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A COMPARATIVE STUDY OF WOODED AND NON-WOODED LAND IN A PART OF THE ENGLISH LAKE DISTRICT

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Introduction

There is concern in some quarters at the present time (e.g. Friends of the Lake District, Newsletter, January 1972) that changes in the economics of hill sheep farming may result in a reduction in the numbers of sheep on the hills and a consequent change in the landscape. It is stated that "the slopes would be invaded by rank grass and scrub and the once open fells would become overgrown with small trees". Alternatively, it is feared that such land would be acquired by timber-growing interests and covered with Sitka spruce. Donaldson and Donaldson (1972) claim that "large areas of the hills would revert to scrub or bracken if they were not farmed", and that "bracken, thistles, and scrub would have little charm for the visitor".

The latter statement is a matter of opinion rather than established fact, and the word "woodland" could perhaps have been used in place of the less pleasing word "scrub". It is also possible that the numbers of sheep will not decline, or that, if they do, there will be at least a partial replacement of their role as grazing animals by an expansion of existing deer populations. However, it would be useful to know what changes might occur if grazing were to become much reduced; and the present study was undertaken in an attempt to assess the changes in vegetation which might take place, in as objective a manner as possible. This involved the examination of a number of wooded and non-wooded sites and an attempt to correlate sites of different types with the vegetation growing on them.

Selection of study area

An area of approximately 230 square miles (600 square kilometres) was selected in the eastern part of the Lake District National Park (Map 1). Areas marked as limestone or granite on the geological map were not included within the study area as their inclusion would have introduced a further measure of complexity into the study without a commensurate gain in useful information. Granitic areas are not very extensive in this part of Britain; and limestone areas are less likely to be taken out of agricultural usage than areas overlying shales, mudstones, and other rocks.

Within the study area, any land of less than 500 ft. (152 metres) elevation was excluded, as such land is normally under relatively intensive usage and forms the better agricultural land. Land over 1500 ft. (457 metres) was also excluded, as it is unlikely that any appreciable woodland cover would develop above this elevation, and there is insufficient existing woodland at that altitude to enable any valid predictions to be made as to what might develop if grazing were to cease.

Selection of sample sites

Within the study area there were 263 woods, or parts of woods, marked on the 1970 edition of the Ordnance Survey 1" (1:63,360) map. Eighteen of these lay above the 1000 ft. contour, 50 lay athwart this contour, and 195 below it. Eighteen woods were selected at random from each of these three groups, and one sample site was placed within each wood by reference to random coordinates. A similar number of non-wooded sites were also selected, covering a similar range of altitude, by reference to randomly generated grid coordinates; giving a total of 108 sample sites.

Some of the wooded sites were conifer plantations of various ages, rather than semi-natural woodland, but it was decided to include these in the survey as the information obtained from them was also likely to be of interest.

One sample site was later re-located as the site selected originally fell in a permanent camping site rather than in an area whose main use was grazing.

Sampling methods

At each of the 108 sites information was collected on:

1) Soil

   a. depth (four auger borings, up to a maximum depth of 60 cm. at the corners of the 2 x 2 m. quadrat).

   b. pH (from a sample of the four borings).

   c. % organic matter (from a sample of the four borings).

2) Topography

   a. altitude at centre of plot (from 1:25000 map).

   b. difference in altitude between top of plot and bottom of plot (from 1:25000 map).

   c. slope (across 14 x 14 m. quadrat).

   d. aspect (across 14 x 14 m. quadrat).

   e. aspect of whole plot (from 1:25000 map).

   f. slope of whole plot (from 1:25000 map).

3) Gross vegetational features

a. % cover of whole plot by bracken (estimated).

b. % cover of whole plot by trees (estimated).

c. mean height of tree cover (estimated).

d. mean height of herbage (estimated), excluding bracken.

e. presence/absence of grazing.

f. presence/absence of burning.

4) Plant species (vascular plants only)

a. presence in 1 x 1 m. quadrat.

b. presence in 2 x 2 m. quadrat.

c. presence in 14 x 14 m. quadrat.

d. presence in 70 x 70 m. quadrat.

The four differently sized quadrats were laid out concentrically and at right angles to the main slope, except in those cases where a woodland was less than 100 m. wide, when the plots were laid out parallel to the edge of the wood.

A few of the woodland sites were less than 70 m. wide. In two cases, where there was a substantially sheep-proof fence around the wood, the largest plot size was taken as approximately 50 m. x 100 m. to give the same total area, and, in cases where there was no sheep-proof fence, the plot was taken to include some of the surrounding grazing land, and would be reflected in a reduction in the estimated % tree cover for the plot.

