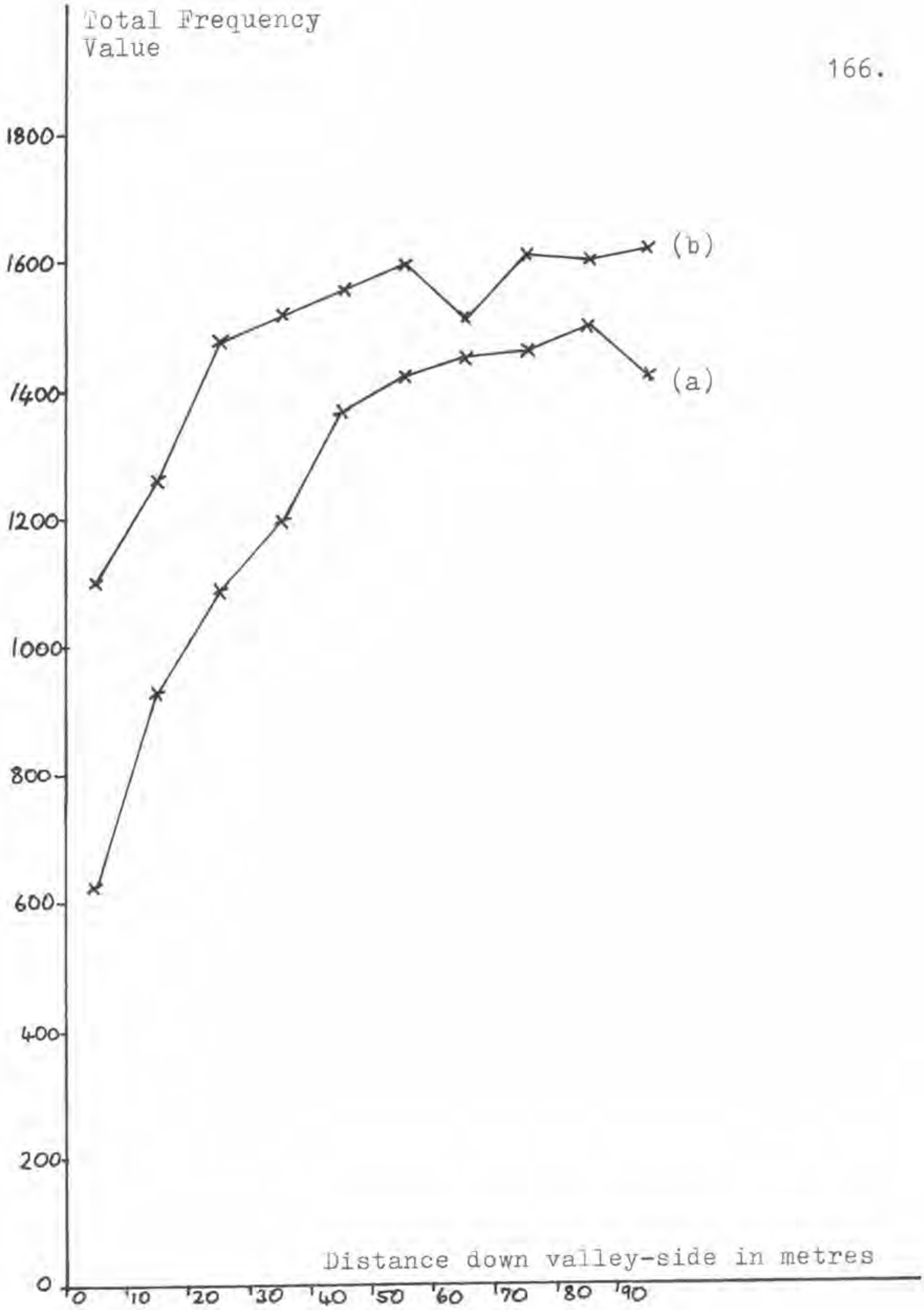


Fig. 21 : The Variation in T.F.V.s along :-

(a) XI (E.)

(b) XI (W.)

around a mean of about 1590 for XI W., and around 1470 for XI E.

The patterns of gross downslope variation in the lichen vegetation of Horsley Hope Ravine have been outlined above, by reference to simple graphs and brief explanatory notes. To examine, in similar detail, the changes in the distribution of individual lichen species with distance down the valley-side for each transect, would obviously be a laborious and not necessarily rewarding task. For this reason, a different approach has been adopted. Correlation coefficients (r) were calculated to show the relationship between changes in % frequency of each species with distance along the transects (except for transects IX and X which were too short to permit the calculation of correlation coefficients.) The r values express the degree of relationship between the frequency of a lichen species and distance down the valley-side. If r = +1, then there is a perfect relationship between the increase in % frequency of a lichen species and distance down the valley-side. If r = -1 then there is a steady and regular decline in the occurrence of a species towards the foot of a slope. If r = 0, then the downslope distribution of that lichen species bears no relation to slope position.

Correlation coefficients were worked out and entered under column 'r' on each table, alongside the species for which they were caluclated. Each lichen species in each table was then ranked according to its r value, and TABLES XV - XXVI are prepared in descending species r value rank order.

Significance levels of r at .05% significance level were obtained from statistical tables, according to the number of samples i.e. the number of % frequency results used in calculating r. Thus, for example, in TABLE XVI, the number of % frequency results = 13, and at a significance level of .05%, for 13 samples, r = significant at 0.514. So, where r for a species is greater than +0.514 or less than -0.514, then there is a significant positive or negative correlation between species % frequency and distance down the valley-side.

Gaps have been introduced into the tables to show where the levels of significance occur. For instance, in TABLE XVI there is a gap between Catillaria griffithi (r = +0.516) and Thelotrema lepadinum (r = +0.506) showing that the correlation coefficient of species above this gap in the table are statistically significant; and a gap between Parmelia subaurifera (r = -0.493) and Ochrolechia turneri (r = -0.599) as values of r less then -0.514 are significantly negatively correlated with distance downslope. For the 9 species with r values between +0.514 and -0.514, r is not statistically significant, and the variation in % frequency of each of these species may not be related to to distance down the valley-side.

In certain cases, r values may be misleading. For example, a high positive correlation coefficient does not necessarily imply that a lichen species becomes gradually more frequent towards the floor of the ravine. In TABLE XVI, Lecanactis abietina has an r value of +0.962, yet the % frequency of this species only increases between 0 and

60 m. Between 60 and 132 m. the % frequency of Lecanactis abietina is more or less constant. Similarly, Hypogymnia physodes in TABLE XV has an r value of -0.566 implying that H. physodes declines in frequency down transects I, II, and V (E.). In fact, the occurrence of this species increases from 0-30 m., then stays constant between 30 and 60 m., and declines from 60 m. to the bottom of the slope. However, in general the correlation coefficients are indicative of the distribution pattern of each lichen species with respect to distance downslope.

It can be seen from TABLES XV-- XXVI that there is a considerable degree of variation in the number of significant r values for each set of transects. For example, for transects I, II and V (E.), 18 species are positively correlated with distance downslope and 9 species are negatively correlated; but in transects VI and VII (N.), 9 species are positively correlated and 17 negatively correlated - almost the reverse situation. Agein, in transects VIII and XII (E.) only 20 species have any statistically significant relationship with distance downslope, but in transects III and IV (W.) the variation in % frequency of as many as 30 species may be statistically related to distance down the valley-side.

As a further complication, it may be noted that the r values of different species are not necessarily similar from one table to the next. Thus, for instance, while Lecanora conizaeoides displays a significant negative r with distance downslope on every table; the % frequency of Pertusaria amara increases significantly (+0.639) with slope in transects I, II and V (E.), yet decreases significantly (-0.932) with slope in transects VI and VII (N.). In an attempt to make this situation more comprehensible, and because the % frequencies of most species follow a characteristic downslope pattern from one transect to the next, mean r values of % frequencies and distance downslope for each species on all transects are presented in TABLE XXVII. These means were obtained by summing the r values of each species in every table, and dividing by the number of tables. The mean r values for transect XI are separated from the means for the other transects, because transect XI was carried out under different conditions (see above).

The mean correlation coefficients of a species measures the overall variation in % frequency of a species with distance downslope for all the transects. At a significance level of .05%, r is significant at values greater then +0.349 or less than -0.349 (the sample size is 33). In TABLE XXVII, the mean r values are sorted into groups according to this significance level. Thus:

Group 1 - comprises species with a significant negative mean r value in both transects I-X and XII, and XI.

Group 2 - comprises species with a significant positive mean r value in both sets of transects.

Group 3 - includes lichens which are negatively correlated with distance downslope in transects I-X and XII, and positively correlated in transect XI.

Group 4 - contains species which show no statistical

	Mean r of species % frequencies for all transects, except XI	Mean r of species % frequencies for transect XI	
Lecanora conizaeoides	-0.950	-0.837	GROUP I
Toninia caradocensis	-0.68I	-0.785	
Lecidea scalaris	-0.9I8	-0.47I	
Ochrolechia turneri	-0.69I	-0.585	
O. androgyna	-0.783	-0.456	
Parmeliopsis ambigua	-0.63I	-0.545	
Chaenotheca ferruginea	+0.826	+0.708	GROUP 2
Lecanactis abietina	+0.844	+0.633	
Catillaria griffithi	+0.788	+0.687	
Lecidea quernea	+0.8I5	+0.524	
Calicium viride	+0.682	+0.628	
Arthonia spp.	+0.73I	+0.4I6	
Phlyctis argena	+0.52I	+0.555	
Evernia prunastri	-0.769	+0.902	GROUP 3
Cetraria glauca	-0.536	+0.889	
Alectoria fuscescens	-0.580	+0.782	
Hypogymnia physodes	-0.872	+0.448	
Parmelia sulcata	-0.667	+0.669	
Cetraria chlorophylla	-0.506	+0.792	
Lecanora chlarona	-0.6II	+0.5I4	
Pertusaria hymenea	-0.387	+0.674	
Pertusaria albescens	+0.346	+0.883	GROUP 4
P. amara	-0.044	+0.846	
Parmelia subaurifera	+0.329	+0.826	
Pertusaria pertusa	+0.2I6	+0.79I	
Usnea subfloridana	-0.026	+0.782	
Parmelia glabratula	+0.243	+0.503	
Lecanora chlarotera	-0.2I6	+0.396	
Opegrapha vermicellifera	+0.7I9	+0.II0	GROUP 5
Lepraria candelaris	+0.665	+0.339	
Thelotrema lepadinum	+0.584	0	
Pertusaria hemisphaerica	+0.453	+0.250	
Gyalecta flotowii	+0.433	0	
Hypogymnia tubulosa	-0.862	+0.335	GROUP 6
Parmelia saxatilis	-0.599	+0.340	
Lepraria incana	+0.003	+0.I49	GROUP 7
Lecanora expallens	-0.I02	+0.3I8	

TABLE XXVIII : Mean r of species % frequencies and distance down slope for the transects.

relationship with distance downslope in transects I-X and XII, but are positively correlated in transect XI.

Group 5 - is the reverse of Group 4.

Group 6 - comprises species with a significant negative mean r value in the first column, but with a non-significant mean r value in the second column.

Group 7 - these two species show no statistical relationship with distance downslope in either set of transects.

Lichen species belonging to the same group may be considered to show a broadly similar pattern of downslope distribution on most of the transects. Obviously there are exceptions to this - and these will be discussed more fully in the following chapter.

Downslope changes in the lichen flora of Horsley Hope Ravine are thus complex - the % frequencies of different species decline, increase, or follow an irregular pattern with distance down the valley-side; and these distribution phenomena may vary from transect to transect. Reflecting these changes, the summed values - species numbers and total frequency - also fluctuate significantly.

C) The Distribution of Lichens in Relation to Aspect

Two important features relating to aspect emerge from the results of the transects. These are described below :-

(i) As mentioned previously, species numbers and T.F.V.s show no relationship with tree trunk aspect on the floor of the ravine (from about 40-50 m. to the stream). Irrespective of aspect, species numbers are in the range

27-33 species per 10 m. length of valley-side, and T.F.V.s maintain a constant level of 1150-1300 (except in transect XI, where the T.F.V. averages 1450-1600). Between 0 and about 40 m., however, species numbers and T.F.V.s vary considerably. It is noticeable that figures for the E. sides of trees - transects I, II, V (E.), III, IV (E.), VIII, XII (E.) and XI (E.) - in the sections 0-40 m., are almost invariably lower than the values recorded for the N. S. or W. sides of trees.

(ii) Although gross values of lichen performance show little or no correlation with aspect, the distribution of individual species is significantly related to aspect. This fact enabled N.-S. or E.-W. patterns of lichen distribution to be clearly recognised. For each transect, the distribution of lichens with respect to aspect was consistently either N.-S. or E.-W. in pattern. This circumstance varied for only a few trees, so that the lichen/aspect pattern of the transects could be readily categorised as N.-S. or E.-W.

It is apparent from the descriptions of the transects given previously that E.-W. patterns of lichen distribution obtained only on slopes which were E. or W. facing. Similarly, N.-S. patterns of lichen distribution occurred only on transects with slope aspects of around either 0^o or 180^o. Thus, it was concluded that the pattern of lichen distribution was related to slope aspect - where the slope faced E. or W.; then the lichen distribution pattern was oriented E.-W., when the slope aspect was N. or S., then the pattern of lichen distribution responded accordingly.

To fully describe the results obtained, it is necessary to examine this concept further. Figs. 22 and 23 plot the variation in % frequency of two species - Lecanactis abietina and Phlyctis argena - along transects I, II and V, and III and IV. Fig 22 shows that in transects I, II and V (W.-facing slope), L. abietina occurs abundantly on the on the W. sides of trees, but is much less common on the E. sides. P. argena, on the other hand, clearly prefers the E. sides of trees and is not frequent on the W. sides. Fig. 23 shows that in transects III and IV (E. facing slope) this pattern is reversed. Thus, L. abietina occurs on nearly all the E. sides of trees in transects III and IV, but is rarely seen on more than 40% of the W. sides of trees; while the distribution of P. argena shows a strong affinity with the W. sides of trees in these two transects - in marked contrast to the results observed in transects I, II and V.

The distribution of other species exhibits a similar pattern - for example, Calicium viride behaves like L. abietina, being abundant on the W. sides of trees in I, II and V, and uncommon on the E. sides - but showing a reversal of this pattern in transects III and IV.

Where the slope aspect is N. or S., the same phenomenon occurs. Thus, in transect IX (S. facing slope) L. abietina and C. viride are more frequent on the S. sides of trees, and P. argena more frequent on the N. sides. Transect X (N. facing slope) shows a reversal of this pattern.

It is therefore apparent that the distribution of

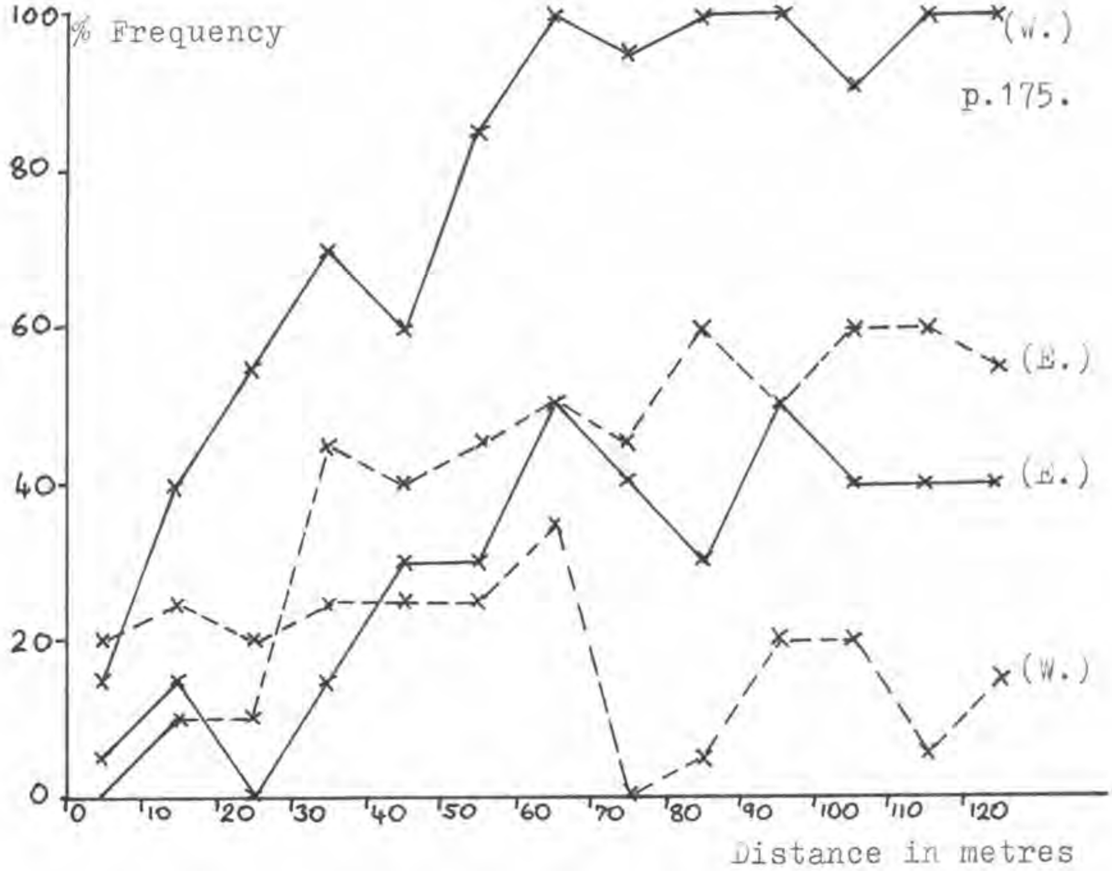


Fig. 22 : Distribution of Lecanactis abietina (——) and Phlyctis argena (– – –) along transects I, II, V.

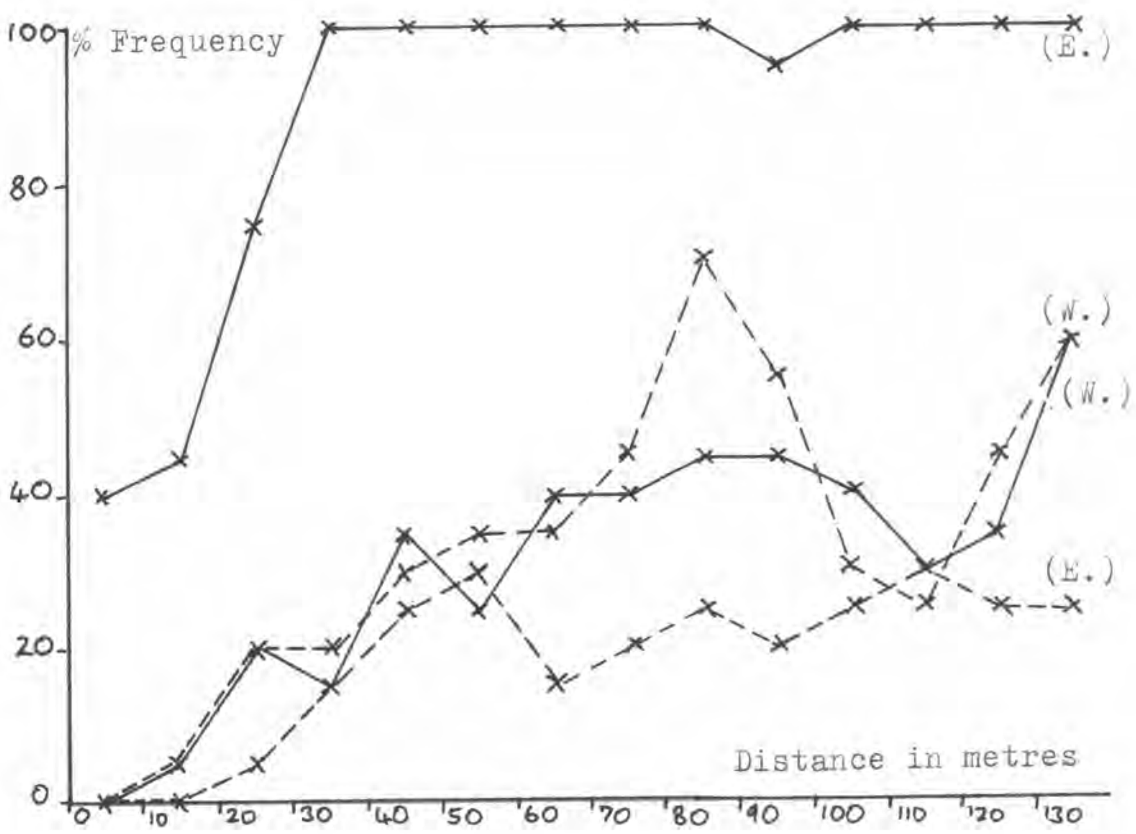


Fig. 23 : Distribution of Lecanactis abietina (——) and Phlyctis argena (– – –) along transects III, IV.

corticolous lichen species is related to slope aspect in a more complex manner than simply in terms of whether the distribution pattern is generally oriented in a N.-S. or E.-W. direction. Reference to the above examples shows that Lecanactis abietina always 'prefers' the sides of trees which face downslope. That is, if the slope aspect is N., L. abietina occurs predominantly on the N. sides of trees; if the slope aspect is W., this species favours the W. sides of trees. L. abietina may thus be said to be more frequent on the downslope sides of trees in all transects. Conversely, P. argena is more abundant on the E. sides of trees in I, II, and V (W.-facing slopes), on the W. sides in III and IV (E.-facing), on the N. sides in IX (S.-facing), and on the S. sides in X (S.-facing slopes). P. argena may therefore be described as a species consistently favouring the upslope sides of trees.

In TABLE XXVIII the summed % frequencies for each species on each transect have been totalled and sorted into two categories. Column A shows the summed % frequencies of species for the downslope sides of trees on all transects. Column B shows the summed % frequencies of species from the upslope sides of trees in all transects. Column $\frac{A}{B}$ measures, for each species, its preferred position on the tree with respect to trunk aspect. Values greater than 1 in column $\frac{A}{B}$ imply that a species is concentrated on the downslope sides of trees; values less than 1 show that a species is more frequent on the upslope sides of trees. The lichen species have been ranked in descending $\frac{A}{B}$ order, and class intervals established (every 0.2 units) to show

	A : Summed % frequencies of species on downslope sides of trees	B : Summed % frequencies of species on upslope sides of trees	$\frac{A}{B}$ or $\frac{\text{Downslope side}}{\text{Upslope side}}$
Lepraria candelaris	I070	I35	7.93
Calicium viride	2830	I0I5	2.79
Lecanactis abietina	2820	I045	2.77
Chaneotheca ferruginea	2670	II80	2.26
Pertusaria hymenea	50	30	I.66
Cetraria chlorophylla	II5	75	I.53
Pertusaria albescens	I780	I390	I.28
Lecanora chlarotera	280	235	I.28
Catillaria griffithi	2950	2370	I.24
Pertusaria pertusa	I985	I675	I.I8
Gyalecta flotowii	80	70	I.I4
Pertusaria amara	I745	I535	I.I4
Parmeliopsis ambigua	745	625	I.I3
Lecidea quernea	2540	2270	I.I2
Lecanora expallens	3370	3I75	I.06
Lepraria incana	3545	3480	I.0I
Toninia caradocensis	605	6I0	0.99
Evernia prunastri	I795	I850	0.97
Usnea subfloridana	225	235	0.96
Lecidea scalaris	I095	II50	0.95
Arthonia spp.	7I5	800	0.89
Hypogymnia physodes	2II0	2375	0.88
Parmelia sulcata	I445	I675	0.86
Hypogymnia tubulosa	I675	I955	0.85
Parmelia subaurifera	770	905	0.85
Lecanora conizaeoides	I490	I775	0.84
Parmelia saxatilis	2080	2505	0.83
Opegrapha vermicallifera	630	745	0.83
Pertusaria hemisphaerica	I325	I655	0.80
Ochrolechia androgyna	955	II90	0.80
Ochrolechia turneri	225	305	0.74
Cetraria glauca	335	455	0.74
Thelotrema lepadinum	530	8I0	0.65
Alectoria fuseescens	75	I20	0.62
Lecanora chlarona	260	430	0.60
Parmelia glabratula	5I5	905	0.56
Phlyctis argena	695	I325	0.52

TABLE XXVIII : Summed % Frequencies of Species on the Upslope and Downslope Sides of Trees, and Comparison of these Values.