Results

Only one sample site showed evidence of burning; and only thirteen were adequately fenced to exclude sheep (seven of these being young plantations). To some extent, therefore, the flora of the woodlands sampled does not represent that of ungrazed woodland, although it is evident that these woodlands must have originated at a time when grazing was absent or much reduced. The ground flora is likely, therefore to differ from that of ungrazed woodland. (Some work on the effects of sheep grazing on the flora of woodlands is currently being undertaken by Dr. A. D. Horrill).

Three of the woodland sites sampled had been recently felled and replanted, and had no appreciable tree cover, and some of the sites which were not shown as woodland on the map had up to 45% tree cover. Many of the woodland sites were not fenced at all, and the distinction between woodland and open grazing land was by no means clear-cut in all cases.

Numbers of plant species in relation to quadrat size

A previous study of the effects of coniferous afforestation in a part of south-west Scotland (Helliwell 1971) showed that, at the 1 x 1m. scale, afforested sites had fewer species than non-afforested sites. This difference was also found in the present study. At the 70 x 70 m. scale the difference was still present, but was less pronounced, in the afforestation study; but in the present study the wooded sites contained more species than the non-wooded sites at this scale (Table 1 and Fig. 1).

Table 1

Mean canopy density of 26 sample sites, and Standard Error	Mean number of plant species in quadrats and Standard Error			
	1 x 1 m. quadrats	2 x 2 m. quadrats	14 x 14 m. quadrats	70 x 70 m. quadrats
0	9.31 ± 0.95	11.69 ± 1.24	17.31 ± 1.66	29.65 ± 2.70
0.27% ± 0.15	9.12 ± 0.78	11.23 + 0.96	17.77 ± 1.69	31.04 ± 2.58
49.62% ± 2.36	7.50 ± 0.48	10.31 ± 0.85	18.61 ± 1.68	37.73 ± 3.80
84.85% ± 2.47	7.04 ± 0.80	9.81 ± 1.04	18.42 ± 1.85	35.46 ± 2.56

There is no statistically significant difference between the mean numbers of species at different canopy densities in the case of 2 x 2 m. or 14 x 14 m. quadrats but the difference at the 1 x 1 m. and 70 x 70 m. scales is significant at the 5% probability level. (This table is based on only 104 sites, as recently-felled woodland sites were excluded as being somewhat ambiguous in this context.)

In a separate study of the Lake District, Miss S. K. Morrell has prepared lists of vascular plants present in sample 1 km. squares. Five of these squares contain sites sampled in the present study, and the relationship between species numbers and area is shown in Fig. 2. The two wooded sites show a steep rise in numbers between the 1 x 1 m. and 70 x 70 m. quadrat sizes, as in Fig. 1, and then a lesser rate of increase as the non-wooded portion of the 1 km. square is included. The other three 1 km. squares contain insignificant amounts of tree cover.

In the case of the non-wooded sites in the present study, the relationship between size of quadrat and numbers of plant species can be expressed as $N = nA^{0.14}$, where

N = no. of species

n = no. of species per unit area

A = area of quadrat.

This is similar to the relationship in the previous study (Helliwell, 1971). The relationship in the case of the wooded sites is $N = nA^{0.19}$, and in the previous study the afforested sites were covered by the expression $N = nA^{0.16}$. This would appear to indicate that the vegetation in the wooded areas is somewhat less homogeneous than in non-wooded areas; which is not unexpected, as the variation in light intensity within the wooded areas will result in a greater diversity of conditions for plant growth.

Analysis of environmental data

Taking, in the first instance, data which are not likely to be influenced by land management, a list of twelve factors was drawn up, and the values of each factor at each of the 108 sites were listed and subjected to a correlation analysis. Factors which were significantly correlated at the 5% level are marked with an asterisk and those significantly correlated at the 1% level are marked with two asterisks in Table 2. (See Appendix 1 for correlation coefficients.)

Table 2

	1	2	3	4	5	6	7	8	9	10	11	12
1. Slope across 70 x 70 m. plot			*	*	**	**	**			**	**	**
2. Aspect, as °divergence from 200°			**	*						**	*	
3. Aspect x slope												
4. Altitude										*		
5. Mean soil depth, from 4 borings						**	**					**
6. Maximum soil depth							**					
7. Minimum soil depth								**	**			**
8. Maximum - minimum									**			
9. Loss on ignition of soil sample										**		
10. pH of soil sample												
11. Difference in slope between 14 m. and 70 m. plots, divided by slope of whole plot												
12. Difference in aspect, multiplied by slope.												

(Factor no. 3 = ^{o}divergence from 110^{o} or 290^{o} x slope + a constant. Aspects between 110^{o} and 290^{o} are positive and others are negative. The constant is added to give all sites a positive value.)

As can be seen, there are significant correlations between a number of these factors, and a principal components analysis accounted for 78% of the variation in the first five components. Subsequent attempts to correlate these component values with the vegetation on the site were not very successful, however, and it appeared that the data were overloaded with information on soil depth and aspect, which account for much of the variation in the data but little of the variation in vegetation. Factors numbered 2, 3, 6, 7 and 8 in Table 2 were, therefore, omitted and a principal components analysis was carried out on the remaining seven factors. Correlation of these component values with the floristic data was more successful. There was also a greater degree of correlation with the extent of bracken cover, % tree cover, height of trees, and numbers of plant species. These correlations may be summarised:

	Principal components	% variation accounted for	Significant correlations
1.	strongly related to steep slopes with low pH	27.7	a. Extent of bracken cover b. Short herbage
2.	strongly related to shallow soils with low organic matter content	20.8	a. Height of trees b. Number of plant species
3.	strongly related to even topography, low organic matter content and high pH	14.1	a. Height of trees (negative correlation) b. Extent of tree cover (negative correlation)
4.	strongly related to low altitude and uniform topography	12.9	
5.	strongly related to variation in aspect within the site, and deep soil with a high pH	10.8	a. Number of plant species
		86.3%	

None of these components showed a significant correlation with the "value" of the plant species present on a site; evaluated as described later in this paper.

Details of these correlations are given in Appendix 1.

Analysis of floristic data

A total of 247 different species of vascular plants were recorded in the survey. Sphagnum spp. and Polytrichum spp. were also recorded. Each species was given a code number and, after omitting 41 species which occurred only once in the survey,* the presence of species in the 70 x 70 m. plots was subjected to an association analysis. The analysis is illustrated at the end of this paper.

The association analysis gave 26 groups of sites at a chi-square level of 3.84, and subsequent examination shows a fairly close similarity between sites in any one group at this level, both in terms of the environmental data and in terms of an ordination of the floristic data.

Fig. 3 shows the distribution of the sites in the 26 groups of the association analysis, using the first 2 axes of an ordination of the floristic data, based on the perpendicular axes method described by Orloci (1966), with interstand distance as the coefficient of similarity. All 249 species were included in the ordination. Some of the groups have been encircled in Fig. 3, but as the groups overlap on these 2 ordination axes it is not possible to encircle them all without confusing the diagram too much.

If the 13 groups given by the association analysis at a chi-square level of 10.0 are taken, these are, with the exception of the first such group, also distributed fairly compactly in terms of the ordination.

It is evident that no single method can fully illustrate the complex relationships between the different vegetation types to be found in 108 different sites in a one or two dimensional model. It is likely, however, that the 26 groups produced by the association analysis are sufficiently homogeneous within themselves to serve as a useful basis for classification; though the relationship between, say, group 11 may be closer to group 26 than to groups 12 or 13 in the analysis, - i.e. the relative proximity of groups in the analysis is not a valid measure of their similarity.

* See Madgwick & Desrochers (1972) for the reasons for omitting these species.

Fig. 4 shows the distribution of sites with predominantly broadleaved woodland, conifer plantations, and non-wooded land in relation to the first 2 axes of the ordination, and it is evident that the presence or absence of woodland strongly influences the composition of the vegetation on a site.

(It is assumed that the presence or absence of woodland is largely a matter of history and is not determined mainly by the type of site. This assumption is borne out by the subsequent analyses, whereby both wooded and non-wooded sites are found in conjunction with most site types. An examination of aerial photographs of the area shows that most of the wooded areas occur where walls or fences enclose areas of not more than about 200 hectares. Larger areas than this contain very few trees or shrubs, and have probably been grazed continually for several centuries.)

Fig. 5 shows the distribution of sites with few and many plant species in relation to the ordination, and it is evident that sites with a diverse flora occur in both wooded and non-wooded areas. Sites with few species lie, as may be expected, near to the centre of the diagram and are not related to the wooded/non-wooded trend, which lies along a diagonal line across the diagram (Fig. 4).

The numbers of plant species are not significantly correlated with the amounts of bracken or the height of the herbage (see appendix 1).