A : Transects I, II, V, VIII, XII (W. side); III, IV (E. side); VI, VII, IX (S. side); X (N. side).

B : Transects I, II, V, VIII, XII (E. side); III, IV (W. side); VI, VII, IX (N. side); X (S. side).

groups of species with certain degrees of preference for the upslope or downslope sides of trees in Horsley Hope Ravine. It is obvious that certain species have a marked preference for either the upslope or downslope sides of trees (and are therefore in the lower or upper sections of the table, respectively), while other species are less closely related to slope aspect. It is the varying distribution pattern of these lichens shown to be strongly 'upslope species' or 'downslope species' which causes the significant response to aspect which is so noticeable in the different transects undertaken in Horsley Hope Ravine.

4. Angle and Direction of Tree Inclination

As explained in Chapter III, when sampling along the 12 transects, the angle and direction of inclination were measured, for each tree sampled. These results are not set out in detail, as a few facts and figures will serve to outline the general trends of tree angle and direction of inclination in Horsley Hope Ravine.

The steep slopes of the ravine caused the great majority of trees to be inclined towards the floor of the ravine. Thus, the direction of inclination of trees was predominantly downslope, in line with the slope aspect.

Many trees in the ravine were leaning at an angle exceeding 15°, and were thus excluded from the sample. Of those trees which were included, 97.8% were inclined at an angle greater than 2° in the downslope direction, and 86.2% were inclined at an angle between 5° and 15°

in the downslope direction. It may thus be concluded that the general pattern of tree angle and direction of inclination in Horsley Hope Ravine is one of trees leaning downslope at an angle exceeding 2^{o}.

5. Atmospheric Pollution

The following results were obtained for the work carried out on atmospheric pollution:

A) Average SO2 Concentrations in the Area

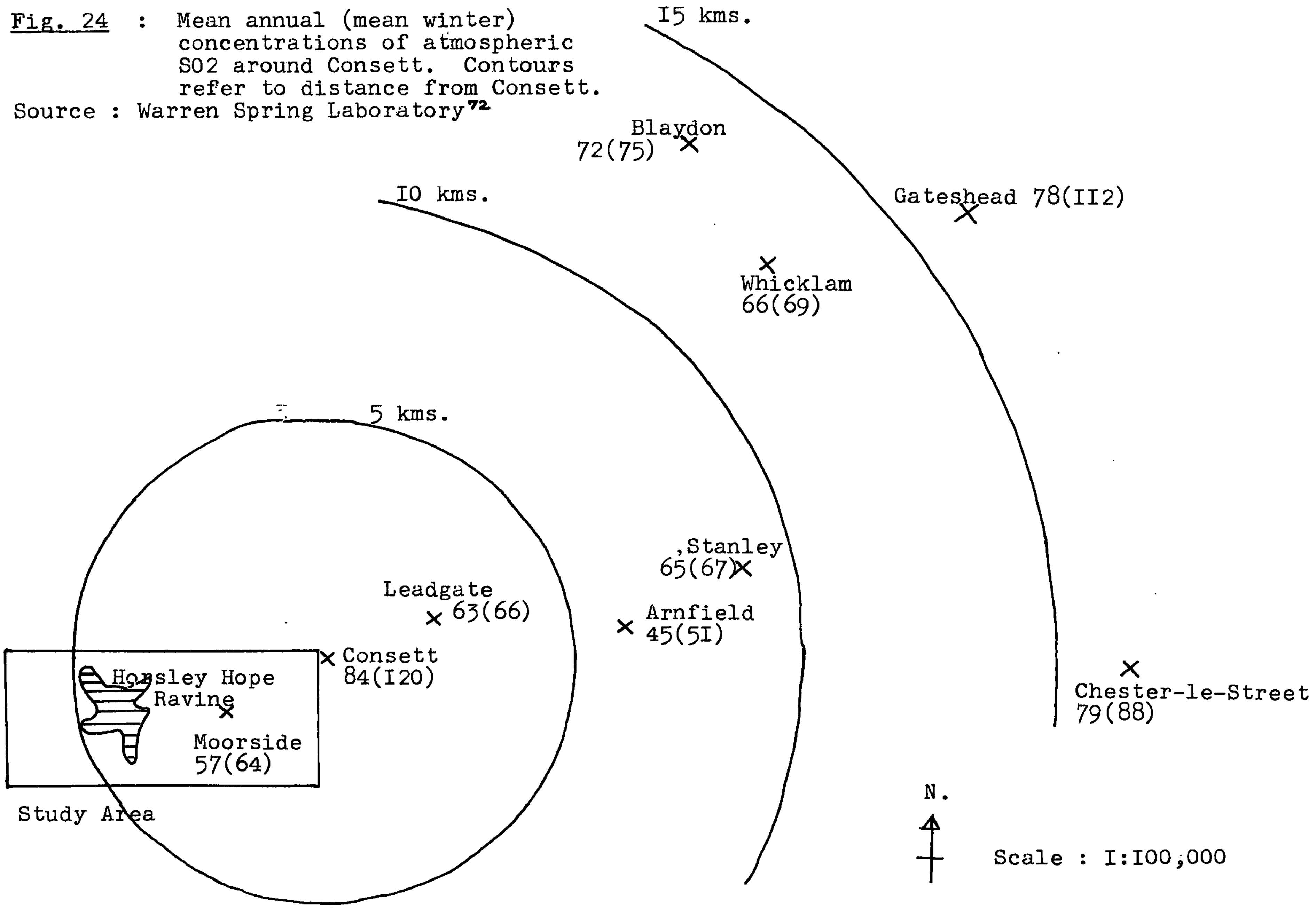
Fig. 24 shows the distribution of measurements of mean SO2 obtained by the National Survey of Smoke and Sulphur Dioxide[92] in the Consett area. These figures provide background information on SO2 levels in and around the study area.

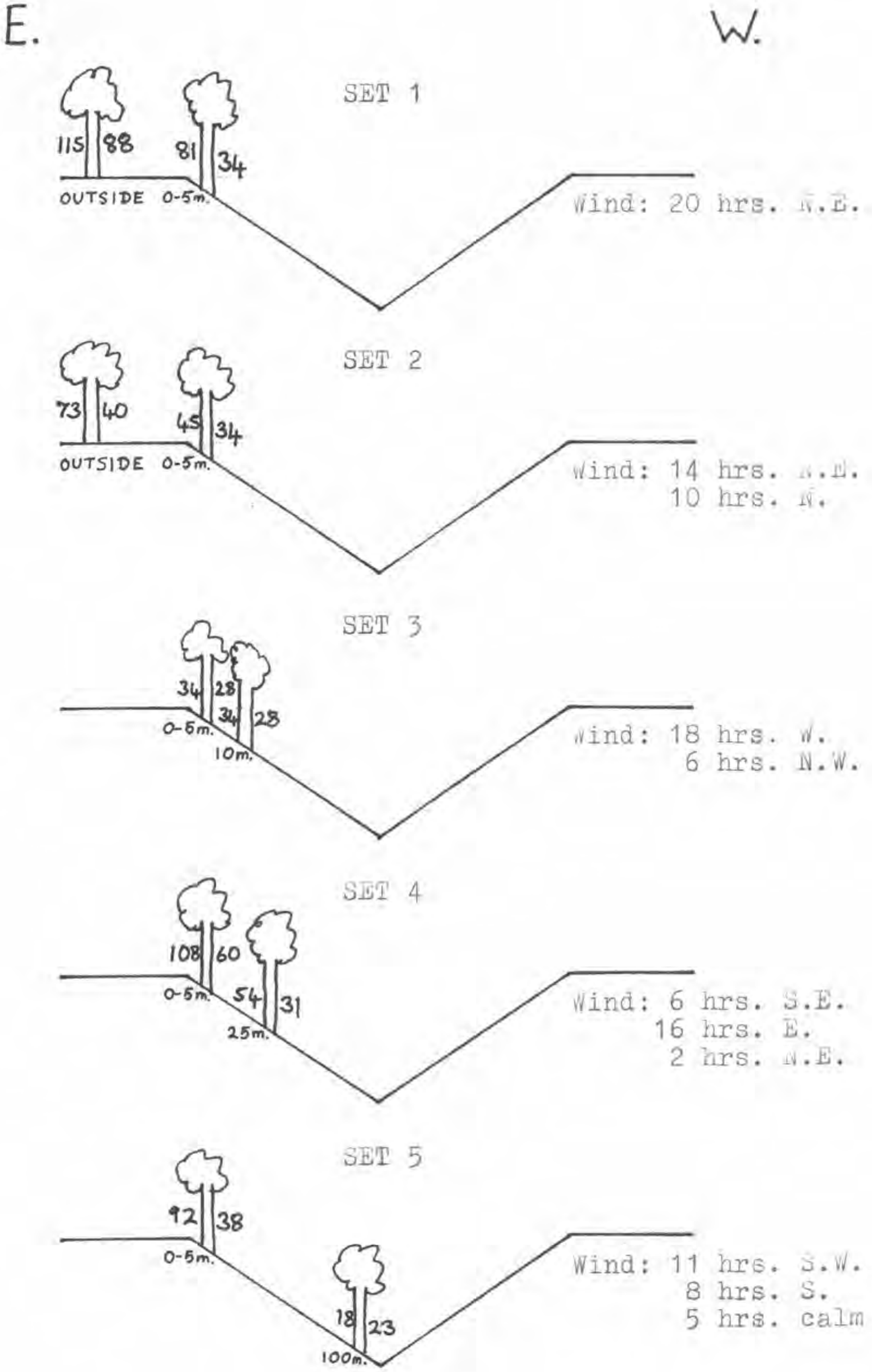
B) Measurements of SO2 Concentrations in Horsley Hope Ravine

As was explained previously, only sets of contemperaneous SO2 samples may be directly compared. Fluctuations in wind direction and velocity were too variable to permit comparison of the results of SO2 measurements taken on different days. Therefore, the results of the 9 sets of SO2 samples (36 samples in all) are presented individually and diagrammatically in Figs. 25 and 26, and are described below.

The first 5 sets of samples were all taken along the W.-facing slope of transect II. Numbers 1 and 2 were identical experiments (see Fig. 25) and both showed that the tree at 0-5 m. within the ravine received less SO2 per unit time than the tree 20 m. outside Horsley Hope Ravine.

<u>Fig. 24</u> : Mean annual (mean winter) concentrations of atmospheric SO2 around Consett. Contours refer to distance from Consett.
Source : Warren Spring Laboratory[72]





SET 1

Wind: 20 hrs. N.E.

SET 2

Wind: 14 hrs. N.E.
10 hrs. N.

SET 3

Wind: 18 hrs. W.
6 hrs. N.W.

SET 4

Wind: 6 hrs. S.E.
16 hrs. E.
2 hrs. N.E.

SET 5

Wind: 11 hrs. S.W.
8 hrs. S.
5 hrs. calm

Fig. 25: The Location and Results (in $\mu g/m^3$) of SO2 Sample Sets 1-5 at Horsley Hope Ravine

The values of mean S02/24 hours are higher in 1 than 2 - and this fact probably relates to the steady N.E. wind, carrying polluted air, which persisted throughout experiment 1. Set number 3 indicates that with a W. wind, pollution-levels are generally low, and no differences in atmospheric S02 concentration were recorded for the trees sampled.
In 4, the S02 values are high, and there is a considerable difference between the measured S02 concentrations of the tree at 0-5 m. and the tree at 25 m. down the valley-side. The winds were generally easterly for the duration of experiment 4. In sample sets 1-4, the E. sides of trees consistently recorded higher S02 values than the W. sides. The fifth set of samples shows that at 0-5 m. high levels of S02 were again measured, but that S02 concentrations in the air around the tree on the floor of the ravine were much lower. It is noticeable that for the tree on the floor of the ravine, the measured concentration of S02 on the W. side of the tree is higher than the mean 24-hour level recorded on the E. side.

Sets of samples 6 and 7 were taken along transect III. Number 6 shows that S02 levels were low, and varied little between the top and bottom of this W.-facing slope, with a W. wind. Number 7 indicates again that the W. sides of trees receive less S02 pollution than the E. sides, although values were generally low.

The 4 samples carried out on transect XII (sample set number 8) illustrate, as in number 3, that there are considerable differences in atmospheric S02 concentration between stations only 10 m. apart on the valley-side, and

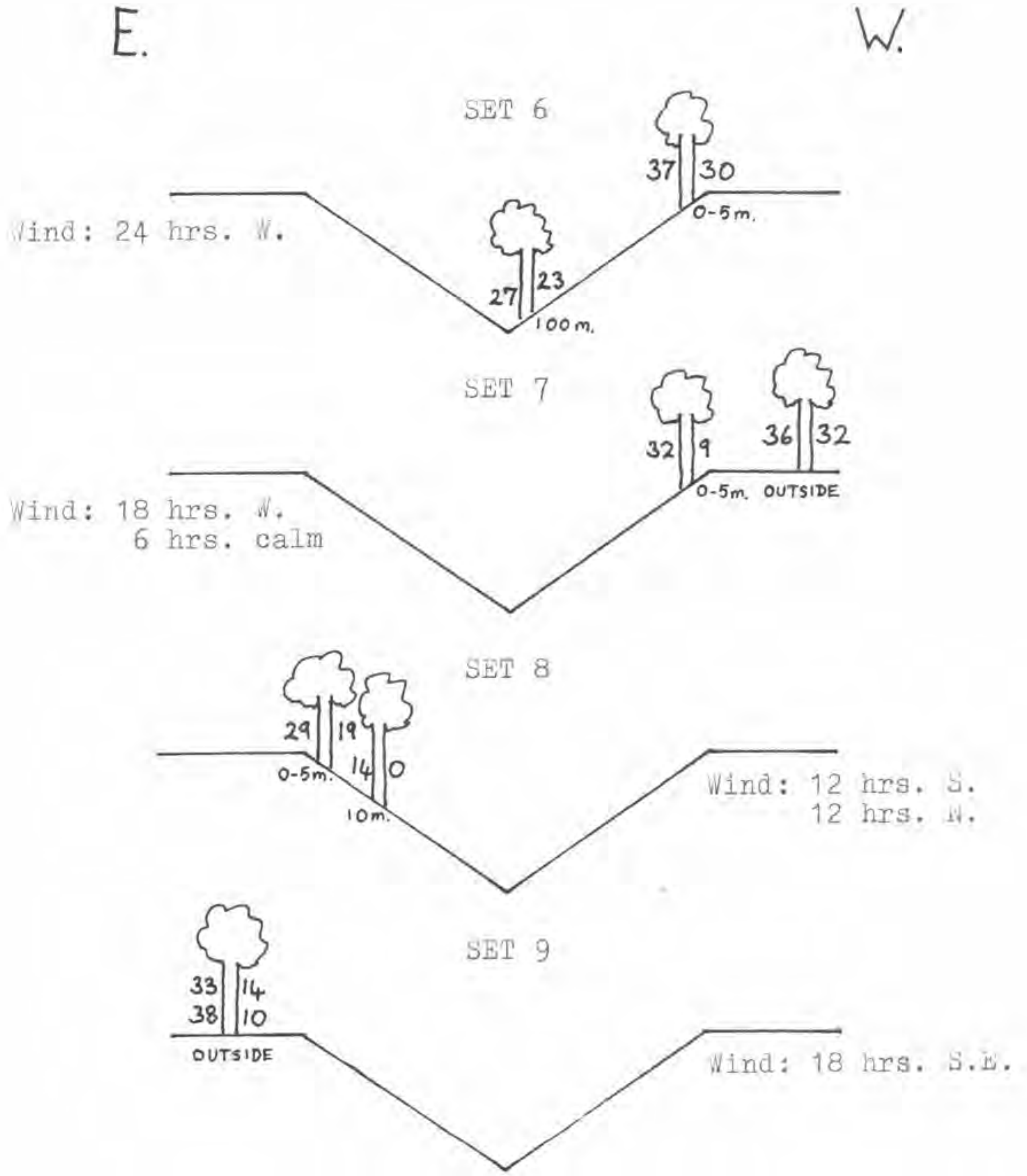


Fig. 26: The Location and Results (in $\mu g/m^3$) of SO2 Sample Sets 6-9 at Horsley Hope Ravine

between the E. and W. sides of trees.

The final set of samples measured differences in SO2 concentration at a height of 10 cms. and 1 m. on the tree trunk. No clear results emerged from this experiment.

Although it is not possible to directly compare all the SO2 measurements, in sets of samples 1-5 and 8, a tree between 0 and 5 m. on the W.-facing slopes of the S. arm of Horsley Hope Ravine was used for recording SO2 levels in the air. Thus, SO2 concentrations measured at the other stations in samples 1-5 and 8 may be expressed as relative proportions of those values obtained on the tree at 0-5 m. - in order to obtain relative figures of atmospheric SO2 for the other stations within and without Horsley Hope Ravine - irrespective of variable factors such as wind direction. In other words, for sets of samples 1-5 and 8, the figures recorded at 0-5 m. are assumed to be 1 (for both sides of the tree) and the figures recorded at 10 m., 25 m., 100 m., and 20 m. outside the ravine (again for both sides of the trees) are transformed into relevant proportional values of 1, by the equation :

$$\frac{\text{SO2 measurements at station X}}{\text{SO2 measurements at 0-5 m.}}$$

The results obtained by this approach are shown below,(and presented graphically in Fig. 30): The figures show that there is a marked decline in atmospheric SO2 concentrations from outside Horsley Hope Ravine to the floor of the valley. Values of SO2 fall steeply up to about 25 m. down the valley-side and then the rate of decline becomes more gradual between 75 m. and 100 m. (see Fig. 30).

Location of Sample Station X	S02 measurements at X / S02 measurements at 0-5 m.
20 m. outside the ravine	1.54
0-5 m.	1
10 m.	0.78
25 m.	0.51
100 m.	0.29

From the results of the S02 measurements, therefore, the following points emerge:-

- The S02 levels recorded depend to a large extent on wind direction.
- Trees outside and on the edge of the ravine record higher levels of S02 than trees within the ravine (even where these sample stations are only a few metres apart).
  S02 concentrations generally decrease towards the floor or the ravine.
- The E. sides of trees are consistently more polluted than the W. sides, except near the bottom of the ravine.
- There are no clear differences in S02 concentrations at different heights on the tree trunk surface.

C) Measurements of Atmospheric Particulate Iron

The values obtained from analysis of the filter papers were all extremely low. These results are not presented in full. The highest value recorded was 0-1 μg/cu. ft. or 0.04 $\mu g/m^3$.

D) Wind Velocity and Direction

The 68 days of records for wind direction around Horsley Hope Ravine are presented in the form of a wind-rose,

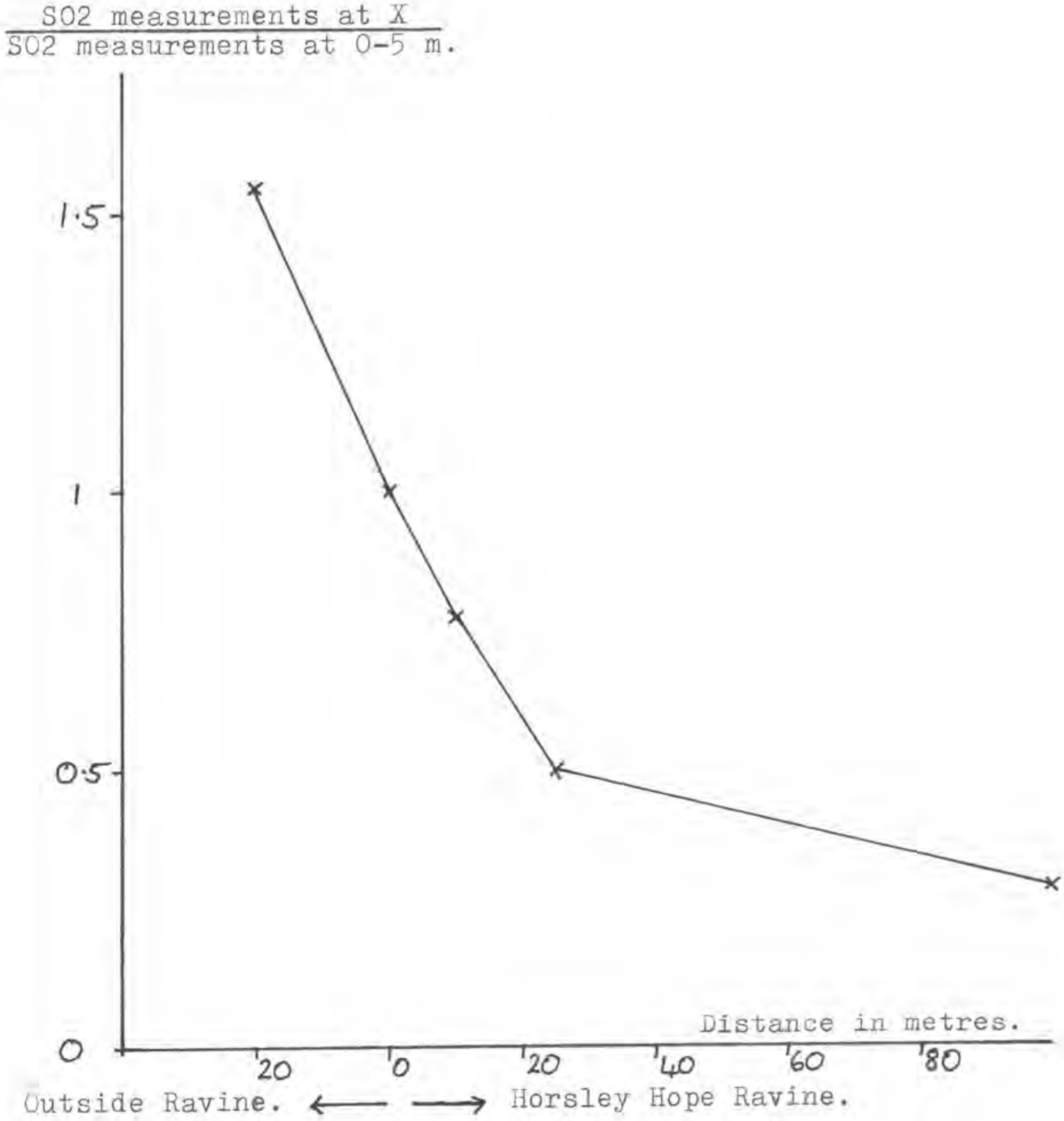


Fig 27 : Relative Values of SO2 Concentration in Horsley Hope Ravine.

in which the figures have been converted to approximate % values (see Fig. 28). It may be seen that the wind pattern around the ravine is fairly typical of that occurring in most of G.B., with the prevailing winds being S.W. and W. Wind velocity figures, as measured by the Beaufort scale, are shown in the same diagram.

6. Light, Relative Humidity and Temperature

The results of the measurements of these 3 parameters are presented below.:

A) Light

The measurements of light intensity, as recorded with the meter, were converted to %s by taking the measured value in bright light to be 100%, and the measured value in total darkness to be 0%. Then, values between these extremes were converted to %s accordingly.

A total of 7 light recording transects were carried out. These were taken along 7 of the transects used in lichen recording: transects I, II, III, IV, V, VII and XI. As with the lichen records, the measurements of light intensity were found to be very similar in certain cases, and there was some amalgamation of the results. Thus, the results for transects I, II and V were combined, and the results for III and IV likewise amalgamated.

In consideration of the upslope/downslope lichen distribution pattern with respect to aspect, light records were differentiated in the same way. So, for example, for transects I, II and V there is a set of light readings for

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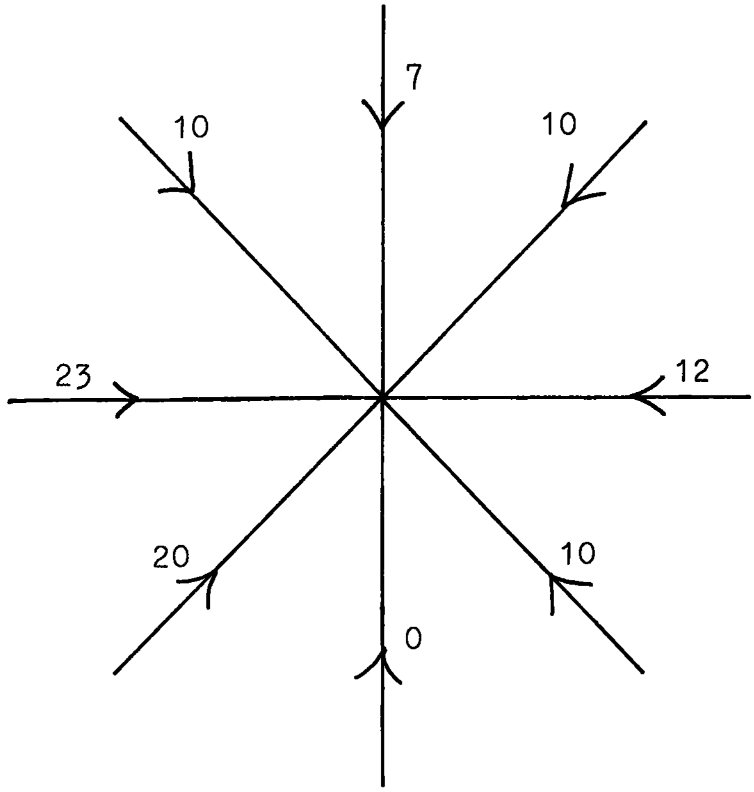

(a) Wind-Rose. Figures refer to the % number of days in which the wind blew in the direction of the arrow.

Direction	Mean Velocity (Beaufort Scale)	Mean Velocity (in knots)
S.W.	4.2	14
S.E.	1.8	4
E.	3.2	9.5
N.E.	2.5	7
N.	1.5	3.5
N.W.	5	19
W.	3	8.5
Average	2.87	8

(b) Mean Wind Velocities

Fig. 28 : Measurements of Wind Direction and Velocity taken on the edge of Horsley Hope Ravine.

the E. sides of trees and a set for the W. sides of trees; and in transect VII, a set for the N. sides of trees and a set for the S. sides.

The results of the 7 transects are reproduced graphically in Figs. 29 and 30. As might be expected in a ravine woodland, light intensity generally decreases from a high value at 0-10 m. to a lower value near the foot of the transect. Figures of 60-70% are usual for the top of the slope, and values of 45-55% characteristic of light intensities on the ravine floor. Light intensities decrease steadily and consistently from high values in the first 10 m. length of slope to a figure of about 50%, which is usually attained between 40 and 60 m. down the valley-side. From this point to the stream, light intensity appears to be fairly constant - between 45 and 55%.

Transect XI is an exception to this rule, for as explained earlier, the woods here were more open in nature, and accordingly the light values higher.

There are differences in the measured light intensities of the upslope and downslope sides of trees (excluding transect XI). The upslope sides - I, II and V (E.), III and IV (W.), VIII (W.) - are usually lighter than the respective downslope sides of trees in the same 10 m. lengthe of valley-side - at least for the first 30-40 m. This is presumably related to the influence of light penetrating obliquely or horizontally into the ravine from outside the woods (as distinct from through the canopy), a factor which would affect the upslope, but not the downslope, sides of trees. After 30-40 m., tree trunk aspect does not appear to be a significant factor. In transect XI, which

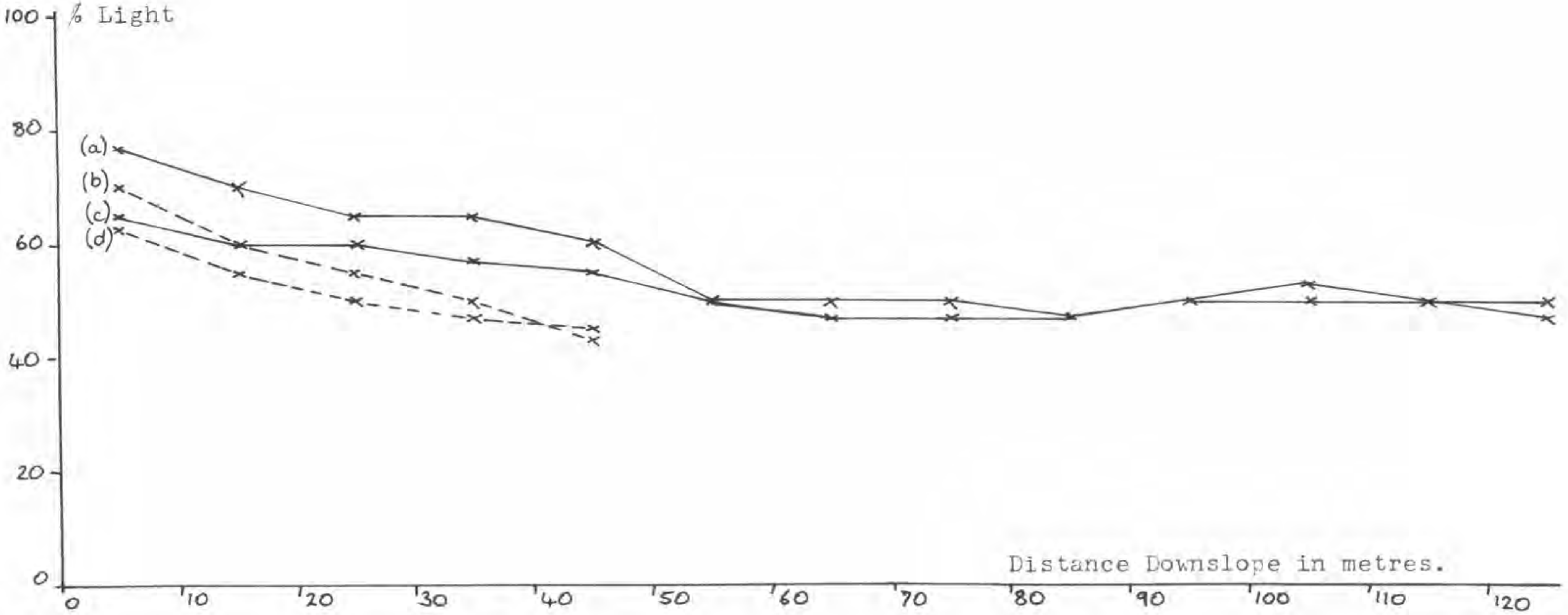

Fig. 29 : The Downslope Variation in Light Intensity along (a) I, II, V (E.); (b) I, II, V (W.); (c) VII (N.); (d) VII (S.)

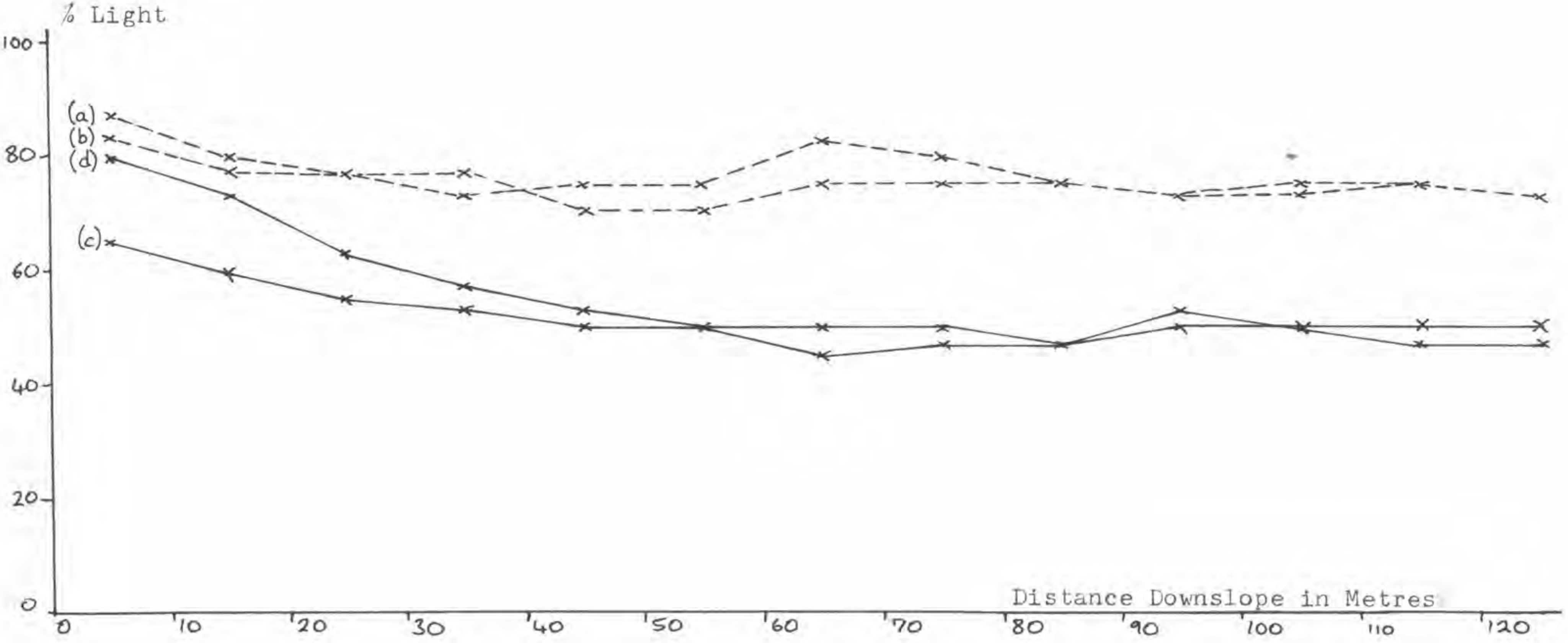

Fig. 30 : The Downslope Variation in Light Intensity along (a) XI(E.); (b) XI (W.); (c) III, IV (E.); (d) III, IV (W.)

is fairly light throughout, there is no relationship between trunk aspect and light intensity.

Correlation coefficients were calculated for the 7 transects in order to examine the statistical relationship between light intensity and distance down the side of the ravine. None of the correlation coefficients obtained were statistically significant, and all values fell within the range -0.268 to -0.412.

B) Relative Humidity (RH)

The 4 transects taken down the valley-side in order to measure variations in RH in Horsley Hope Ravine, produced results of little or no significance. The 4 transects were taken on 4 different days (on each occasion at about 10 a.m.) yet RH values were invariably in the range 66-71%. For 3 of the transects, RH measurements were the same from beginning to end of each transect. For the fourth, there was a difference of 2% between the RH at the bottom of the ravine (71%) and the RH outside the ravine (69%) - the increase down the valley-side occurring within the top 30 metres. The results of the RH measurements indicated, therefore, that this parameter varied little within and around Horsley Hope Ravine.

C) Temperature

The temperature records were all taken on bright, sunny days and there were considerable differences between the air temperatures of Horsley Hope Ravine and those measured in the open countryside outside the woods. The figures for the 3 temperature-measuring transects have been combined to provide a composite picture of the downslope

Distance Downslope	Air Temperature in ^{o}F.
Outside the ravine	72
0-10 m.	70
10-20 m.	69
20-30 m.	69
30-40 m.	68.5
40-50 m.	68.5
50-60 m.	68.5
60-70 m.	68.5
70-80 m.	68.5
80-90 m.	68.5
90-100 m.	68.5
100-110 m.	68.5
110-120 m.	68.5
120-stream	68.5

TABLE XXIX : The changes in air temperature in Horsley Hope Ravine (composite of measurements from transects I, II, and III).

changes in air temperature (see TABLE XXIX). It may be seen from the table, that the temperature falls markedly within the top 20 m. of the valley-side, and is then more or less constant from 20 m. to the valley bottom.

In addition, a few air temperature records were taken along transect XII. No changes in air temperature were recorded.

V. DISCUSSION

The preceding chapter has shown that the distribution of corticolous lichens within the study area, and particularly within Horsley Hope Ravine, is fairly complicated. In part, the complexity of the distribution pattern may be ascribed to the small-scale environmental fluctuations indigenous to the corticolous epiphyte habitat - and described in chapter 2, section 1.

Nevertheless, certain general trends of lichen distribution have emerged quite clearly from the results and have been described. A significant proportion of the inherent variability in the occurrence of corticolous lichens may be explained in terms of these major distribution patterns.

Furthermore, measurements of certain abiotic factors have demonstrated that the corticolous lichen environment is by no means uniform. Changes in some of these ecological parameters may be responsible for the observed trends of lichen distribution.

In the discussion presented below, the results which emerged from analysis of the fieldwork data are considered in turn, and an attempt is made to explain the biological and physical processes operating in each case. Finally, a model is devised, accounting for the distribution of corticolous lichens throughout the study area.

1. Lichen Distribution in the Study Area

A) General Pattern of Lichen Distribution

It was shown previously that there was a distinct and rapid improvement in the corticolous lichen flora with distance from Consett in a S.W. direction. Numbers of species and T.F.V.s increased S.W.; lichen zones shifted significantly; and two highly statistical correlation coefficients between distance in kms. and species numbers were obtained.

This is clearly a response to the decreasing atmospheric SO2 concentrations S.W. of Consett. Although, no long-term SO2 measurements are available for the area S.W. of Consett - apart from the station at Moorside where recorded SO2 levels are indicative of the improved atmospheric quality S.W. of Consett - it may be expected that mean atmospheric SO2 concentrations would decrease significantly in this direction, for 3 reasons;

(i) the steelworks constitutes a point-source of SO2, and Consett provides only a small amount of blanket pollution, so that SO2 is probably dispersed in the atmosphere relatively quickly (see chapter 2, section 2, A);

(ii) there are no other major sources of air pollution within the study area;

(iii) the prevailing winds are S.W. (see Fig. 28) so that most of the SO2 emitted in Consett is carried N.E. of the town.

A steep gradient of decreasing SO2 pollution S.W. of Consett would thus explain the rapid improvement in the corticolous lichen flora in this direction. There is no reason to assume that other ecological factors which might influence lichen distribution, such as light, bark moisture, and temperature vary within the study area.

The spatial relationships between SO2 pollution and lichen distribution were considered at length in chapter 2, section 2, D, and the situation S.W. of Consett provides a good example of a classic case of lichen flora improvement (as measured by species diversity, % frequency of a number of species, and the change in lichen zones) with decreasing atmospheric SO2 concentrations.

B) Distribtuion of Individual Species

The distribution of individual species in the study area is of some interest. The work carried out on the sensitivity of lichen species to SO2 was considered in Chapter 2, section 2, D (a); and TABLE VIII shows the approximate order of species sensitivity to SO2 as obtained from a number of references. If TABLE VIII is compared with TABLES XIII and XIV (which show the occurrence of lichens in km. sections in the study area), it may be seen that in all 3 tables, the order of species sensitivity is very similar. That is, with increasing distance from a source of SO2, the order in which corticolous lichen species are first recorded (their inner limits of occurrence) is reasonably consistent. Thus, the 2 most tolerant lichens in the 3 tables are Lecanora conizaeoides and Lepraria incana; while species such as Parmelia subaurifera, Pertusaria amara, and P. pertusa are shown to be sensitive in all cases to SO2.

There are exceptions and differences within these 3 tables - not surprisingly in view of the varied data used to compile TABLE VIII. For the same reason, absolute figures of distance from SO2 source at which certain species were first recorded are not comparable. However, the general order of species sensitivity is noticeably constant in the 3 tables - and this is additional proof linking the improvement in the corticolous lichen flora S.W. of Consett with the decline in SO2 pollution.

In TABLES XIII and XIV the % frequency of most lichens increases with distance from Consett, in line with the overall trends of increasing species numbers and T.F.V.S. However, for a few species (notably Parmeliopsis ambigua and Calicium viride in TABLE XIV, and P. ambigua and Chaenotheca ferruginea in TABLE XIII) values of % frequency increase at first and then decline. This is thought to be the result of greater competition amongst lichens for space on the tree trunk with increasing distance from Consett. As more lichens are able to survive in the purer air, competition increases, and certain species which may thrive nearer Consett where SO2 levels are higher are out-competed by more vigorous lichens as SO2 levels decline.

C) The Lichen Distribution / Aspect Pattern in the Study Area

As described in Chapter 4, corticolous lichen distribution in the study area is markedly E.-W. oriented. There are significant differences between the vegetation on the E. sides of trees and that colonising the W. sides. The W. sides of trees consistently bear more species, are characterised by higher T.F.V.S, show a faster change of lichen flora with distance from Consett (as expressed in the steeper regression line, and rapid shift of lichen zones), and within the same km. sectors support a lichen vegetation assemblage more SO2-sensitive than that carried on the E. sides of trees.

With reference to chapter 2, section 1, there are 4 factors which might explain this observed pattern with respect to aspect:

(i) E.-W. differences in light intensity
(ii) E.-W. differences in temperature
(iii) E.-W. differences in moisture-supply
(iv) E.-W. differences in air pollution.

The first two may be discounted, for any long-term E.-W. differences in light intensity and temperature are likely to be minimal or non-existent. Concerning (iii), the prevailing rain-bearing W. and S.W. winds of Britain could account for the richer flora of the W. sides of trees. Jones[46] and Smith[86] subscribe to the view that the luxuriant epiphytic flora of western Britain is due primarily to higher rainfall, while Barkman[5] put forward the same hypothesis to account for the rich flora of the W. Netherlands. On a smaller scale, therefore, this factor could explain floral differences related to tree trunk aspect, with the W. sides of trees being typically wetter, and having a higher bark moisture-content, than the E. sides of trees which are sheltered from the prevailing westerlies.

Alternatively, the position of the SO2 source E. of the study area could account for the impoverished lichen vegetation of the E. sides of trees in the study area, with SO2-laden (E.) winds affecting mainly the E. sides of trees.

Available evidence seems to indicate that the latter idea is more applicable. The reasons are summarised below:

(i) Those species found on the W. sides of trees (TABLE XIV) but not on the E. sides are known to be sensitive to SO2 (see TABLE I).

(ii) Even on the W. sides of trees, near Consett the corticolous lichen flora is impoverished. This fact cannot be explained by a decline in levels of bark moisture-content towards Consett.

(iii) The E. sides of trees can support a luxuriant flora. Between 5 and 7 kms. from Consett, where SO2 concentrations are generally lower, lichens such as Parmelia subaurifera, Pertusaria pertusa and P. amara can survive on the E. sides of trees.

(iv) Observations on the corticolous lichen vegetation of trees to the N. and S. of Consett indicated that the distribution/aspect pattern was oriented N.-S. in these sectors. Thus, the lichen distribution pattern with respect to aspect varied in response to changes in the position of the tree trunk surface relative to the SO2 source; e.g. S. of Consett, the S. sides of trees bore a richer epiphytic flora than the N. sides, as the S. sides were not exposed to the SO2-laden winds coming from the N. This fact certainly seems to indicate that the lichen distribution/aspect pattern of the study area is controlled by the position of the SO2 source rather than by bark moisture-content differences.

(v) Finally, measurements of SO2 taken outside Horsley Hope Ravine, (Figs 25 and 26), showed that in all cases, SO2 concentrations were greater on the E. sides of trees than on the W. sides. Numerically, for trees outside Horsley Hope Ravine which were sampled for SO2 levels, the E. sides of trees received an average 1.8 times more SO2 than the W. sides.

It therefore seems likely that the distinct differences in the lichen vegetation of the E. and W. sides of trees are due to the controlling influence of SO2 distribution. The mechanism by which this process might operate was outlined in Chapter 2, section 2, C (b). Essentially, the W. sides of trees in the study area constitute 'sheltered niches', in that they are protected from E. winds which transport SO2 from Consett.

To consider this in greater detail, SO2 is a light gas, such that its distribution in the atmosphere depends to a great extent on wind-speed and direction. Moreover, because it is light, SO2 is generally deposited by impaction rather than gravitational fall-out.[81,95] This implies that the quantity of SO2 reaching a surface is dependent upon the air-flow (and the SO2 content of the air-flow) over that surface. Thus, for a given surface, the amount of SO2 impacted on the surface is directly proportional to:
(a) air-flow over the given surface/unit time (wind-speed), and (b) SO2 content of the air-flow.

So, for a tree in the study area, the amount of SO2 received by the trunk surface depends to a great extent on:

(i) Wind-direction. E. winds carry significant amounts of SO2 from Consett to the study-area. N., S. or W. winds are less pollution-laden. This is shown quite clearly in the measurements of SO2 taken at Horsley Hope Ravine, e.g. in sample set 3, with W. and N.W. winds for the 24 hour period, SO2 levels are low; whilst in sample set 4, with S.E., E. and N.E. winds, SO2 concentrations are much higher.

(ii) Wind velocity. Stronger winds will transport a greater quantity of SO2 per unit time, and allow less diffusion to occur. The measurements of wind velocity around Horsley Hope Ravine show that the study area is characterised by strong winds.

(iii) Tree trunk aspect (orientation of surface). On the E. sides of trees, exposed to strong pollution-laden E. winds, there will obviously be more impaction of SO2/unit time than on the sheltered W. sides of trees where little impaction of SO2 may be expected to occur (i.e. there is less air-flow over the W. sides). With W., N., or S. winds, the differences in air-flow per unit time over the trunk surface are less important, for the SO2 content of these winds will be lower. Again, this is brought out in Figs. 25 and 26 - in sample set 3 (W. wind) there is little difference in the measured SO2 levels of the E. and W. sides of trees; but in 4 (E. wind) it is obvious that there is more impaction of SO2 on the E. sides of trees than on the W. sides.

The theory that sides of trees which are sheltered from strong, pollution-laden winds, and are thus relatively free from impacted SO2, may probably only be applied to rural areas receiving SO2 from a point-source. In areas of blanket pollution, this concept would not operate, for over a sufficiently long period of time the air-flow over a surface would be fairly constant, irrespective of aspect; and if the ambient SO2 concentration of the air was consistently high, then SO2 would be deposited on all surfaces regardless of the direction in which they were facing. This fact probably explains why the distribution of lichens in relation to aspect has received scant attention in the relevant literature - although a highly significant E.-W. pattern of lichen distribution emerged from the study S.W. of Consett. Barkman[5] stresses the importance of aspect in controlling lichen distribution, and Rose, Hawksworth and Coppins[77] found in the Lake District that the N. sides of trees were covered with Parmelia species and Evernia prunastri, while the S. sides(exposed to pollution laden winds from industrial Lancashire) bore an impoverished lichen flora. Otherwise, no references to corticolous lichen distribution/aspect phenomena were encountered in the scientific literature (see References); and it is thus assumed that the marked lichen/aspect pattern S.W. of Consett is applicable only to rural areas receiving point-source SO2. In this respect, it may be presumed, for example, that the Hawksworth and Rose[41] zonation scheme was devised for more uniform conditions of pollution distribution - for S.W. of Consett a tree may be classed as belonging to two entirely different zones, depending on the side of the tree examined.

In summary therefore, the deposition of SO2 by impaction on exposed tree surfaces adequately explains the E.-W. orientation of corticolous lichen distribution S.W. of Consett. The sheltered W.-sides of tree which are characterised by relatively low rates of air-flow/unit time under polluted conditions (i.e. E. winds) support a more luxuriant lichen flora than the E. sides of trees, upon which SO2 - carried by the E. winds - is deposited by impaction. Generally speaking, SO2 concentrations throughout the study area decline with distance from Consett, which explains the overall improvement in the lichen flora S.W. of Consett, and more particularly accounts for the gradual appearance of SO2-sensitive species.

2. The Lichen Flora of Horsley Hope Ravine

Figs. 15 and 16 clearly illustrate that the lichen flora of Horsley Hope Ravine is more diverse and abundant than that of the adjacent open countryside around the ravine. It also contains species which are very sensitive to SO2. These results reflect the findings of others who have studied corticolous lichen vegetation in ravine situations (see Chapter 2, section 3) and found a more luxuriant epiphytic flora.