An attempt was made to evaluate the floristic data in terms of its value for nature conservation, using an approach developed previously, (Helliwell, 1971 and 1973). An area of 97 10 km squares was taken as the "region", being approximately the new county of Cumbria plus a few additional squares. Using the Atlas of the British Flora (Perring and Walters 1966), the number of squares in which each of the 247 vascular plant species occurs was noted, both in the region and in the British Isles. It was assumed that the presence of a plant in 1% of the squares represents n plants, presence of a plant in 50% of the squares represents 500 n plants, and presence of a plant in 100% of the squares represents 10,000 n plants. Using the methods adopted previously (Helliwell 1973), a single plant from a population of n is worth 360 times as much as a plant from a population of 10,000 n; and a plant from a population of 500 n is worth 6.8 times as much. Using these three values it is possible to derive a mathematical expression from which intermediate values may be calculated, and these are tabulated in Appendix 2. Each species was evaluated regionally and nationally and a mean figure taken. The values for each species at a site were summed, to give a value for the site. (No account was taken of the abundance of each species within the site, as no information on this was collected.)

It is interesting to note that, unlike the number of species per site, the "value" of the species on a site is not significantly correlated with any of the environmental factors examined (see Appendix 1). There is a correlation of about 0.58 between the number of species at any quadrat size and the sum "value" of those species, and this is highly significant, statistically, but it means that the number of species is accounting for only 34% of the variation in their "value".

The six sites with the highest "values" are all non-wooded, the high values being due to the occurrence of a number of the less common upland species, including Alchemilla alpina, Saxifraga aizoides, Lycopodium selago, Cryptogramma crispa, and Carex pauciflora. The next 16 sites on the list are, however, equally divided between wooded and non-wooded sites. Of the 31 sites with the lowest "values", 17 are non-wooded, 13 are conifer plantations, and one is broadleaved woodland.

Correlation of floristic and environmental data

In order to predict what type of woody vegetation would be likely to occur on a currently non-wooded site it is necessary to establish some sort of correlation between the soil, slope, altitude, etc. of a range of sites and the vegetation to be found on them. For example, if it could be shown that a certain type of site consistently supports:

a) Agrostis/Festuca grassland of a certain type

b) coniferous plantations of a certain type

c) Quercus/Betula woodland of a certain type, it could be inferred that one could change a) to b) by planting conifers or to c) by removing or reducing the amount of grazing.

It is possible that the environmental data collected does not include sufficient information to permit this to be done. Rogers and King (1972), for example, took weekly readings of soil moisture, oxygen, and carbon dioxide levels in addition to pH and soil nutrient content in order to establish a correlation with the vegetation of a 24 ha upland pasture. Such detailed work was not possible in the present study, but it was expected that some correlations would be obtained with the data that could be collected.

Plotting the groups produced by the association analysis of the floristic data onto the first two components of the principal components analysis of the environmental data did not give a very clear picture. This was not unexpected, however, as, even assuming that sufficient environmental data had been collected, the first two components accounted for less than 50% of the variation in the data, and it is obvious that such data cannot be adequately expressed by reference to only two components.

A recently developed method of plotting multidimensional data (Jeffers, 1972) was, therefore, employed. This enables one to plot, for varying values of t, the relative distance between different points in Euclidean space. It is thus possible to represent in 2 dimensions the relationship between two or more sites in several dimensions. Fig. 6 illustrates this. Sites numbered 10 and 95 are fairly similar in terms of slope, elevation, depth of soil, soil pH, etc., but are different from sites 64 and 65.

Sites 64 and 65 occur in the same group in the association analysis, but sites 10 and 95 occur in separate groups as one has been planted with conifers and the other has not. The vegetation of the two sites differs, therefore, although the sites themselves are similar. The basic data which went into the analysis for these 4 sites is given below:-

Site No.	Slope	Altitude	Mean soil depth	Loss on Ignition	pH	Slope variation	Aspect variation
10	30°	1385 ft	23 cm	16.5	4.3	0.8	68
95	9°	1430	7	26.4	4.1	0.9	17
64	6°	660	19	13.7	5.5	0.8	50
65	1°	560	13	10.9	6.0	0.2	55

The values of the first five components in the principal components analysis were:-

	1	2	3	4	5
10	1.306	- 0.803	0.956	- 1.301	- 0.281
95	0.639	- 1.182	0.450	- 1.098	- 1.239
64	- 1.591	0.294	0.597	0.887	0.076
65	- 2.020	0.838	0.954	1.345	0.164

It is evident that these two pairs of sites are not completely identical with each other, but they are similar with respect to most of the seven variables measured.

As mentioned previously, it is possible that the inclusion of other variables, such as the amount of available soil nutrients or soil aeration, might improve the correlation between the environmental and the floristic data. Similarly, a different method of analysing the data collected might be more useful, although the method adopted does appear to be reasonably satisfactory.