It is now pertinent to refer back to the aims of this study as set out in Chapter 2, section 3. It has been shown that (i) the distribution of SO2 is an important parameter (in fact the most significant controlling factor) in the distribution of lichens S.W. of Consett and (ii) the corticolous lichen flora of Horsley Hope Ravine is richer than that of the surrounding countryside.

It is therefore relevant to proceed to the investigation of possible causes of the luxuriant lichen vegetation and its variability observed in Horsley Hope Ravine. Clearly, some factor or factors of the ravine environment are instrumental in creating suitable conditions for the growth of a variety of lichen species. Hawksworth and Rose[41] state (referring to the luxuriance of ravine epiphytic vegetation) "the microclimate of the bases and trunks of trees may differ markedly from that of trees in adjacent open situations" and "the reasons for these differences are unknown, for although Gilbert has proved that air pollution in ravines can be less than that on adjacent plateaux, in at least some cases, RH and different patterns of air currents may also be contributory factors".

As a prelude to discussion about the probable factors controlling lichen distribution in Horsley Hope Ravine, the results of the transects measuring the % frequencies of lichen species, and the details obtained concerning the variation in abiotic parameters in the ravine, are summarised below.

3. The Distribution of Lichens in Horsley Hope Ravine

A) Changes in Gross Values of Lichen Performance

i) For all transects, between about 40-50 m. and the valley-floor, values of total frequency, and to a lesser extent, species numbers, are approximately constant.

Except for transect XI, the 'constant level' is 27-32 species per 10 m. section, and 1150-1300 T.F.V per 10 m. section of valley-side. These figures are maintained, in the vast majority of cases, from 40 m. to the stream. It may be predicted, moreover, that if the 4 short transects (VI, VII, VIII and XII) were longer, measurements of T.F.V.s and species numbers would remain constant throughout.

In transect XI 'constant levels' are still attained but are higher - species numbers 30-34, and T.F.V.s approximately 1450-1600.

No relationship to aspect may be observed in the variation of these values.

The T.F.V. constant level of 1150-1300 is strikingly consistent from transect to transect, and is taken to represent the standard gross figure for lichen performance between 40 m. and the valley floor within Horsley Hope Ravine.

ii) Between 0 and 40-50 m. the summed values of species numbers and T.F.V. vary considerably. As explained previously, the variation in T.F.V.s probably constitutes the more useful guide to gross downslope changes in the lichen flora. Accordingly, the patterns of T.F.V. change between 0 and 40-50 m. in each set of transects are categorised as follows, in order to classify the results presented in Figs. 19-21:

T.F.V.s increase from 0 to 40-50 m: I, II, V (E.); VIII & XII (E.); XI (E. & W.)

T.F.V.s decrease from 0 to 40-50 m: III, IV (W.); VI, VII (N. & S.)

T.F.V.s increase then decrease from 0 to 40-50 metres:
I, II, V (W.); VIII & XII (W.); III, IV (E.).

B) Distribution of Individual Species

i) Downslope changes in the distribution of lichen species were enumerated by the calculation of correlation-coefficients between distance downslope and changes in % frequency for each species. Although, as considered in chapter 4, this might in certain cases lead to false assumptions concerning the downslope distribution of lichens, it does permit straightforward comparisons to be made between the varying downslope distribution patterns shown by different species.

For each set of transects, the numbers of species which were positively or negatively correlated with distance downslope varied. Predictably, these variations reflected to some extent the changes in downslope T.F.V.s between 0 and 40-50 m. Thus, for example, along transects I, II and V (E.), and XI (E. and W.) the % frequency of many species was positively correlated with distance downslope, and T.F.V.s increased between 0 and 40-50 m. In transects I, II and V (W.) and VIII and XII (W.) most species were significantly negatively correlated with distance downslope, and along these two sets of transects T.F.V.s declined between 0 and 40-50 m.

More useful were the results which emerged from TABLE XXVIII, in which the mean r values for each species in (a) transect XI and (b) all other transects, were presented. This enabled lichen species with similar overall trends of downslope distribution to be grouped into 7 types. The patterns of lichen distribution represented by these seperate groups reveal the complexities of individual species distribution down the valley-side within Horsley Hope Ravine.

(ii) Concerning aspect, and the distribution of lichen species within Horsley Hope Ravine, a clear distinction emerged between the lichen assemblage on the upslope sides of trees and that associated with the downslope sides of trees - regardless of compass direction. Thus, the upslope sides of trees supported a similar lichen flora throughout Horsley Hope Ravine - irrespective of whether the upslope side faced N., S., E. or W. Clarification of species 'preference' for the upslope or downslope sides of trees is provided in TABLE XXVIII, which compares the distribution of individual species in relation to aspect, as measured from all transects.

It is therefore clear that corticolous lichen distribution within Horsley Hope Ravine displays a number of significant trends, explanations for which might be sought from the variation in certain environmental parameters described below.

4. The Variation of Certain Environmental Parameters in Horsley Hope Ravine

A) Substrate Character

As explained in Chapter 3, it was originally intended that substrate character should be kept constant throughout the sampling programme, so as to remove certain elements of variability from the pattern of corticolous lichen distribution. Ideally, sampling should have been confined to a single uniform type of substrate. This was achieved, with one exception. It was discovered that most trees in Horsley Hope Ravine lean towards the floor of the ravine (in line with the slope aspect), and it was therefore impossible to restrict sampling to vertical trees. In fact, as described in Chapter 4, section 4, 97.8% of the trees sampled were inclined at an angle greater than 2^{0} in the downslope direction.

The ecological implications of inclined trees are described in Chapter 2, section 1, A. Briefly, the upper sides of inclined trees collect more water than the undersides. Thus, xerophytic species are associated with the undersides of such trees, while a hygrophilous flora tends to develop on the upper sides of inclined trees. The angle of tree trunk inclination is thus an important factor in lichen distribution.

In relation to the striking pattern of downslope tree inclination observed in Horsley Hope Ravine, it may be concluded that the downslope sides of trees were typically drier than the moisture-collecting upper sides, for the vast majority of trees sampled in all transects. No measurements of bark moisture-content were taken to substantiate this point.

Apart from tree inclination, all other features of corticolous lichen substrate habitat were kept constant. The other environmental factors measured related to variations in the lichen microclimate.

B) SO2 Concentrations

Three significant results emerged from the measurements of SO2 concentration taken in Horsley Hope Ravine:

(i) levels of SO2 pollution fluctuate - largely according to variation in wind-direction (this was discussed earlier)

(ii) Atmospheric SO2 concentrations decline towards the floor of the ravine. The rate of decline is shown in Fig. 27 - from outside the ravine to about 25 m. within the ravine, there is a steep decrease in atmospheric SO2 levels, which flattens out between 25 m. and the ravine floor. SO2 levels at 100 m. are low. These results accord with Gilbert's findings in Jesmond Dene (Chapter 2, section 3).

(iii) The E. sides of trees receive more impacted SO2 than the W. sides, except towards the floor of the ravine where these differences did not apply. Even at 25 m. down the vallye-side, the E. sides of trees received about 1.8 times more SO2 than the W. sides. But samples taken at 100 m. stations were generally low, and constant with respect to aspect.

C) Atmospheric Particulate Iron

The measured values of particulate iron in the atmosphere around Horsley Hope Ravine are extremely low, in fact several orders of magnitude less than the values for particulate iron referred to in Chapter 2, section 2, A.

Robinson[75] considers that lead and copper at levels in excess of $0.04\ \mu g/m^3$ of air, constitute criteria for polluted air, However, $0.04\ \mu g/m^3$ of iron may not be considered to be of equivalent importance, as iron is not as toxic as lead and copper are. In fact, 1,000 gms./m^3

of iron is recommended for nutrient solutions added to algal cultures (P. Patrick, pers. comm.).

Thus while atmospheric iron in quantities as high as 90,000 ppm. (James[45]) may be dangerous to corticolous lichens (see Chapter 2, section 2, A) - the figures recorded in and around Horsley Hope Ravine are so low that they are extremely unlikely to influence lichen distribution and do not merit further consideration.

D) <u>Light</u>

Measurements of light show that:-

(i) Light intensities are fairly constant from about 50 m. down the valley-side to the ravine floor - and are between 45% and 55%, except for transect XI. Barry and Chorley[6] consider light intensities of about 50% to be normal for deciduous woods.

(ii) From 0 m. to 40-50 m. light intensities decline. The rate of decline is greater for the upslope sides of trees, which receive light from outside the woods (horizontal and oblique penetration) - again, excepting transect XI.

(iii) Transect XI is fairly light (about 70%) throughout, owing to the operation of a different land management regime, as outlined previously.

E) <u>RH and Temperature</u>

The measurements of RH and temperature indicated that these factors varied little within and around Horsley Hope Ravine. It appears as though air temperatures are generally lower within the ravine; and RH slightly higher - but the results are inconclusive.

However, the importance of RH and temperature in controlling corticolous lichen distribution should not be dismissed on the basis of these results alone. For instance air temperature differences - though insignificant in summer may be crucial to lichens in winter; and RH values were only in the range 66-71% - during conditions of generally lower humidity, RH differences between Horsley Hope Ravine and the surrounding open countryside may be higher and thus of greater importance in lichen survival. Ideally, at least a whole years measurements of variations in RH and temperature should be taken in order to assess the relevance of these factors to lichen distribution.

On the other hand, Barkman[5] considers that lichens are resistant to changes in air temperature; and Barry and Chorley[6] state that the RH of woods is, on average, only between 3 and 10% higher than the respective RH of open conditions. However, previous consideration of the importance of RH as a controlling factor in lichen distribution (Chapter 2, section 2, E) suggested that its influence is of little consequence.

It is therefore assumed that elevated RH values and even air temperatures are parameters of the ravine environment which encourage lichen growth; but that these factors do not vary sufficiently to significantly affect lichen distribution in Horsley Hope Ravine. The following explanation for the patterns of lichen distribution recorded in Horsley Hope Ravine accounts for the observed facts irrespective of any changes in temperature and RH which may or may not occur.

5. The Downslope Distribution of Lichens in Horsley Hope Ravine : Explanations and Model.

The marked downslope changes in the corticolous lichen flora of Horsley Hope Ravine may be related to the equally distinct downslope changes in two parameters: light intensity and SO2 concentration. All the other abiotic factors measured were more or less constant with distance downslope. Light and SO2 levels, however, both showed an overall decline in values downslope in all the samples taken.

To analyse the situation in more detail, features of the downslope pattern of lichen distribution are discussed individually:-

A) The 'Constant Level'

Between 40-50 m. and the ravine floor, T.F.V.s and species totals are more or less constant. It is obvious from Figs. 29 and 30, that light intensities are also more or less constant at about 45-55% (except for transect XI) within this stretch of the valley-side. Morover, Fig. 27 indicates that at about 40-50 m., SO2 levels are low, and remain low between this point and the valley floor. Thus the lichen environment between 40-50 m. downslope and the stream in the ravine floor is unpolluted and relatively dark. These conditions are invariably maintained throughout the lower portions of all the long transects (I-V), and must account for the constant levels of gross lichen performance (T.F.V.s 1150-1300, species numbers 27-32) regularly observed during sampling.

The purity of the air towards the floor of the ravine is advantageous for lichen growth, but the lack of light must inhibit photophilous species[1,5]. Thus values of total frequency and species numbers between 40-50 m. and the base of the transects are not as high as they might be under lighter conditions. Essentially, the constant levels of T.F.V. and species numbers measure the standard gross lichen performance under the consistently dark, unpolluted conditions of the true ravine environment between 40-50 m. and the valley bottom.

Transect XI reveals that the 'constant level' may in fact be higher where light intensities are also higher. Species numbers below 40-50 m. are in the region of 30-34 per 10 m. sector, and T.F.V.s in Fig. 21 average 1450-1600; light intensities vary around a mean of about 70% over this stretch of valley-side.

B) <u>The Variation in Total Frequency Values and Species Numbers Between 0 and 40-50 m.</u>

Whereas T.F.V.s, species numbers, light and SO2 are all seen to be approximately constant between 40-50 m. and the valley-bottom, above this point, the situation is more variable.

The records of light intensity show that between 0 and 40-50 m., light intensities are generally higher than between 40-50 m. and the valley-floor. Predictably, the amount of light declines steadily from a high value at 0 m. to about 50% at 40-50 m., and moreover, the rate of decline is greater on the downslope sides of trees.

It was explained above that T.F.V.s and numbers of species per 10 m. sector were depressed between 40-50 m. and the valley floor by the low light intensities associated with the lower slopes of the ravine. Thus, it might be expected that T.F.V.s and species numbers for all transects would be very high between 0 and 10 m. reflecting the high light intensities of this sector; and then would decline between 0 and 40 m., the rate of decline being greater on the downslope sides of trees in accordance with the controlling influence exerted by the changes in light intensity.

Examination of the T.F.V. data shows that this situation is in fact only attained in transects VI and VII (N.), VI and VII (S.) and in transects III and IV(W.). Transects VI and VII (N. and S.) do, however, clearly exemplify the expected change in T.F.V.s. In Fig. 20, the T.F.V.s of the upslope sides of trees (VI, VII,N)fall from a high value of 1600 between 0 and 10 m. to 1195 (the constant level) at 40 m. The T.F.V.s of the downslope sides of trees (VI, VII S.) decline even more rapidly from 0-40 m. (1835-1180) as light intensities decrease more markedly.

In the remaining transects, T.F.V.s do not decline between 0 and 40-50 m: they increase, or increase and then decrease. Clearly some factor other than the variation in light intensity is the cause of these aberrant patterns of lichen distribution - and again the other effective environmental parameter seems to be the variation in atmospheric SO2 concentration.

It was shown in Fig. 27 how SO2 levels decrease sharply between 0-5 m. and 25 m., and then decrease more steadily between 25 m. and 100 m. down the valley-side. Moreover, the higher levels of SO2 received by the E. sides of trees near the top edge of the ravine (an average 1.7-1.8 times the amounts recorded on the W. sides) were referred to.

Now, although the 24-hour period records of SO2 which were measured may not be directly converted into values of mean annual SO2 (these long-term figures of SO2 concentration being significant for lichen survival as explained in Chapter 2, section 2, D) - an indication of the absolute levels of mean annual SO2 prevalent around Horsley Hope Ravine may be gained from the following calculation. It is winds from the E. quartile (N.E.-E.-S.E.) which transport SO2 to Horsley Hope Ravine; it is considered that from other directions winds are not SO2-carrying. When winds from the E. quartile persisted during the whole 24 hour period of SO2 sampling (sample sets 1 and 4) then average SO2 concentrations measured for the tree at 0-5 m. were 95 $\mu g/m^3$ on the E. sides of trees and 47 $\mu g/m^3$ on the W. sides. With winds blowing from all other compass directions for the duration of the SO2 samples (sample sets 3,5,8), then average SO2 concentrations measured for the tree at 0-5 m. were 50 $\mu g/m^3$ for the E. sides of trees and 30 $\mu g/m^3$ for the W. sides.

Records of wind direction around Horsley Hope Ravine (Fig. 28) suggest that winds blow from the E. quartile for 32% of the time. Thus if trees at 0-5 m. on the edge of the ravine record 95 $\mu g/m^3$ on the E. sides and 47 $\mu g/m^3$ on the W. sides for 32% of the year; and 50 $\mu g/m^3$ on the E. sides and 30 $\mu g/m^3$ on the W. sides for 68% of the year - then annual mean SO2 concentrations are 64 $\mu g/m^3$ on the E. sides of trees and 41 $\mu g/m^3$ on the W. sides.

It must be stressed that the calculation used to obtain these values are based on inadequate data - so that these figures provide only a very rough guide to long-term SO2 concentrations at this location.

However, previous discussion - including referrence to the Hawksworth and Rose scale - has shown that mean levels greater than 60 $\mu g/m^3$ severely restrict the occurrence of many corticolous species. Thus it may be presumed that at 0-5 m. on transects I, II and V (i.e. where the SO2 samples were taken), the lichen vegetation is affected by SO2 - these effects being of greater significance on the E. sides of trees than on the W. sides.

Referring again to Fig. 27, if absolute values of 64 $\mu g/m^3$ and 41 $\mu g/m^3$ are assumed to be correct for trees between 0 and 5 m., then at 10 m. levels of SO2 should be roughly 80% of these values (i.e. 52 $\mu g/m^3$ on the E. sides, 30 $\mu g/m^3$ on the W. sides), at 25 m. SO2 concentrations would be 32 $\mu g/m^3$ and 20 $\mu g/m^3$ (50%) and at 100 m. they would be 21 $\mu g/m^3$ on the E. sides of trees and 13 $\mu g/m^3$ on the W. sides.

Therefore, it may be postulated that on the E. edge of Horsley Hope Ravine, atmospheric SO2 concentrations are sufficiently high to cause some depletion of the lichen vegetation. The E. sides of trees, which receive more SO2 than the W. sides would suffer more in this respect.

From the edge of the ravine towards the valley-floor, SO2 concentrations decline significantly, eventually (between 25 m. and 100 m.) reaching levels which are too low to be harmful to lichens, and becoming equally distributed with respect to tree trunk aspect. The lichen flora from 0 to 100 m. might be expected to improve as SO2 levels decline downslope.

Re-examining the T.F.V.data (as described in this chapter, section 3, A), it has been shown that in transects I, II, V (E.), VIII and XII (E.) and XI (E. and W.) T.F.V.s increase from 0 - 40-50 m. These transects were all undertaken on the E. edge of Horsley Hope Ravine, and it is therefore suggested that the improvement in the lichen flora in the upper part of these transects is due entirely to the decline in SO2 levels -- irrespective of the decreasing light values. The steady rise in T.F.V.s and species numbers in these 4 sets of transects - up to attainment of the constant level at about 40-50 m. - is adequately explained by the recorded decline of SO2 concentrations over this section of Horsley Hope Ravine. Below 40-50 m., SO2 levels are clearly too low to cause any inhibition of lichen species, so that as with light intensity, the effects of SO2 variations are confined to the upper 40-50 m. of the transects.

Finally, on some transects - I, II, V (W.), VIII, XII (W.), and III, IV (E.) - T.F.V.s were shown to rise at first (0 - 20-30 m.) and then to decline. In the preceding discussion, it has been made clear that an increase in T.F.V.s is due to declining SO2 levels, while a decrease in T.F.V.s is explained by declining light levels.

Thus, where both an increase and decrease in T.F.V.s occur on the same transect - it may be hypothesized that both light and SO2 influence lichen distribution. So, in transects I, II, V (W.) SO2 depresses gross values of lichen performance between 0 and 10 m. (about 41μg/m^3 of SO2 per annum on the W. sides of trees). As SO2 levels decline downslope (only 20μg/m^3 at 25 m.) T.F.V.s increase (1300-1520) - but at about 30 m. light becomes inhibiting (particularly as it is the downslope sides of trees in all 3 sets of transects) and T.F.V.s therefore decrease (1520-1345) until the constant level is attained at 50-60 m.

From these 3 patterns of T.F.V. variation between 0 and 40-50 m., a model may thus be built:-

(i) T.F.V. decline. Levels of SO2 pollution are low and do not affect lichen performance. The steady fall in light intensity downslope leads to an equally steady decline in T.F.V.s from a high value at 0-10 m. to the constant level at 40-50 m. The rate of decline is faster on the darker downslope sides of trees. Transects: VI and VII (N. and S.); III, IV (W.). Transects VI and VII were carried out in the sheltered heart of Horsley Hope Ravine where SO2 levels are likely to be low. Transects III and IV (W.) suffered minimally from SO2 pollution, presumably through a combination of the effects of aspect (W. sides of trees) and position (W. edge of Horsley Hope Ravine).

(ii) T.F.V. increase. Levels of SO2 are high and depress lichen performance at 0-10 m. The improvement in air quality downslope causes an increase in T.F.V.s. Light is not a significant factor in explaining the distribution of lichens - until 40-50 m., when T.F.V.s become constant in the dark, unpolluted conditions of the ravine environment. Transects I, II, V (E.); VIII, XII (E.); XI (E. and W.) - all carried out on the apparently more polluted E. edge of Horsley Hope Ravine.

(iii) T.F.V. increase and decline. Levels of SO2 are sufficiently high to inhibit lichen performance at 0-10 m. T.F.V.s increase downslope, as SO2 concentrations decline, but then attain values at which light intensities become limiting (on the downslope sides of trees), and consequently T.F.V.s decline until the constant level is attained. Transects I, II, V (W.); VIII, XII (W.); III, IV (E.). The first two sets of transects, on the W. sides of trees, received less SO2 than the respective E. sides, so that their patterns of T.F.V. change differ markedly from those calculated for I, II, V (E.) and VIII, XII (E.). In transects III, IV (E.), presumably some SO2 was deposited on the E. sides of trees on the W. edge of Horsley Hope Ravine - from which the W. sides of trees were protected.

The model thus suggests that SO2 is a more important factor in the downslope distribution of corticolous lichens than light; for SO2 inhibits gross values of lichen performance, irrespective of light intensities. Transect XI is interesting in this respect, because light intensity is obviously not (or at least, is only slightly) depressing T.F.V.s. So, T.F.V.s increase in both XI (E.) and XI (W.) as SO2 concentrations decrease, until a high constant level is attained at about 50 m. downslope. Transect XI (W.) does not display the T.F.V. increase/decrease pattern exhibited in I, II, V (W.) and VIII, XII (W.) where light intensity is limiting.

In Figs. 31-33, examples are shown of each T.F.V. pattern, and the downslope distribution of SO2 and light pertinent to each example. It is apparent from these graphs that variations in SO2 concentration and light intensity adequately explain the downslope changes in values of gross lichen performance.

C) The Downslope Distribution of Lichen Species

Obviously, the downslope variation in T.F.V.s reflects the downslope distribution of the % frequency measurements of individual lichen species. The explanations put forward to account for the changing values of total frequency down the valley-side are therefore also applicable to the patterns of downslope distribution revealed by each lichen species.

In TABLE XXVII, the mean correlation coefficients between % frequency in 10 m. sectors and distance down the valley-side - for each species - are presented. The first column shows the mean correlation coefficients for all transects except XI, and the second column shows the mean values obtained in transect XI. The table is subdivided into a number of lichen groups on the basis of the significance of the correlation coefficients - each group comprising species with a similar pattern of downslope distribution according to the two mean correlation coefficients obtained.

Considering the downslope variations of SO2 and light intensity described above, different patterns of lichen

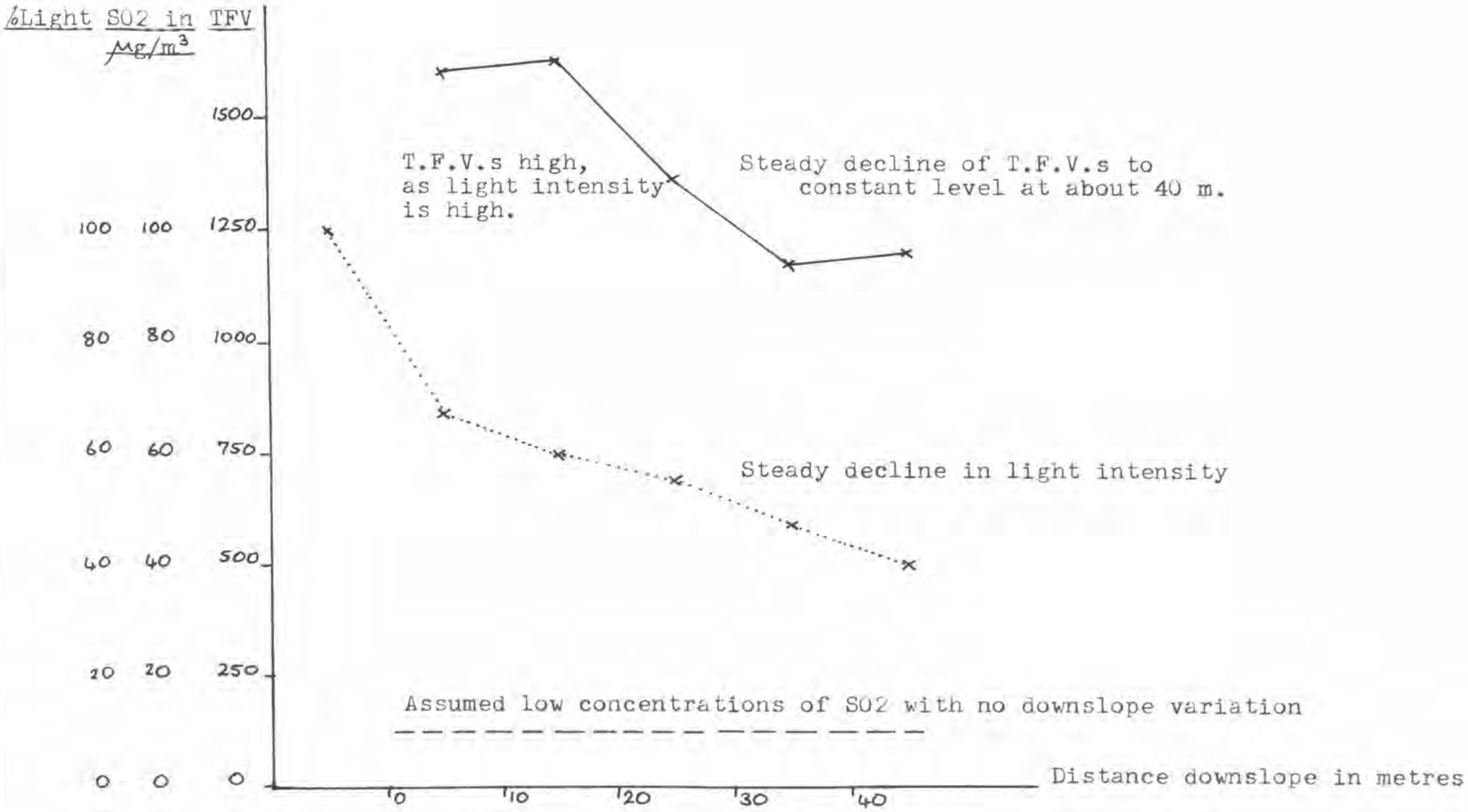

Fig. 3I : Distribution of T.F.V.s, light intensity and SO2 along transects VI, VII (N.).
Model type (i): T.F.V. decline.

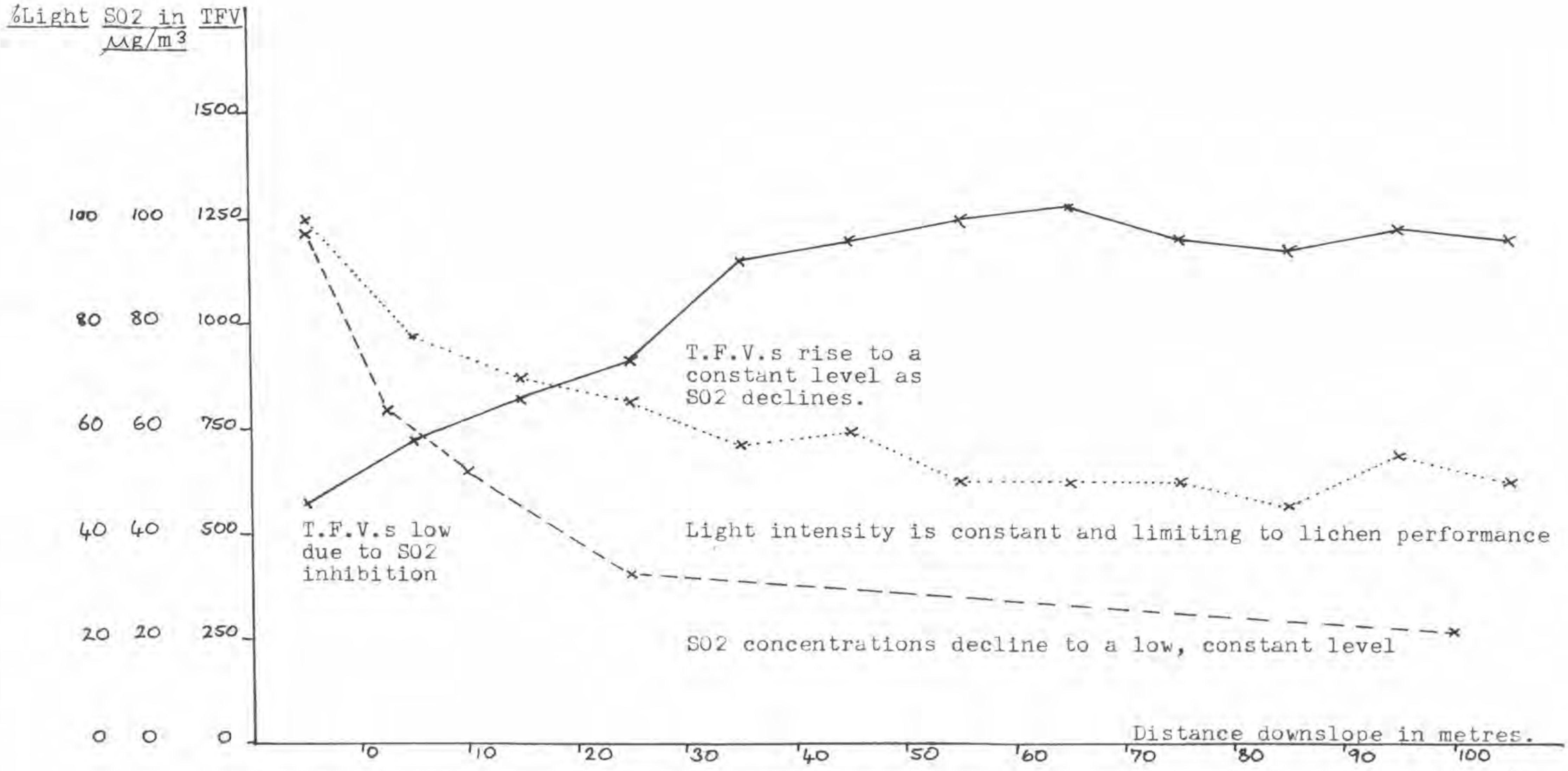

Fig. 32 : Distribution of T.F.V.s, light intensity and SO2 along transects I,II,V,(E.) Model type (ii):T.F.V. increase

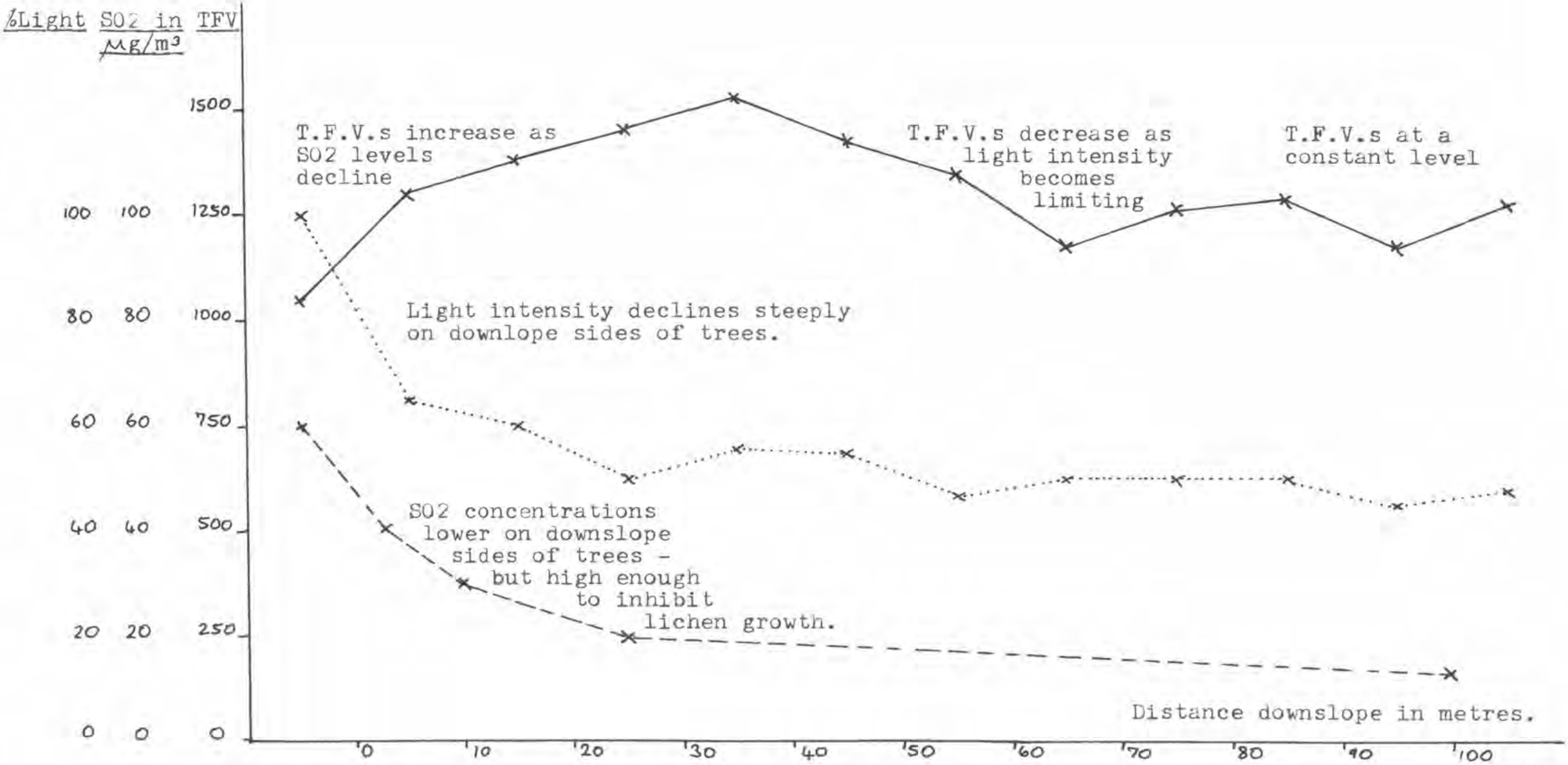

Fig. 33 : Distribution of T.F.V.s, light intensity and SO2 along transects I,II,V,(W.). Model type (iii): T.F.V. increase and decrease.

distribution, as revealed in the groups identified in TABLE XXVII, may be accounted for as follows. A significant positive correlation in column 1 indicates species which find the dark, unpolluted conditions of Horsley Hope Ravine favourable - that is, photophobous, SO2-sensitive species. A significant positive correlation in column 2 implies that these lichens are light-demanding and SO2 sensitive. Negative values show that the opposite conditions apply. Thus, considering each group and its response to the ecological implications of declining levels of SO2 and light as shown by positive or negative r values, the following relationshipe are clarified:-

Group 1 - Negative r values in both columns of TABLE XXVII show that these species are not sensitive to SO2; nor are they photophilous - for they decline in abundance along transect XI - and the negative r value in column 1 is therefore not a response to decreasing light intensity, but is presumably related to decreasing SO2 levels. It is thus suggested that the species in Group 1 are SO2-tolerant, not influenced by light-intensities, and they decline in frequency downslope as a result of competition from other vigorous lichens which are SO2-sensitive and thus able to survive in Horsley Hope Ravine.

Group 2 - These lichens increase in frequency in all transects. This implies that they are sensitive to SO2; and again, that they display no reaction to changes of light intensity. The downslope increase in the SO2-sensitive species of group 2, in part accounts for the downslope decrease of SO2-tolerant species belonging to group 1.

Group 3 - The positive r values of column 2, and negative r values of column 1, point to the strongly photophilous nature of the species in group 3. Concerning SO2-sensitivity, the results are conflicting, but in view of the obvious light-demanding habit of these lichens, it is suggested that the significant negative r values of column 1 are due to the decline in light intensity, rather than to the downslope decrease of SO2 levels. Thus, group 3 species are considered to be SO2-sensitive, as suggested by the r values of column 2.

Group 4 - With positive r values in column 2, and constant mean r values in column 1, the lichens of group 4 are seen to be photophilous - but not as strongly so as in group 3. They are, however, probably more sensitive to SO2, or else would show negative r values in column 1, as did group 3 species (i.e. highest % frequencies between 0 and 10 m.).

Group 5 - The positive r values of column 1 indicate that these species are photophobous and SO2-sensitive. Their complete absence, or slight increase downslope in transect XI tends to confirm that they are true ravine woodland species.

Group 6 - These two species are really similar in ecological characteristics to the lichens of group 3 - but clearly less photophilous and less SO2-sensitive.

Group 7 - Neither of these lichens appears to show any relationship to downslope changes in light intensity or SO2 concentrations. Both record consistently high values of % frequency throughout the transects, and it is presumed that these two species are very resistant to fluctuations in the measured environmental parameters.

These results are summarised in TABLE XXX. Moreover, included in TABLE XXX is a breakdown of the ecological requirements of each group, as obtained from the ecological details given for each species in TABLE I, from a variety of sources.

It can be seen that there is good agreement between the two sets of data, which supports the validity of the results obtained from Horsley Hope Ravine, and again suggests that SO2 levels and light intensity control the downslope distribution of lichens in the ravine.

Of particular interest are the figures for group 5, which show that not only are the 'ravine-loving' species SO2-sensitive and photophobous, but that they are also in the main hygrophilous as well. This unexpected, but not surprising detail indicates that the lichen groups might possibly be further differentiated on the basis of response to moisture-content. The only two groups to show positive mean r values in column 1 (2 and 5) were also the only two groups in which hygrophilous species appeared. The ravine environment is by implication, therefore, damper as well as darker, and this factor is well brought out in TABLE XXX.

~~Model type (i), in which T.F.V.s are high between~~

	From TABLE XXVII		From TABLE I.		
	SO2-sensitive	Photophilous	S	P	H
Group I	/	-	0	0	0
Group 2	+	-	42	0	28
Group 3	+	+	62	75	0
Group 4	+	+	I00	7I	0
Group 5	+	/	80	20	60
Group 6	+	+	0	I00	0
Group 7	-	-	0	0	0

TABLE XXX : Relation of lichen groups to SO2 and light - comparison of details revealed from Horsley Hope Ravine, with general knowledge of lichen ecology.

+ = relationship exists

/ = reverse relationship exists

- = no relationship exists

S = % of species in group designated as sensitive to more than 65 μgSO2/m^3 in TABLE I

P = % of species in group designated as photophilous in TABLE I

H = % of species in group designated as hygrophilous in TABLE I

Finally, the downslope distribution of individual lichen species, as categorised into the 7 groups of downslope distribution pattern, may be considered in relation to the model developed previously (see TABLE XXXI).

Model type (i), in which T.F.V.s are high between 0 and 10 m. and then decline downslope with decreasing light intensities, is obviously characterised by a fall in the frequency of photophilous lichens. Thus groups 3,4 and 6 must decline in type (i); and the photophobous species of group 5 will increase downslope. As SO2 levels are thought to be consistently low along type (i) transects, group 1 species will probably be uncommon throughout, and group 2 lichens constantly abundant.

In model type (ii), in which T.F.V.s increase as SO2 concentrations decline, the SO2-sensitive groups of lichens (2-6) should all increase. The rate of increase should be greater in groups 2 and 5 which will not be so affecred by the downslope fall in light intensity. The SO2-resistant lichens in group 1 will decline in frequency, as a result of competition by other species.

For model type (iii) - again groups 2 and 5 will steadily increase downslope, and group 1 will decline. But the increase-decrease pattern of T.F.V.s in type (iii) should be reflected in a similar increase-decrease sequence in the % frequencies of lichen groups 3,4, and 6 which will at first become more common as SO2 levels fall, but then will decline in abundance as light intensities become limiting to the photophilous species of these 3 groups.

Comparison of the lichen groups recognised in

	Lichen Groups						
	1	2	3	4	5	6	7
Model type (i)	0	0	-	-	+	-	0
Model type (ii)	-	+	+	+	+	+	0
Model type (iii)	-	+	X	X	+	X	0

TABLE XXXI : Relationship between lichen groups and the three model types.

+ = downslope increase

− = downslope decline

0 = no change

X = downslope increase and decrease

TABLE XXVII, with their detailed distribution patterns presented in TABLES XV - XXVI, shows that these relationships do in fact occur. Thus, each lichen group - with its varying pattern of downslope distribution - responds in a different way to changes in light intensity and SO2-concentration, (TABLE XXXI). In this way, the distribution of individual lichen species down the valley-side is related to downslope changes in T.F.V.s, and may be explained in terms of the same two environmental parameters.

6. Explanations for The Relationships Between Lichen Distribution and Aspect in Horsley Hope Ravine.

The significant differences in the corticolous lichen vegetation of the upslope and downslope sides of trees have been described previously. The relationship between aspect and lichen flora (in terms of component species - not T.F.V.s or species numbers) is most marked within Horsley Hope Ravine.

Part of the explanation for this distinct distribution pattern has already been provided in section 5: the upslope sides of trees are lighter, and in certain cases more polluted, than the downslope sides. Thus, lichens which are photophilous and/or SO2-resistant may be presumed to be more common on the upslope sides of trees. However, variations in light intensity and SO2 concentration according to tree trunk aspect, have been shown to occur in only the upper 40 m. or so of the ravine slopes. Reference to Figs. 22 and 23 reveals that the distribution of Lecanactis abietina and Phlyctis argena is closely related to aspect throughout the lengths of transects I-V, and moreover, the upslope/

downslope patterns of distribution shown by these 2 species are particularly well differentiated below the 40-50 m. mark. In fact, upslope/downslope differences are rather obscure between 0 and 40-50 m. (especially in Fig 22) and become clear-cut between 40-50 m. and the ravine floor.

This suggests that some factor other than SO2 and light intensity is responsible for the observed lichen distribution/aspect features in Horsley Hope Ravine.- particularly between 40-50 m. and the valley bottom where SO2 and light intensities are virtually constant, irrespective of aspect.

The cause of the distinct upslope/downslope lichen vegetation pattern is thought to be related to tree trunk inclination. Circumstantial evidence for this opinion is provided by thefact that throughout every transect a very marked upslope/downslope pattern of lichen distribution occurred - irrespective of slope aspect; and on every transect the great majority of trees leaned downslope - again irrespective of slope aspect.

The ecological link between inclined trees and corticolous lichen vegetation patterns was referred to in Chapter 2, section 1, A. The upslope sides of trees collect and retain more moisture than the downslope sides of trees. Thus, the damp upslope sides can support moisture-loving (hygrophilous) lichens, which cannot survive on the dry undersides of trees. Xerophytic species occupy the lower sides of inclined trees; and consequently a distinct upslope/downslope pattern of lichen distribution occurs in response to these variations in bark moisture-content.

From Figs. 22 and 23, therefore, it may be assumed that Lecanactis abietina, which is recorded mainly from the downslope sides of trees, is a xerophytic lichen, tolerant of dry conditions; while Phlyctis argena which favours the upslope sides of trees is a hygrophilous species, with a high moisture requirement.

Further evidence to support the postulated relationship between tree trunk inclination and lichen distribution/ aspect phenomena is provided by the following two points:

(i) Bryophytes are especially dependent upon high levels of substrate moisture. The presence of mosses on the upslope sides of trees in Horsley Hope Ravine, but not on the downslope sides, confirms that the upslope sides are wetter.

(ii) Occasionally, trees leaned in directions other than that of the slope aspect. For instance, on flatter slope sections, some trees were not inclined in the downslope direction, but leaned upslope. It was observed that on these trees, the lichen vegetation pattern changed in relation to the change of tree trunk inclination. Thus, if an odd tree was inclined to the N. on a S.-facing slope, the lichen species characteristic of the upslope sides of trees occurred on the S. sides and those species favouring the downslope sides of trees were recorded on the N. side - contrary to the expected pattern. This observation can only be explained by assuming some relationship between corticolous lichen vegetation and direction of tree trunk inclination.

Thus, angle and direction of tree inclination are important controls on corticolous lichen substrate ecology - affecting moisture availability to lichens. Effectively, a leaning tree creates two different micro-habitats, which support two different lichen assemblages - one on the wetter upslope sides of trees, and one on the drier downslope sides.

As considered above, between 0 and 40-50 m., variations in light intensity and SO2-concentrations also affect the upslope/downslope pattern of lichen distribution. The influence of these two parameters is such that in Figs. 22 and 23, the distinct % frequency/aspect relations of Lecanactis abietina and Phlyctis argena, as revealed from 40-50 m. to the valley-floor, are disrupted and obscured between the edge of the ravine and 40-50 m. downslope.

For this reason, the results presented in TABLE XXVIII are not in themselves conclusive. Species preference for the upslope or downslope sides of trees is expressed in this table by comparing the summed % frequencies of a species on the downslope sides of trees with its summed % frequencies on the upslope sides - for all transects over their entire lengths. In the third column of TABLE XXVIII, species towards the top of the list are generally more common on the downslope sides of trees, and species near the base of the table are typically associated with upslope sides. However, in this table a lichen species may be classed, for example, as an 'upslope species', whereas in fact it could be an upslope species only from 0 - 40-50 m. (perhaps being photophilous), and from 40-50 m. to the ravine floor it may be constant with respect to trunk aspect.

In other words, because TABLE XXVIII calculates the preferred position of lichen species with respect to aspect over the whole valley-side, differences which exist between the distribution/aspect pattern of the upper (where light and SO2 levels are significant) and lower (where moisture availability is the only factor to vary with aspect) sections of the valley-side are not revealed.

In TABLE XXXII this matter is rectified. Summed % frequencies of species on the upslope and downslope sides of trees are compared, as in TABLE XXVIII, but the comparison is carried out separately for: (a) the results obtained between 0 and 40-50 m., and (b) the results obtained between 40-50 m. and the valley-floor. Only the results of transects I-V were used in this exercise - the other transects being too short to be of use, or not uniform, as in transect XI. The ratios of % frequency on the downslope sides of trees/% frequency on the upslope sides of trees, as obtained for the upper and lower slope sections, are presented in descending order of values obtained for the section 40-50 m. - valley floor.

As with TABLE XXVIII, values greater than 1.0 imply that a species is more common on the downslope sides of trees, and values less than 1.0 indicate the reverse.

Thus, species towards the top of the table, are downslope species (from 40-50 m. downslope) and are likely to be xerophytic; while those near the foot of the table are upslope species and probably hygrophilous. It has been assumed that values between 0.8 and 1.2 do not differ sufficiently from unity to permit species with

	0 - 40-50 m:	40-50 m. - stream:
	Total % frequencies on downslope sides. / Total % frequencies on upslope sides.	Total % frequencies on downslope sides. / Total % frequencies on upslope sides.
Lepraria candelaris	-	5.73
Lecanora chlarotera	0.92	3.36
Chaenotheca ferruginea	I.73	3.I4
Calicium viride	2.50	2.93
Lecanactis abietina	3.20	2.48
Toninia caradocensis	0.75	2.09
Pertusaria albescens	I.26	I.30
Catillaria griffithi	I.43	I.2I
Pertusaria pertusa	I.22	I.II
Lecidea scalaris	0.95	I.08
Usnea subfloridana	0.4I	I.08
Gyalecta flotowii	-	I.07
Pertusaria amara	I.23	I.04
Lecidea quernea	I.II	I.02
Lecanora expallens	I.08	I.02
Lepraria incana	0.99	I.0I
Parmeliopsis ambigua	I.20	I.00
Hypogymnia physodes	I.24	0.85
Evernia prunastri	I.30	0.85
Hypogymnia tubulosa	0.98	0.83
Lecanora conizaeoides	I.03	0.8I
Alectoria fuscescens	0.50	0.8I
Arthonia spp.	0.82	0.80
Parmelia saxatilis	I.04	0.7I
Parmelia sulcata	I.I3	0.69
Thelotrema lepadinum	0.95	0.68
Pertusaria hemisphaerica	I.09	0.64
Ochrolechia androgyna	0.78	0.55
Parmelia glabratula	0.87	0.5I
Ochrolechia turneri	0.62	0.48
Parmelia subaurifera	0.79	0.47
Lecanora chlarona	0.90	0.46
Phlyctis argena	0.9I	0.43
Cetraria glauca	0.8I	0.33
Cetraria chlorophylla	I.50	-
Pertusaria hymenea	-	-

TABLE XXXII : Comparisons (ratios) of the summed % frequencies of each species on the upslope and downslope sides of trees - for two different valley-side sections : 0 - 40-50 m., and 40-50 m. - stream.

downslope/upslope ratios of this order to be classified into one category or the other. The gaps in the table thus separate those species which show little relationship with aspect between 40-50 m. and the ravine floor, from those which are considered to be clearly upslope or downslope oriented.

Some interesting features are highlighted in TABLE XXXII. All the downslope species (from 40-50 m. downslope) as recognised in the table, are crustose lichens. It was considered in Chapter 2, section 1 that the crustose growth-form is generally less moisture-demanding - and this fits the expected xerophytic habit of those species associated with the downslope sides of trees. Concerning the upslope species (of column 2) 5 of these were noted as hygrophilous in TABLE I, and of the remaining 7, 4 are foliose (high substrate moisture-requirement) - which again supports the idea of upslope/downslope lichen pattern differentiation being due to moisture availability.

Details revealed in TABLE XXXII may usefully be compared with points noted in TABLE XXVIII. For example, in TABLE XXVIII, 5 species were included in the bottom group (lichens with a very marked upslope preference). In TABLE XXXII, 4 of these species - <u>Thelotrema lepadinum</u>, <u>Lecanora chlarona</u>, <u>Parmelia glabratula</u>, and <u>Phlyctis argena</u> - are again in the bottom group, suggesting that these 4 are hygrophilous species with a marked preference for the upslope sides of trees in the lower parts of Horsley Hope Ravine. Moreover, all these 4 species record values greater than 0.87 between the edge of the ravine and 40-50 m.

downslope, showing that their distribution may not be related to aspect in the upper slope sections of the ravine. Presumably therefore, the influence of increased light intensities and/or increased levels of SO2 on the upslope sides of trees between 0 and about 40 m. restricts the frequency of these 4 species, such that no distribution/ aspect pattern may be detected. The fifth species (<u>Alectoria fuscescens</u>) is shown in TABLE XXXII to be fairly evenly distributed between the upslope and downslope sides of trees from 40-50 m. to the valley floor; but there is a clear preference for the upslope sides of trees (0.50) between 0 and 40-50 m. This is undoubtedly a function of the known photophilous habit of <u>Alectoria fuscescens</u>. Thus, of 5 species recognised as upslope lichens in TABLE XXVIII, it may be seen that the upslope preference of 4 species is related to their hygrophilous nature, an ecological factor which is obviously subordinate to the influence of light and SO2 above 40-50 m., where these 4 species show little or no relation to aspect; and the upslope preference of the remaining species is due to its high light requirement which encourages its growth on the upper sides of trees between 0 and 40-50 m. - whereas, it is fairly constant with respect to upslope/downslope distribution below this point.

This sort of analysis could be carried out for every species, but in fact this would only duplicate information which may be gleaned from TABLE XXXII. Therefore, the details contained in TABLE XXXII are summarised below.

It is apparent that the distribution of corticolous lichens with respect to aspect in Horsley Hope Ravine follows a clear upslope/downslope pattern. The controlling factors responsible for this observed pattern are:-

(i) 40-50 m. to the valley-floor: the upslope sides of trees are wetter and bear hygrophilous lichens (lower group on table); the downslope sides are drier and bear xerophytic species (top group in table). These lichen assemblages are quite distinct, although T.F.V.s have been shown to be constant with respect to aspect in the lower slope sections.

(ii) 0 - 40-50 m.: a confused pattern exists, because a number of ecological parameters are active here (the variation in T.F.V.s with aspect showed a similar complex pattern). The upslope sides of trees are lighter (hence photophilous species are more common e.g. <u>Alectoria fuscescens</u>, <u>Usnea subfloridana</u>), more polluted (hence the low ratios of SO2-resistant lichens e.g. <u>Ochrolechia turneri</u>), and again wetter (although no hygrophilous species show a significant preference for the upslope sides of trees between 0 and 40-50 m., presumably because of the overriding influence of the first 2 factors). The downslope sides of trees are similarly influenced by variations in light and SO2 between 0 and 40-50 m. - but to a lesser extent. Because they are darker and less polluted, conditions on the downslope sides of trees do not differ so markedly from those of the true ravine environment below 40-50 m. Thus the downslope xerophytic species such as <u>Lecanactis abietina</u>, <u>Calicium viride</u> and <u>Chaenotheca ferruginea</u> (as noted for the section 40-50 m to the valley floor) are relatively unaffected by the higher levels of light and SO2 characteristic of the upper slope sections. (Note the equivalence of the two ratios for each species in the top part of the table.) Certain SO2-sensitive and fairly photophobous species predictably occur more frequently on the downslope sides of trees (e.g. Pertusaria pertusa, P. amara) between 0 and 40-50 m., and then show no relationship to aspect further downslope. Generally, however, species favouring the drier undersides of trees between 40-50 m. and the ravine bottom are more frequent on the downslope sides of tree trunks over the whole valley-side (this explains why species near the top of TABLE XXXII are also consistently towards the top of TABLE XXVIII). This statement may clearly not be applied to the upslope sides of trees, where light and SO2 are so significant within the upper 40 m. of the valley-side, and markedly disrupt lichen/aspect distribution patterns.

7. Phytosociological Relationships of the Lichen Species Recorded in Horsley Hope Ravine

It has now been shown that the distribution of corticolous lichens in Horsley Hope Ravine may be considered to be controlled by 3 factors: light, SO2, and substrate moisture-content. Patterns of corticolous lichen distribution in a downslope direction and in relation to tree trunk aspect are clearly influenced by these 3 parameters.
An attempt is now made to sort the lichen data collected in Horsley Hope Ravine into a number of units, which comprise lichen species showing uniform ecological relationships and

overall distribution characteristics (with respect to both changes in % frequency down the valley-side, see TABLE XXVII; and tree trunk aspect pattern, see TABLE XXXII). This is no simple matter, owing to the complex patterns of lichen distribution observed in the ravine, and described in previous sections. Moreover, the use of mathematical methods of floristic association are precluded by the volume of data collected. However, in TABLE XXXIII, this exercise has been carried out, and the lichens recorded on Horsley Hope Ravine have been sorted into 4 reasonably homogenous units.

The final column in TABLE XXXIII refers to certain alliances and associations recognised by Barkman[5] in his work on lichen phytosociology. These are described below:-

(i) *Alliance Parmelion Saxatilis (Physodion, Almborn)*. Photophilous, toxiphilous, and common on oak.

a) Association Parmelietum furfuacea: *Hypogymnia physodes*, *H. tubulosa*, *Evernia prunastri*, *Parmelia furfuracea*, *P. saxatilis*, *P. sulcata*, *Cetraria glauca*, *C. chlorophylla*, *Alectoria fuscescens*, *Usnea subfloridana*.

(ii) *Alliance Graphidion Scriptae*

Hygrophilous, photophilous, toxiphilous, and common on oak.

a) Association Pertusarietum amarae: *Pertusaria pertusa*, *P. coccodes*, *P. hemisphaerica*, *P. amara*, *Phlyctis argena*, *Lepraria incana*, *Evernia prunastri*, *Opegrapha varia*.

b) Association Thelotremetrum lepadini: as above plus *Thelotrema lepadinum*, *Opegrapha viridis*.

iii) *Alliance Calicion Hyperelli (Leprarion, Almborn)*

Xerophytic, photophobous, acidophytic, fairly toxitolerant, and common on dry undersides of oak.

a) Association Lecanactidetum abietinae: *Chaenotheca ferruginea*, *Arthonia spp.*, *Lepraria incana*, *Lecanactis abietina*, *Ochrolechia androgyna*, *Parmeliopsis ambigua*.

b) Association Chaenothecetum melanophacae: *Calicium viride*, *Lepraria candelaris*, *Lecidea scalaris*, *Lecanora expallens*, *Lepraria incana*, *Chaenotheca ferruginea*.

(iv) Alliance Lecanorion Variae

Acidophytic, photophilous, toxitolerant

a) Association Lecanoretum pityreae: *Lecanora conizaeoides*, *L. expallens*, *L. chlarona*, *Hyopgymnia physodes*, *Parmelia saxatilis*, *Lecidea scalaris*, and other crustose spp.

Referring to TABLE XXXIII, the first unit includes species shown in TABLE XXVII to be photophilous and SO2-sensitive (groups 3, 6 and 4). These lichens all increase downslope in transect XI, and decrease in frequency (or are constant) with respect to distance down the valley-side in the remaining transects. Concerning preferred position on the tree trunk - this is more variable. None of the species in unit 1 are seen to be xerophytic. In fact, mostly they show no relationship to upslope/downslope sides of trees between 40-50 m. and the ravine floor - but some do indicate a preference for the upslope sides of trees (hygrophilous). Between 0 and 40-50 m., the distribution of many species exhibits no connection with aspect. Two species are associated with the upslope sides of trees, and these are both known to be extremely photophilous lichens. Others clearly favour the downslope sides of trees between the edge of the ravine and 40-50 m. It is most

Species	Downslope Distribution			Aspect		TABLE I			Growth Form	Phytosociology
	Group	SO2	Light	0-40-50m	40-50m->	S	P	H		
UNIT I										
Alectoria fuscescens	3	+	+	U		S	P		Fr	(i)
Usnea subfloridana	4	+	+	U		S	P		Fr	(i)
Hypogymnia tubulosa	6	+	+				P		Fo	(i)
Pertusaria hymenea	3	+	+						C	
Cetraria glauca	3	+	+		U	S	P		Fo	(i)
Parmelia saxatilis	6	+	+		U		P		Fo	(i)/(iv)
Parmelia sulcata	3	+	+		U	S	P		Fo	(i)
Lecanora chlarona	3	+	+		U				C	(iv)
Evernia prunastri	3	+	+	D		S	P		Fr	(i)
Hypogymnia physodes	3	+	+	D			P		Fo	(i)/(iv)
Cetraria chlorophylla	3	+	+	D		S	P		Fo	(i)
Pertusaria pertusa	4	+	+	D		S	P		Fo	(ii)
Pertusaria amara	4	+	+	D		S	P		Fo	(ii)
UNIT 2										
Phlyctis argena	2	+			U			H	C	(ii)
Pertusaria hemisphaerica	5	+	–		U	S	P		C	(ii)
Thelotrema lepadinum	5	+	–		U			H	C	(ii)
Opegrapha vermicellifera	5	+	–		U			H	C	
Parmelia glabratula	4	+	+		U	S		H	Fo	
Parmelia subaurifera	4	+	+		U	S			Fo	
Gyalecta flotowii	5	+	–			S			C	
Lecidea quernea	2	+							C	
Arthonia spp.	2	+				S		H	C	(iii)
UNIT 3										
Lecanactis abietina	2	+		D	D				C	(iii)
Calicium viride	2	+		D	D	S			C	(iii)
Chaenotheca ferruginea	2	+		D	D				C	(iii)
Catillaria griffithi	2	+		D	D				C	
Lepraria candelaris	5	+	–		D				C	(iii)
Lecanora chlarotera	4	+	+		D	S			C	
Pertusaria albescens	4	+	+	D	D	S			C	
Toninia caradocensis	I	–		U	D				C	
UNIT 4										
Ochrolechia androgyna	I	–		U	U				C	(iii)
Ochrolechia turneri	I	–		U	U				C	
Parmeliopsis ambigua	I	–							Fo	(iv)/(iii)
Lecanora conizaeoides	I	–							C	(iv)
Lecanora scalaris	I	–							C	(iv)/(iii)
Lepraria incana	7							H	C	(iv)/(iii)/(ii)
Lecanora expallens	7								C	(iv)/(iii)

TABLE XXXIII : Lichen units, classified according to species ecological relations and distribution in the Ravine + = positively related to light or SO2; – = negatively related to light or SO2; D = Downslope, U = upslope (TABLE XXXII); Fr = fruticose; Fo = foliose; C = crustose; Phytosociology - see text noticeable that with few exceptions, the lichens in this first unit are all fruticose and foliose, and photophilous and SO2-sensitive (see TABLE I).

Referring to Barkman's phytosociological system, it may be seen that most species in this first unit belong to his (i) *Alliance Parmelion Saxatilis*, a) Association Parmelietum furfuracea. Barkman describes the alliance as photophilous and toxiphilous - as indeed, all the lichens in this first unit are. It is thus considered that the mainly foliose and fruticose lichens of unit 1, which are photophilous, SO2-sensitive, and perhaps slightly hygrophilous; and which are constant or decline in frequency downslope (except for transect XI), and show no homogenous pattern with respect to tree trunk aspect, broadly conform to Barkman's alliance (i), association a). It may also be noted that the inclusion of certain species in unit 1, gives this unit some affinities with other alliances recognised by Barkman - (ii) the *Graphidion Scriptae* and (iv) the *Lecanorion Variae*. Included in the latter are three of the more SO2-resistant lichens in the first unit; whilst *Pertusaria pertusa* and *P. amara* might by some criteria be better placed in unit 2 (equivalent to the *Graphidion Scriptae*) than in unit 1.

The unifying features of lichens in unit 2 in TABLE XXXIII are that they are SO2-sensitive and not photophilous (groups 2, 5 and to a lesser extent 4), and hygrophilous (prefer the upslope sides of trees between 40-50 m. and the ravine floor). They are mainly crustose species, and being associated with low light intensities, never fruticose.

A high proportion of these species were noted as being hygrophilous in TABLE I. None of the lichens in unit 2 show any relationship with aspect in the upper slope sections, and they are all considered to be true 'ravine lichens'.

Comparing this unit with Barkman's phytosociological classification, it can be seen that three of the lichens in unit 2 are placed in the (ii) *Alliance Graphidion Scriptae*, Associations a) and b). This alliance is described by Barkman as hygrophilous, photophilous, and toxiphilous. Apart from the varying response to light shown by the species in unit 2, this ecological description tallies well. Thus unit 2 is assumed to represent a version of the *Graphidion Scriptae*.

Between units 2 and 3, are three lichens which clearly favour the ravine environment, (they belong to groups 2 and 5, and thus increase in frequency downslope) but do not show any preference for the upper or lower sides of leaning trees. They may therefore be considered to belong to both units 2 and 3.

In unit 3 are the xerophytic lichens which are strongly associated with the downslope sides of trees between 40-50 m. and the valley floor. Again, all are 'ravine-loving species', becoming more common downslope, and showing little or no relationship to light intensity. Many of the lichens in unit 3, besides being essentially downslope species in the lower slope sections, also prefer the downslope sides of trees between the ravine edge and 40-50 m. down the valley-side (the reason for this was explained in the previous section). All the species in this unit have a crustose growth-form. This unit may be readily compared with the (iii) *Alliance Calicion Hyperelli*, Associations a) and b) - both in terms of component species, and ecological characteristics.

Toninia caradocensis is thought to have some relation with both units 3 and 4. It is a crustose lichen, which decreases in frequency downslope, preferring the lower sides of trees towards the floor of the ravine, and the upper sides near the top of the ravine. Its distribution pattern thus has affinities with both units 3 and 4.

Unit 4 comprises lichens classified as belonging to group 1 in TABLE XXVII. That is, they are SO2-resistant, unresponsive to changes in light intensity, and decline in frequency downslope. In general, the distribution of this unit does not appear to be related to tree trunk aspect, although two species show a clear preference for the upper sides of trees. The species in unit 4 are predominantly crustose, as expected of SO2-resistant lichens. With reference to Barkman's phytosociological system[5], unit 4 has affinities with two alliances - (iii) the *Calicion Hyperelli* and (iv) the *Lecanorion Variae*. The toxitolerant nature of unit 4, and the fact that it displays no xerophytic preferences, suggests that this unit is more closely related to (iv) the *Lecanorion Variae*, Association (a).

Finally, two species - *Lepraria incana* and *Lecanora expallens* - are apparently unrelated to light, SO2 or substrate moisture, for their frequency of occurrence is consistently high throughout Horsley Hope Ravine. These two species may therefore not be included in any one of the 4 units. It appears as if Barkman[5] also found these species to be ubiquitous for he includes them in a number of alliances and associations.

To summarise, therefore, 4 distinct lichen vegetation assemblages may be recognised in Horsley Hope Ravine:-

Unit 1 - Photophilous, SO2-sensitive lichens (foliose and fruticose) which decline in frequency towards the floor of the ravine, and show no clear preference with respect to tree trunk aspect. Related to the *Alliance Parmelion Saxatilis*

Unit 2 - Hygrophilous species with a marked preference for the upslope sides of trees (lower slope section), SO2-sensitive, and mainly photophobous. Mostly crustose and generally becoming more common downslope. Similar to the *Alliance Graphidion Scriptae.*

Unit 3 - Xerophytic lichens, associated with the undersides of trees, photophobous, increasing in frequency downslope, and all crustose. Corresponds to the *Alliance Calicion Hyperelli*.

Unit 4 - SO2-resistant species, which decline in occurrence downslope. Crustose lichens, showing in general no relationship with tree trunk aspect. Similar to the *Alliance Lecanorion Variae*.

8. Elaboration of the Model; Further Consideration of the Abiotic Controls on Lichen Distribution in the Ravine.

A. The Detailed Model

Corticolous lichen distribution in Horsley Hope

Ravine has been shown to be related primarily to the variation of 3 abiotic factors: light, SO2, and substrate moisture content. A number of lichen distribution patterns have been analysed in order to interpret the influence of these 3 controls. The distribution of T.F.V.s, downslope and according to the sides of trees, was examined, and a model designed to express the observed relationships. The distribution of lichen species down the valley-side was investigated, and 7 lichen groups with similar trends of downslope distribution (TAB.E XXVII) were recognised. These patterns were explained and incorporated into the model. Then the relationships between lichen aspecies distribution and aspect were outlined in detail, and reasons given to account for the marked upslope/downslope pattern of lichen distribution revealed in TABLES XXVIII and XXXII. Lastly, the observed trends of lichen species distribution - both with respect to distance downslope and preferred position on the tree trunk - were jointly considered to produce 4 units (associations) of lichen species with similar distribution patterns in Horsley Hope Ravine.

Ir is now proposed to elaborate upon the model devised previously, in order that this tool may be used to explain not only the variation in T.F.V.s in Horsley Hope Ravine, but also the distribution of 4 homogenous lichen units, which have been shown to reflect farirly accurately the distribution of individual species in the ravine. Again, this is probably best achieved with the help of diagrams (Figs. 34-37).

Firstly, however, it is necessary to obtain a quantitative measure of abundance for the 4 lichen units, so that their distribution within the ravine may be plotted according to the variation of this measure of abundance. Just as T.F.V.s were produced by summing the % frequencies of all species in each 10 m. sector of valley-side; so adding the % frequencies of all the species in each unit for each 10 m. sector provides a measure of the abundance of each unit within each 10 m. sector. This measure is termed the Unit Frequency Value (U.F.V.).

For each lichen unit, U.F.V.s were calculated separately in each 10 m. sector of the valley-side (for those transects examined by this means). So, for example, the variation in the U.F.V.s of unit 2 along a transect were obtained by summing the % frequencies of the 6 lichens in unit 2 (see TABLE XXXIII) in each 10 m. sector of the transect.

Because each of the 4 units contains a different number of species, U.F.V.s are of relative rather than absolute significance. Lichens considered in TABLE XXXIII to belong to none, or more than one, of the 4 units (<u>Gyalecta flotowii</u>, <u>Lecidea quernea</u>, <u>Arthonia spp.</u>, <u>Toninia caradocensis</u>, <u>Lepraria incana</u>, <u>Lecanora expallens</u>) have been excluded from the calculation of U.F.V.s.

By plotting the variation in U.F.V.s along different transects, the distribution of the 4 lichen associations in Horsley Hope Ravine may be related to the model described previously. Thus, U.F.V.s have been calculated for examples of the 3 model types recognised (see Figs 31-33) and the distribution of U.F.V.s along transects I, II, V (E.);

I, II, V (W.); VI, VII (N.); and VI, VII (S.) is shown in Figs. 34-37.

In Fig. 34, values of summed % frequencies for the species in each of the 4 lichen units are plotted along transects VI, VII (N.). In addition to showing the variation in the 4 U.F.V.s, the distribution of T.F.V.s is given for comparison. Because T.F.V.s decline between the start of the transects and 40-50 m. downslope, transects VI and VII (N.) conform to the pattern of model type (i). It can be seen from Fig. 34 that the high T.F.V.s towards the ravine edge, and their decline downslope, are due almost entirely to the similar distribution of U.F.V.s for unit 1. The lichens in unit 1 are photophilous, and their rapid downslope decrease in frequency is thus expected. The U.F.V.s of the other lichen associations do not vary to the same extent. Units 2 and 3 both increase steadily downslope (in response to the darker conditions); and the hygrophilous species of unit 2 are especially common - for these figures all relate to the upslope sides of trees. The decline in U.F.V.s of association 4 is of interest, for transects VI, VII (N.) are considered to be unpolluted throughout, and it might therefore be expected that the SO2-resistant species of unit 4 would record low, constant U.F.V.s along these transects. (see section 5, C of this chapter). The high T.F.V.s of transects VI, VII (N.) suggest that the cause of the decline in unit 4 species is not due to the influence of SO2 within the top 20 m. of the slope (causing the SO2 resistant lichens to be more abundant) but is related instead to the lower light intensities downslope. Thus, the lichens in

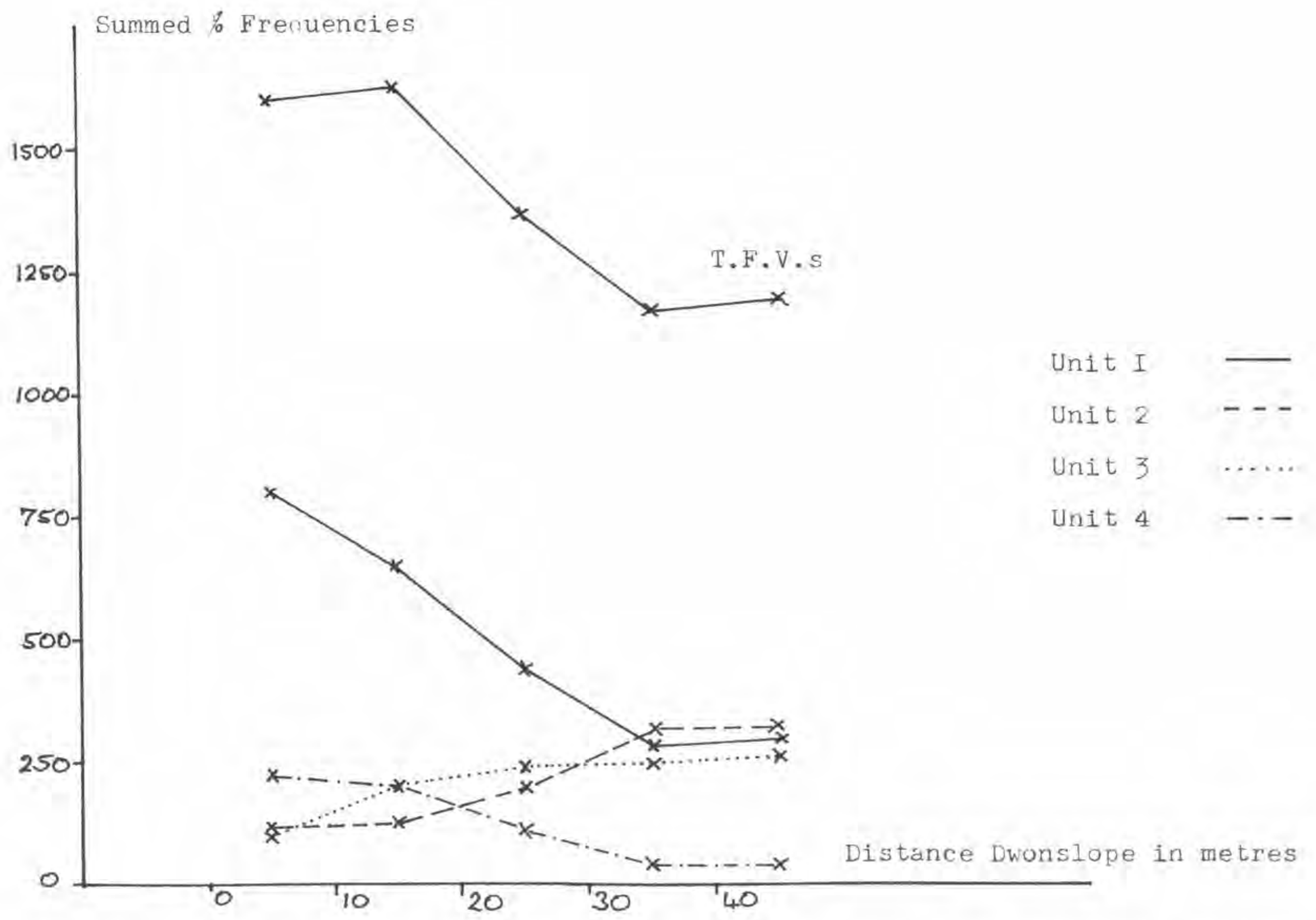

Fig. 34 : The Distribution of U.F.V.s along transects VI, VII (N.) - model type (i)

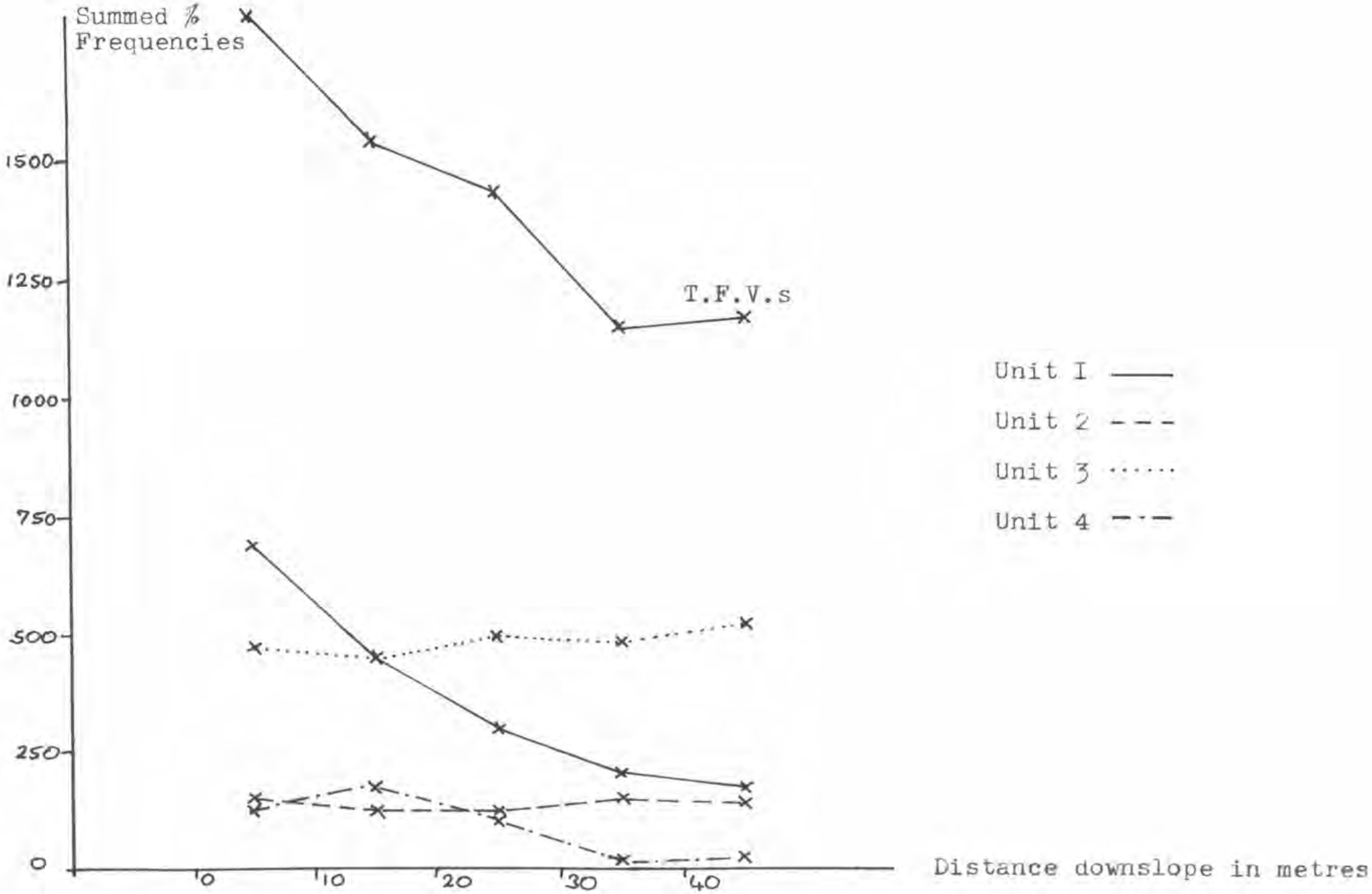

Fig. 35 : The Distribution of U.F.V.s along transects VI; VII (S.) - model type (i)

unit 4 are probably photophilous to some extent - a fact not revealed previously. It is noticeable that all 4 U.F.V.s are fairly constant over the bottom 20 m. of the transects - presumably therefore the concept of the 'constant level', as applied to T.F.V.s, is also referrable to the 4 U.F.V.s below about 40 m.

Fig. 35 plots the distribution of U.F.V.s and T.F.V.s along transects VI, VII (S.), which also belong to model type (i). The interesting feature of this graph is that it shows the change in U.F.V.s occurring on the undersides of trees - as distinct from the patterns pertaining to the upper sides of the same trees which were shown in Fig. 34. Again the distinct downslope decline in T.F.V.s corresponds to the fall of unit 1 species frequencies - although values in both units 1 and 4 are generally lower, because the downslope sides of trees are darker. This is further evidence for the photophilous habit of association 4 lichens. Of particular significance are the high U.F.V.s of unit 3, and the reduced figures for unit 2 - in response to the xerophytic conditions expected on the downslope sides of trees. As before, all U.F.V.s are approximately constant towards the floor of the ravine.

In Fig. 36, the U.F.V. distribution associated with model type (ii) is shown, with reference to transects I, II, V (E.). Here, the influence of relatively high levels of SO2 on the distribution of the 4 lichen units is clearly shown, for the occurrence of units 1, 2, and 3 is severely depressed. The lichens of unit 4 record high frequencies at the ravine edge, which decline slowly downslope.

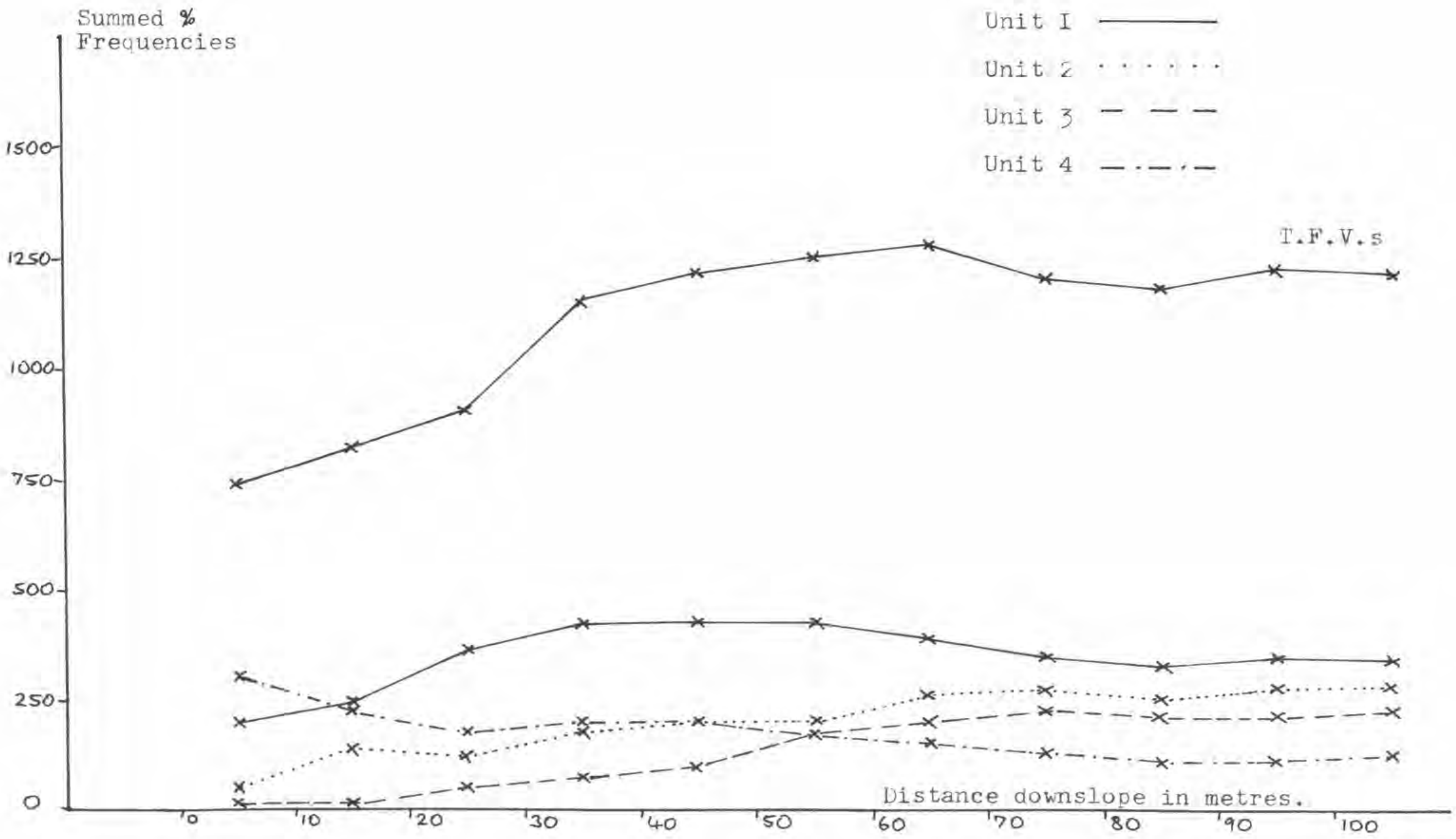

Fig. 36 : The Distribution of U.F.V.s along transects I, II, V (E.) - model type (ii)

The other 3 associations all become more abundant downslope, and this accounts for the increase in T.F.V.s with distance down the valley-side. It is interesting to compare Fig. 36 with Fig. 34 - both record the variation in U.F.V.s and T.F.V.s on the upper sides of trees - but the latter is unpolluted. Thus, in Fig. 36, the U.F.V.s of lichen unit 1 are drastically lowered in the upper slope sections, as these lichens are SO2-sensitive. The same applies to unit 2, and to a lesser extent to unit 3 species. Below about 50 m. down the valley-side, the U.F.V.s along transects I, II, V (E.) more closely resemble those of the lower section of VI, VII (N.) - as indeed do the T.F.V.s. However, it is noticeable that the hygrophilous species of unit 2 are slightly less common in Fig. 36, and the SO2-resistant lichens of unit 4 consistently more abundant. Presumably, this may be ascribed to the influence of low levels of SO2. All 4 series of U.F.V.s again attain a constant level in Fig. 36.

Finally, the variations in T.F.V.s and U.F.V.s for model type (iii) are presented in Fig. 37. In transects I, II, V (W.), T.F.V.s increase and then decline, as a result of changes in light and SO2-concentrations (see section 5, C of this chapter) downslope. The lichens of unit 1, which are very responsive to both light and SO2, reflect this pattern almost exactly. The U.F.V.s of association 1 are generally higher than those detailed in Fig. 36, because SO2 levels are lower. However, the effects of SO2 are such that U.F.V.s are significantly lower than the values calculated for transects VI and VII,

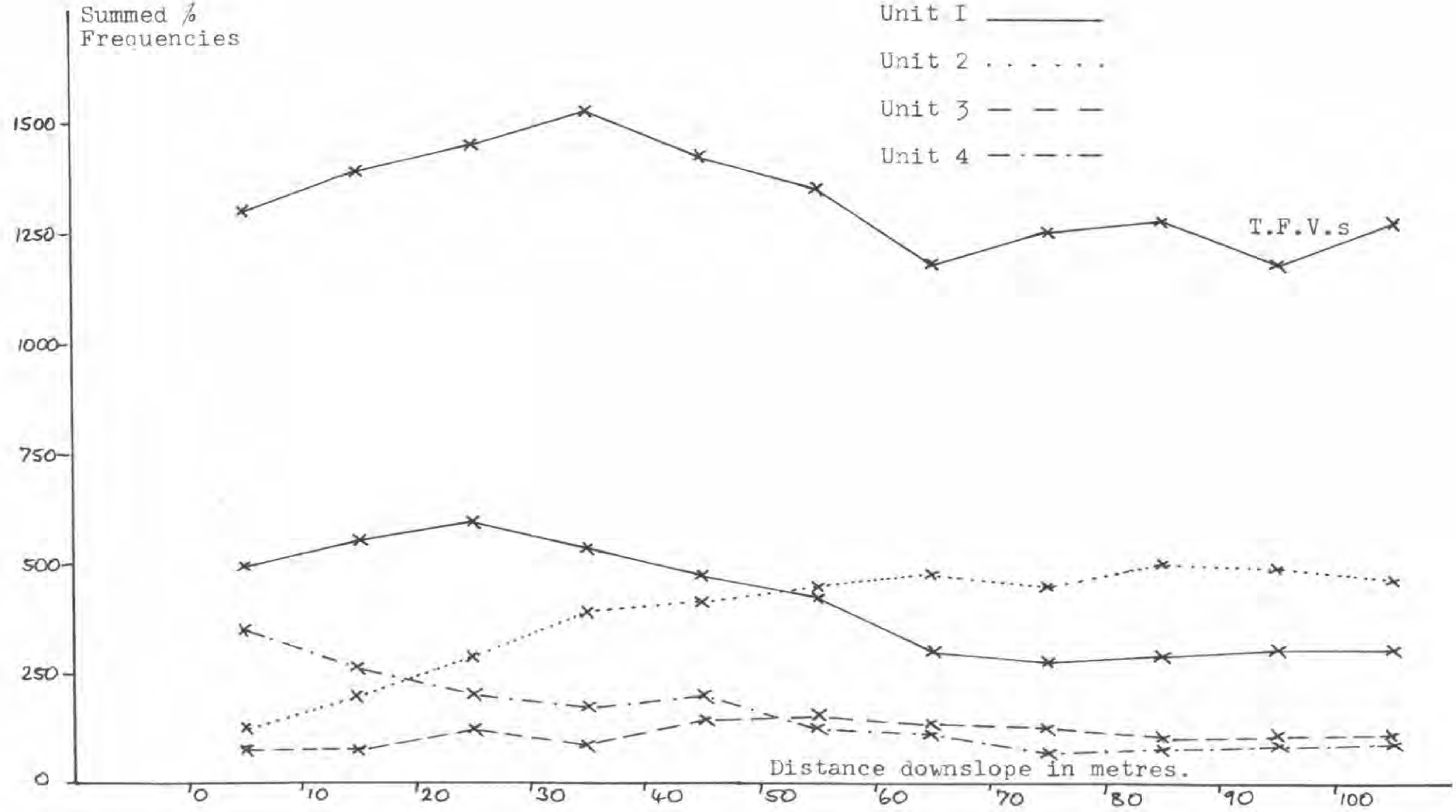

Fig. 37 : The Distribution of U.F.V.s along transects I, II, V (W.) - model type (iii)

and the high U.F.V.s of unit 4 species in the upper slope sections evidence the fact that SO2-concentrations are still important in controlling lichen distribution in model type (iii). The U.F.V.s of units 2 and 3 increase downslope, as in all other transects. As transects I, II, V (W.) record lichens on the undersides of oak trees, the xerophytic species of unit 3 are abundant, and unit 2 species much less common. Again, an interesting comparison may be made between the upper and lower sides of the same trees by contrasting Fig. 37 (undersides, unit 3 common, unit 2 infrequent) with Fig. 36 (upslope sides, unit 2 recording high U.F.V.s, unit 3 reduced in abundance). The increase/decrease pattern of model type (iii) is seen to be largely due to the similar distribution of unit 1. The decline in U.F.V.s of unit 4 is countered by the rise in U.F.V.s of unit 3 (referring to the upper slope section). Below about 50-60 m., U.F.V.s are more or less constant.

To summarise this more detailed version of the model:

type (i) (T.F.V. decline): unit 1 declines steeply from a high U.F.V. due to decreasing light intensity; units 2 and 3 increase gradually as they prefer the relatively dark conditions of the ravine; unit 4 is infrequent and decreases with the drop in light intensity.

type (ii) (T.F.V. increase): unit 4 lichens record high frequencies in the polluted air and decline downslope; units 1,2, and 3 are inhibited by SO2-levels (despite the light conditions), but increase downslope as pollution levels fall.

type (iii) (T.F.V. increase/decrease): unit 4 as above; unit 1 is more abundant and increases in frequency until about 30 m. downslope at which point light becomes limiting and U.F.V.s decline; units 2 and 3 increase downslope.

In all model types:-

(a) The U.F.V.s of unit 2 species are higher on the upper sides of trees than on the lower sides. The reverse obtains for unit 3 species.

(b) The U.F.V.s - despite the variation in absolute values - are all more or less constant towards the floor of the ravine, where ecological conditions are fairly uniform.

B. Light, SO2, and Tree Trunk Inclination - Their Order of Significance to Lichen Distribution

In the model presented above, in all the model types, the U.F.V.s of lichen associations 2 and 3 regularly increase downslope until they become constant at about 50 m. down the valley-side. Unit 4 consistently declines in frequency downslope until the constant level is attained. However, the distribution of unit 1 does not follow any regular pattern within the top 40-50 m. of the ravine. It is noticeable in fact that the variation in the U.F.V.s of unit 1 lichens effectively controls the variation in T.F.V. pattern.

This is readily explained. The species of units 2 and 3 are photophobous, 'ravine-loving' lichens, which do not record high frequency values towards the edge of the ravine, but simply increase downslope as light (and sometimes SO2) declines. The species of unit 4 are SO2-resistant and only slightly photophilous - their response to changing levels of SO2 and light is thus not significant. The lichens of unit 1, however, are photophilous and SO2-sensitive. Accordingly, within the top 40-50 m. of Horsley Hope Ravine where SO2-concentrations and light intensity fluctuate considerably, the distribution of this lichen association is correspondingly variable.

Thus in model type (i), SO2 levels are very low, and the U.F.V.s of unit 1 are high. As light intensity declines downslope, so U.F.V.s decrease; T.F.V.s show the same trend. In model type (ii), SO2 levels are high, so that irrespective of the amount of light,unit 1 U.F.V.s are low. As SO2 concentrations decline downslope, the U.F.V.s of this association increase. Model type (iii) is intermediate between these two extremes.

This is important, because it indicates the extent to which variations in light and SO2 influence corticolous lichen distributions within Horsley Hope Ravine. Viewed another way, in the lower slope sections of Horsley Hope Ravine, all 4 lichen associations are represented, and in the relatively dark and unpolluted conditions of the ravine, lichen distribution parameters are constant. The one operative variable is tree trunk inclination - for hygrophilous species (unit 2) occupy the upper sides of trees and xerophytic species (unit 3) the lower sides. The other units show little or no relationship to aspect. From about 50 m. to the edge of the ravine, this upslope/downslope pattern is disrupted, even though trees are still inclined downslope (see Figs. 22 and 23 for example) - the U.F.V.s of associations 2 and 3 decline, the U.F.V.s of unit 4 increase, the U.F.V.s of unit 1 fluctuate considerably, and T.F.V.s follow the pattern of unit 1 U.F.V.s.

It is obvious therefore, that variations in light-intensity and SO2-concentrations exert a more significant influence on corticolous lichen distribution than substrate moisture-content. Only where light and SO2 are reduced and constant does substrate moisture-content become an important feature of lichen distribution. Otherwise, higher levels of light and SO2 permit units 1 and 4 to dominate over the tree trunk surface, and the photophobous or non light-reactive species species of units 2 and 3 (especially the hygrophilous species of unit 2) may not survive.

Furthermore, it is clear from previous discussion that SO2 is a more significant control on lichen distribution than light. Within the first 10 m. of transects VI and VII, - or III, IV (W.) - the high light intensities and very low levels of SO2-pollution create ideal conditions for corticolous lichens. The T.F.V.s and U.F.V.s of association 1 at this station are evidence of this fact. However, in the top 10 m. of transects I, II, V (E.) - or VIII, XII (E.) for example - where light intensities are similar, but SO2 pollution is known to occur, T.F.V.s (and the U.F.V.s of unit 1) are markedly reduced.

Therefore, these 3 factors (SO2, light, and substrate moisture-content), which have all been shown to control lichen distribution in Horsley Hope Ravine, may be placed in an order of priority, according to the degree of influence they exert upon the corticolous lichen vegetation:

(i) SO2 is the most important control, for where levels of SO2-pollution are high, the lichen flora is impoverished, regardless of light intensity and substrate moisture-content. With significant concentrations of SO2, T.F.V.s are low, and lichen units 4, and species-poor versions of units 1 and 3, occur.

(ii) Light intensity is the second most significant parameter of lichen distribution. In light and unpolluted conditions, unit 1 is well represented and T.F.V.s are very high. In relatively dark and unpolluted conditions, photophobous species are abundant.

(iii) Substrate moisture-content. Where levels of SO2 and light are both reduced, the influence of this factor is apparent. Species which are photophobous or non-reactive to light increase in frequency, and are differentiated according to moisture-content of the tree surface; with hygrophilous species (unit 2) on the upper sides of trees and xerophytic lichens (unit 3) on the lower sides. T.F.V.s are constant and average; units 1 and 4 reduced.

These features are reproduced diagrammatically in Fig. 38. In fact, Fig. 38 is a condensed version of the model described above.

Ideally, the degree to which each of the 3 factors (SO2, light, and substrate moisture-content) affects corticolous lichen distribution in Horsley Hope Ravine should be examined by multiple regression techniques. However, this is not possible owing to the quality of the data

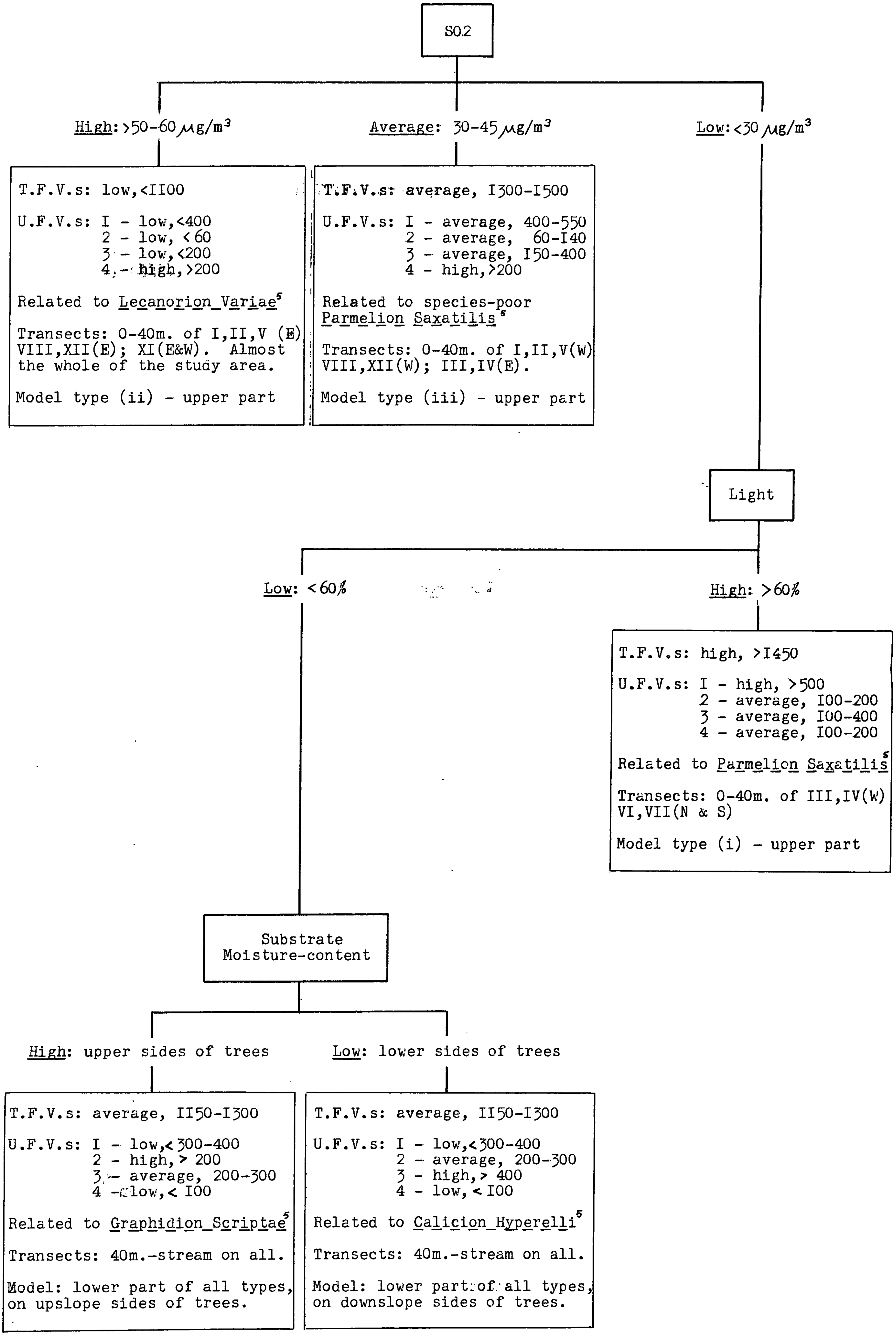

Fig 38 : Influence of Light, S02, and Substrate Moisture-content on the Corticolous Lichen Vegetation of Horsley Hope Ravine.

collected. For some of the parameters measured, insufficient data were recorded - for example, measurements of SO2-concentrations. For others, the information collected is too detailed to permit accurate and simplified quantitative expression - for example, the lichen distribution records.

However, there is no reason to suspect that the order of importance of abiotic factors in controlling corticolous lichen distribution in Horsley Hope Ravine, as recognised above, is not correct; and all available evidence supports these conclusions.

C. Explanation of the Luxuriant Lichen Flora of Horsley Hope Ravine

Referring back to Chapter 2, section 3, the stated aims of this study were that if surveys should confirm that the lichen flora of Horsley Hope Ravine is richer than that of the surrounding countryside, then the following possible causes of this distribution pattern should be investigated:

(i) The ravine is protected from SO2-pollution through the action of canopy filtration.

(ii) The ravine is sheltered from atmospheric SO2 by virtue of its physiographical shape.

(iii) The variation of ecological factors such as light, RH and temperature influence corticolous lichen distribution within the ravine.

(iv) The variety of tree species within the ravine increases the variety of tree bark habitats available to lichen vegetation.

It has been shown that with factors such as RH, light, temperature and tree species (oak) constant throughout the study area, the impoverished lichen flora of the area S.W. of Consett is due entirely to the effects of SO2-pollution.

Moreover, it has been shown that corticolous lichen distribution within Horsley Hope Ravine is controlled by (in order of importance): SO2-concentration, light intensity, and substrate moisture-content.

Thus it is clear that the luxuriant lichen flora of Horsley Hope Ravine is due to :-

(i) The decline in SO2-concentrations, permitting species which are sensitive to this toxic gas to survive in parts of the ravine where SO2 levels are low (below 40-50 m. on all transects, and in the top slope sections of transects III, IV, VI, VII).

(ii) The variations in light intensities within the ravine which enable photophilous species to grow in the upper slope sections and photophobous lichens to exist in the darker parts of the valley (below about 40-50 m. in all transects except XI).

(iii) The differentiation of the tree trunk habitat into dry undersides and damp upper sides - as a result of trees in the ravine leaning downslope - which encourages the growth of two separate lichen associations, one xerophytic and one hygrophilous (below about 40-50 m. in all transects).

So, of the 4 possible causes which it was suggested might account for the diverse and abundant lichen vegetation of Horsley Hope Ravine, all 4 appear to be of some degree of importance in explaining the observed lichen distribution pattern: the decrease in atmospheric SO2-concentrations - causes (i) or (ii); the change in light intensity - cause (iii); and the variation in substrate moisture-content, which although it is not specifically connected with tree species diversity, may in fact be considered under head (iv) because it is related to variation in the conditions of the substrate habitat.

In greater detail, the action of these factors in producing a richer lichen flora in Horsley Hope Ravine may be considered by referring to the distribution of the 4 phytosociological units throughout the study area and within Horsley Hope Ravine. From TABLES XIII and XIV it may be seen that trees in the study area are colonised largely by lichens belonging to unit 4. In addition species-poor (and SO2-resistant) variants of units 1 and 3 occur. Within 4 kms. of Consett, the U.F.V.s of unit 4 species average 209 per km. sector, the U.F.V.s of unit 1 lichens average 140 per km. sector, and the U.F.V.s of unit 3 only 5 per km. sector. No unit 2 species were found at all. Further W., and especially on the W. sides of trees, the occurrence of all 4 units increases, so that eventually, between 5 and 7 kms. S.W. of Consett, U.F.V.s are as follows: unit 4-256; unit 1-418; unit 3-23; unit 2-49. It may thus be seen that within the study area, lichen units 2 and 3 are barely represented, unit 1 is severely depressed, and only unit 4 species achieve high frequency values. Obviously, this situation is explained largely by the high atmospheric SO2-concentrations which exist within the study area (e.g. see Fig. 38).

Within Horsley Hope Ravine, the light, polluted conditions of the study area also occur near the top of transects I, II, V, VIII, XI, and XII. Here therefore, the distribution of U.F.V.s resembles that of thestudy area, with unit 4 species common, and low frequencies for the other units. Where the influence of $SO2$ is reduced, the U.F.V.s of unit 1 increase significantly, and unit 4 U.F.V.s are slightly lower. Where the amount of light is reduced, the U.F.V.s of units 2 and 3 attain high values - their relative proportions depending on the substrate. moisture-content.

Therefore, the rich lichen flora of Horsley Hope Ravine - rich in terms of species numbers, T.F.V.s, and individual U.F.V.s - is explained by: the low levels of $SO2$; the variation in light intensities (low light levels encouraging units 2 and 3, high light intensities favouring unit 1 species); and the variation in substrate moisture content.

As considered previously, of these 3 factors, the most important is undoubtedly the influence of declining $SO2$ levels. From records of the lichen flora associated with light and unpolluted conditions in Horsley Hope Ravine, it may be safely assumed that if the study area was not subject to $SO2$-pollution, then trees S.W. of Consett would exhibit high unit 1 U.F.V.s and thereby high T.F.V.s. On the other hand, if $SO2$ levels were high throughout Horsley Hope Ravine, then irrespective of light intensities or tree trunk inclination, only $SO2$-resistant species could survive (i.e. unit 4 lichens, and some species in units 1 and 3). Thus, variations in light intensity and substrate moisture - although contributing to the diversity of ecological conditions and lichen vegetation within the ravine - are entirely conditional upon relatively unpolluted air for their influence upon the lichen vegetation to be effective. Where SO2 levels are high, T.F.V.s and species numbers are low, regardless of other ecological factors.

Therefore although the variation in these 3 abiotic factors conjointly accounts for the rich lichen flora of Horsley Hope Ravine, it is possible to establish an order of priorities which clearly recognises reduced atmospheric SO2-concentrations as the prime cause of the improvement in the corticolous lichen vegetation. The final question that needs to be asked is why are atmospheric SO2-concentrations lower in Horsley Hope Ravine than in the study area generally?

D. Explanations for the Reduced Levels of SO2 in Horsley Hope Ravine

In Chapter 2, section 3, it was explained that two theories have been put forward to account for the fact that ravines are relatively free from atmospheric SO2. These are:-

(i) That the vegetation canopy in wooded ravines acts as a protective umbrella to the air beneath the trees, by filtering pollutants out of the atmosphere through absorption. This process is termed "canopy filtration".

(ii) That the topographical shape of ravines is such that wind velocities within ravines are reduced, and SO2-levels are thereby lower.

Information collected during this study indicates that the latter provides a more acceptable explanation for the lower levels of SO2 noted in Horsley Hope Ravine. The reasoning behind this statement is discussed below:-

(i) Previous consideration of the mechanics of SO2 deposition has shown that SO2 is a light gas, readily transported by wind, and deposited on surfaces by impaction rather than by gravitational fallout (see Chapter V, section 1, C). The amount of impaction of SO2 particles per unit time is proportional to the air-flow over a surface per unit time, and the SO2-content of the air-flow. It was postulated that surfaces sheltered from pollution-laden air currents would thus receive relatively less SO2 per unit time than exposed surfaces.

If this is so, then it is apparent that SO2 is mainly transported in the horizontal plane, according to the direction and velocity of winds. (measurements of SO2 levels around Horsley Hope Ravine evidence this fact). In this sense, a ravine constitutes a sheltered niche, for as has been shown by Lawrence[55] (see Fig. 6), wind velocities are markedly reduced within valleys, and the main wind currents pass over the top of ravines. On ravine floors, there would be less polluted air flowing over surfaces per unit time than on ravine edges where wind velocities are greater. Thus, by this argument Horsley Hope Ravine is sheltered from pollution-bearing E. winds - which presumably pass horizontally over the top of the valley - by virtue of its topographical shape. The ravine in fact enjoys the same sort of sheltered conditions as the W. sides of trees in the study area, which are similarly protected from the horizontal movement of SO2-laden air.

Canopy filtration, on the other hand, is a process which operates essentially in the vertical plane. To be effective in absorbing SO2, the canopy must filter out SO2 which is passing vertically through it, over the whole surface area of the canopy (i.e. by gravitational deposition). However, as explained above, SO2-laden air moves mainly in the horizontal plane and if this is the case, then the leaves of trees will arrest only a small proportion of the SO2 in the air through the process of canopy filtration. Below and above the canopy, SO2-bearing air currents would continue unchecked, and SO2 impaction could still occur at some distance within ravine woodlands, if canopy filtration was the only process by which they were protected from SO2-laden winds travelling in the horizontal plane.

Patently this is not the case. Measurements of SO2 within Horsley Hope Ravine show that the ravine is much less polluted than the air around it. It must therefore be presumed that the predominant direction of air flow is horizontally over the top of the ravine ("over-barrier transport") so that SO2 is carried clear of the valley. Canopy filtration - if it operates at all - must be of minor significance, except on fairly calm days when gravitational fall-out of SO2 may occur.

(ii) This view is supported by the results obtained for transect XI. Along transect XI, the tree-cover is very light and open, so that if canopy filtration was the only effective factor in protecting ravines from SO2-pollution, it might be expected that the lichen vegetation along transect XI would be extremely impoverished owing to the high levels of SO2 associated with the unprotected slope. However, this is not the case. T.F.V.s in transect XI increase steadily from the ravine edge, where high SO2 concentrations inhibit the lichen flora, to values of around 1450-1600 near the floor of the ravine. T.F.V.s of this order are typical of the values obtained for light, unpolluted conditions (e.g. transects VI and VII, 0-10 m.). Moreover, SO2-sensitive lichens such as <u>Usnea subfloridana</u> can survive along transect XI. It is therefore clear that SO2-levels are not as high as might be expected along transect XI if canopy filtration was the mechanism by which Horsley Hope Ravine was protected from atmospheric pollution. In fact, the increase in T.F.V.s along transect XI matches the pattern of other transects taken down slopes on the E. edge of Horsley Hope Ravine (transects I, II, V, VIII and XII), and the high T.F.V.s recorded near the valley bottom reflect the fact that light intensity is not limiting to the lichen flora.

The results obtained for transect XI thus suggest that the existence of a vegetation-cover in Horsley Hope Ravine bears little relation to the SO2 levels in the valley. Pollution concentrations appear to be low towards the floor of the ravine irrespective of whether the slopes are wooded of not. Work by Hawksworth[37] and Lawrence[55] suggests the same. This fact therefore supports the idea that canopy filtration is not important in protecting Horsley Hope Ravine from SO2-pollution; but that topographical shape is the key factor in alleviating atmospheric SO2-concentrations.

(iii) Conversely, if topographical shape is instrumental in protecting valleys from SO2-pollution, and canopy filtration is of no significance - then woods on flat ground within the study area should be subject to high levels of SO2. This proved to be the case. Four small woods within the study area which were briefly examined, bore impoverished lichen floras, typical of the lichen zone in which they were located. The only species found within the woods, but not on trees in the adjacent open countryside, were photophobous SO2-resistant species such as Chaenotheca ferruginea and Catillaria griffithi.

This again ties in with the theory of SO2 being deposited by impaction from horizontally moving pollution-laden winds. If canopy filtration protected corticolous lichens from the gravitational fallout of SO2, then the 4 small woods would be more or less as sheltered as Horsley Hope Ravine. The lichen vegetation of the 4 woods suggests that this is not so. However, if topographical shape is the protective factor, and wind direction and velocity the SO2-depositing agents, then these 4 woods would be subject to high levels of SO2, whereas Horsley Hope Ravine would be sheltered from SO2-laden winds. The woods on flat ground would be sheltered to some extent, however, because woods exert a braking effect on winds, and the reduced wind speeds would mean that less SO2-laden air passed over the tree trunks per unit time, and so levels of impacted SO2 would be reduced slightly.

(iv) Within Horsley Hope Ravine, it was shown that levels of atmospheric SO2 were sufficiently high to affect the lichen flora within the top 40-50 m. of the E. edge of the ravine (especially on the E. sides of trees) and to a lesser extent to affect the lichen flora on the E. sides of trees in the upper slope section of the W. edge of the ravine. Transects VI and VII, in the heart of Horsley Hope Ravine, and all transects below about 50 m., were thought to be unpolluted.

These facts fit the theory of over-barrier transport and the suggested air-flow/SO2 pattern is described below. Because the E. edge of Horsley Hope Ravine is affected by SO2-pollution this suggests that there is some air-flow down the valley-side (of polluted air), but that this is soon retarded by frictional drag within the ravine woodlands (in about the top 40 or 50 m. of the slope). As wind velocities decline within the upper slope section, so the amount of impacted SO2 is also reduced, and eventually (at about 40-50 m.) becomes insignificant. Thus, the air is 'cleansed' of SO2 within about 40 m. of the ravine edge, due to the decline in wind velocities downslope, and the deposition of SO2 on tree trunks within the top 40 m. or so of the valley-side. The major part of the air-flow (and thus transported SO2), however, passes over the top of the ravine, but predictably has some slight effects on the E. sides of trees on the W. edge of the ravine, which are exposed to low-flowing currents of the pollution-laden winds. The lower parts of Horsley Hope Ravine are entirely sheltered from the main air flow patterns operating over the top of the ravine and receive only minimal amounts of

SO2 carried into the valley by eddies.

If canopy filtration was the cause of low levels of SO2 within Horsley Hope Ravine, then it might be expected that SO2-distribution would be uniformly low throughout the ravine. However, the pattern of observed SO2 distribution is irregular, and is better explained in terms of wind currents and physiographic shape.

(v) Finally, further evidence for the theory that topographical shelter from SO2-bearing winds (rather than canopy filtration) protects ravines from air pollution, is provided by observations in a small and unwooded valley within the study area near Hownsgill Viaduct (NZ 095491). Mature oak trees on the outer (S.W.) edge of the small steep-sided (about 23°) ravine carried a lichen flora typical of polluted atmospheric conditions (zone 3/4), with *Lepraria incana* and *Lecanora conizaeoides* on the E. sides of trees, and these two species + *Parmelia saxatilis* and *Hypogymnia physodes* on the W. sides of trees. However, two oak trees on the valley floor were covered on both sides by a lichen flora comprising, in addition to the above-named species: *Lecidea scalaris*, *Calicium viride*, *Chaenotheca ferruginea*, *Evernia prunastri*, *Lecanora expallens*, *Ochrolechia androgyna*, *Parmeliopsis ambigua*, and *Hypogymnia tubulosa*.

The presence of such a relatively rich lichen flora must indicate that SO2 levels in this small ravine are lower than on the surrounding slopes. All other factors were constant, and there were few trees in and around this valley. It is concluded therefore, that the floor of the ravine is sheltered from N.E. winds by virtue of its topographical position, and that SO2-laden air flows over the ravine (over-barrier transport) to create a pollution inversion profile down the valley-side.

These five points all suggest that the explanation for the reduced SO2-levels observed in ravines in polluted environments is related to the physiographical shape of ravines. There is, however, a fairly large body of literature on the subject of SO2 sorption by vascular plants, which demonstrates thatthe leaves of woody plants both absorb and adsorb gaseous SO2. (Roberts B. – Environmental Pollution 7, 1974,'Foliar Sorption of SO2 by Woody Plants'). The process of canopy filtration cannot therefore be entirely ignored when considering the relatively unpolluted quality of wooded ravines; and as considered previously, canopy filtration is probably significant in the removal of atmospheric SO2 under calm conditions, when gravitational fallout of SO2 may occur. But concerning the evidence obtained from this study, it is quite clear that it is physiographic shape which accounts for the low levels of SO2, and the associated rich corticolous lichen flora observed in Horsley Hope Ravine.

VI. CONCLUSIONS

From the preceding discussion, it is clear that the problem outlined in Chapter 1, section 3, is more complex than originally stated. Nevertheless, a series of results have been obtained which provide answers to the questions posed in Chapter 1.

It has been shown that there is an improvement in the corticolous lichen vegetation S.W. of Consett, due to the steep SO2 pollution gradient across the study area. However, the lichen flora of Horsley Hope Ravine is distinctly more luxuriant than that of the study area as a whole, and may not be accounted for simply in terms of the lower levels of atmospheric SO2 which prevail S.W. of Consett. Instead, measurements of various ecological parameters suggest that changes in light intensity, substrate moisture-content, and SO2-concentrations are significant in the development of a diverse lichen flora in Horsley Hope Ravine. A model was devised which indicates the relative importance of these factors in controlling corticolous lichen distribution within the ravine. The decline of atmospheric SO2-levels in Horsley Hope Ravine is seen to be the single most significant influence on lichen distribution. The ravine is protected from SO2-laden winds by virtue of its topographical shape.

These conclusions are based on studies within an area of only 28 square kms., and relate to the evidence collected from one ravine situation only. It would therefore be presumptuous to assume that the conditions examined at

Horsley Hope Ravine may be automatically applied to all ravine situations. However, it was pointed out earlier that the luxuriant lichen vegetation of ravines has been noted from a variety of situations - and the phenomenon is considered to be characteristic of steep-sided valleys in polluted environments. Moreover, as far as is known, no other detailed investigations have been carried out in order to clarify the ecological relationships of ravine environments and corticolous lichen vegetation. Thus it is tentatively suggested that the diverse corticolous lichen vegetation typical of ravine situations may be explained by the following factors: (a) the reduced levels of atmospheric SO2 associated with ravines on account of the protection from SO2-bearing winds afforded by their topographical shape (b) the variations in light intensity which occur in wooded ravines and encourage the growth of both photophilous and photophobous lichens (c) the variations in substrate moisture-content, occurring on the upper sides and under sides of inclined trees.

Clearly, to put forward this hypothesis with any greater degree of conviction would necessitate undertaking equally detailed fieldwork in other wooded ravines. The application of the results obtained for Horsley Hope Ravine to other areas should therefore be regarded with some uncertainty.

Mention must be made of the sources of error inherent in the methodology and analysis employed in this study - for the value of the conclusions reached depends to a large extent on the accuracy of the means by which the conclusions were obtained. The possible sources of error are summarised below:-

(i) Sampling Inaccuracies. Problems were encountered in the field when certain measurements were taken. In particular, samples of SO2-concentrations were affected by faults in the electrical circuit; and measurements of light intensity were taken with a sensitive light meter which fluctuated considerably according to slight changes in the position of the meter on the tree trunk. Furthermore, there were occasionally problems with the identification of lichen species.

(ii) Scale of Sampling. Because lichens are responsive to small-scale changes of habitat, it is possible that the methods employed in this study were too crude to accurately measure the variation of significant abiotic factors on a microscale e.g. light intensity was measured at only one point on the tree trunk surface - yet there are great differences in light intensity between the ridges and crevices of fissured barks.

(iii) Type of Substrate. Only the lichen flora of oak trees was sampled. It is possible that alternative patterns of lichen distribution might occur on other tree species.

(iv) Length of Study Period. All the data were collected within a period of two months, in the summer. It is therefore dubious to assume that the results obtained may be extrapolated to long-term situations e.g. in winter, light intensities will become more uniform over the valley-sides, and other factors such as temperature may be very significant for lichen growth and survival in the ravine.

(v) Analysis of Data. Because of the quantity of data collected, it was necessary to aggregate results for handling convenience, and some generalisations are thus inevitable e.g. the use of correlation coefficients to describe downslope changes of the lichen species. These generalisations might disguise significant trends obvious from more detailed analysis.

(vi) Analysis of Data. The information collected was analysed on the assumption that all factors varied according to linear functions. There is no evidence to support this, and in fact in many cases the marked changes in lichen distribution within the ravine suggest that threshold levels might more accurately be applied.

It is not possible to estimate the influence of these sources of error on the results obtained in this study. Points (i), (ii) and (iv) are particularly relevant when considering the validity of the conclusions to be drawn from the work; while points (iii), (v) and (vi) are probably only of minor significance. Obviously every effort was made to reduce the margin of error in all six areas in which mistakes could occur, but it is felt that (i), (ii) and (iv) might only be satisfactorily resolved by carrying out more detailed and time-consuming fieldwork. This was not possible in the period of time available.

Again, a more lengthy investigation of lichens and ravine situations might have broached other salient matters e.g. what happens in ravines which are oriented in the direction of a pollution-source?, or do ravines support luxuriant lichen floras under conditions of blanket pollution? Further fieldwork along these lines would do much to clear up some of the outstanding questions concerning lichen vegetation in ravine environments.

However, despite the shortage of time and other sources or error, it is considered that the results obtained from the study of corticolous lichens in Horsley Hope Ravine do provide answers to the problem described in Chapter 1. Furthermore, certain broad conclusions have emerged from this work, which are of general ecological significance.

Firstly, the importance of shelter from pollution-bearing winds in alleviating atmospheric SO2-concentrations is apparent. Horsley Hope Ravine, the small ravine near Hownsgill Viaduct, and the W. sides of trees in the study area were all relatively unpolluted because they were not fully exposed to SO2-laden winds from the E. and N.E. In view of the known damage caused by SO2 to human health and vegetation (including crops) these relationships between wind speed, wind direction and degree of exposure are of obvious relevance when considering subjects such as the siting of SO2-emitting industries, and residential buildings.

Secondly, it is clear that wooded ravines constitute 'ecologically complex' epiphytic habitats owing to their topographical shape. Whilst woods on both flat ground and in ravines are characterised by reduced light intensities, ravine woods are, in addition, sheltered from most atmospheric pollution, and furthermore contain leaning trees which create two distinct lichen habitats on their upper and lower sides.

Thirdly, corticolous lichens have been shown to be very sensitive to changes in ecological conditions. They are thus good indicators of environmental variations. The impoverished flora of the study area, the definition of lichen zones, the rich vegetation of Horsley Hope Ravine, and the changes in T.V.F.s and distribution of individual species within the ravine, all demonstrate the susceptibility of corticolous lichens to a wide range of abiotic influences.

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