It was noted earlier in this paper that the inclusion of all 12 environmental variables was less satisfactory than an analysis based on 7 of these variables, and Figs. 7 and 8 illustrate this point. Each represents the plotted functions of the first 5 principal components for five sites in one group of the association analysis. In the case of Fig. 7 this was based on 12 variables and in the case of Fig. 8 on only seven variables. As can be seen, the curves produced by the latter method bear a closer similarity to each other than when produced from 12 variables; and this was also the case with sites in other groups of the association analysis. As the sites in any one group are likely to be similar in many respects, it is reasonable to assume that the use of the 7 variables gives a more realistic interpretation than the use of 12 variables.

It is possible, by examining the plotted curves for all the sites studied, to find which sites are most similar in terms of these 7 variables. For example, Fig. 9 shows the curve for a non-wooded site (no. 79) and the curves for 5 wooded sites which resemble it most closely. These 5 sites occur in 4 different groups in the association analysis, possibly reflecting differences in the history of the woodland cover and/or environmental factors which were not measured. Some details of these sites are listed below:-

Site No.	Slope	Altitude	Loss on Ignition	pH	Height of trees	% bracken	% tree canopy
29	29°	700 ft	43.1	4.4	11 m	50	55
31	17	625	42.0	4.6	15	20	65
39	19	625	27.7	4.4	12	25	70
43	18	605	14.4	4.3	20	45	75
47	24	500	27.2	4.3	12	1	100
79	36	570	22.6	4.4	-	10	-

The tree and shrub species present were:-

Site No.	Quercus petraea	Fraxinus excelsior	Sorbus aucuparia	Corylus avellana	Prunus padus	Crataegus monogyna	Acer pseudoplatanus	Betula pubescens	Ilex aquifolium	Alnus glutinosa	Prunus spinosa	Pyrus pyraster	Fagus sylvatica	Picea abies	Larix decidua	Sambucus nigra	Castanea sativa	Salix caprea
29		+	+	+	+	+	+				+							
31	+	+	+	+		+		+	+	+		+						
39	+		+	+			+			+								
43	+	+	+		+	+	+	+	+				+	+	+	+	+	
47	+	+	+	+			+	+	+									+
79						+												

It is evident that sites of this type are capable of supporting mixed broadleaved woodland containing oak, ash, sycamore, and a range of smaller trees and shrubs.

Taking a somewhat different type of site, it is again possible to find sites which give similar plotted curves. Details from one such example are given below:-

Site	Slope	Altitude	Loss on Ignition	pH	Height of trees	% bracken	% tree canopy
4	12°	1040 ft	11.4	4.9	21 m	–	90
6	10	1200	10.8	4.7	19	–	70
7	12	1130	16.3	4.9	15	–	50
38	18	740	14.6	4.6	12	80	35
49	12	900	18.6	3.9	16	30	60
71	19	1000	18.7	4.2	–	95	–
84	24	1040	14.1	4.5	–	35	–
91	16	830	17.4	3.9	–	80	–
98	24	1075	19.8	4.5	–	40	–

The tree and shrub species present were:-

Site No.	Larix decidua	Fraxinus excelsior	Sorbus aucuparia	Crataegus monogyna	Acer pseudoplatanus	Ulmus glabra	Quercus petraea	Pinus sylvestris	Alnus glutinosa	Fagus sylvatica	Picea abies	Prunus avium	Sambucus nigra	Pinus mugo	Ilex aquifolium	Malus sylvestris	Corylus avellana
4	+	+	+	+	+	+	+	+	+								
6	+	+	+		+	+				+							
7			+		+	+					+	+	+	+			
38		+		+			+								+	+	+
49	+		+								+						
71																	
84				+													
98			+	+													

These sites are at higher elevations than those in the previous example and, in most cases, have a lower organic matter content in the soil. Four of the five wooded sites are basically coniferous plantations, but also contain a number of self-sown trees, such as ash, rowan, sycamore, and wych elm, indicating the type of woodland which could occur there naturally.

In the case of a few sites, it was not possible to find another site within those examined which was very similar, but in most cases at least one other site could be found which gave a similar curve when the relevant functions were plotted. The main area of difficulty lies in those sites between about 1200 ft (366 metres) and 1500 ft (457 metres), as there were only five wooded sites in the study at this elevation, all of which were first-rotation coniferous plantations currently accessible to grazing sheep. Some birch (Betula pubescens) was present in two of these, and some rowan (Sorbus aucuparia) in one other. These plantations had been planted on un-ploughed ground and it was evident that tree growth of some sort was not precluded by elevation up to the limit adopted in this study. There is, however, insufficient information on sites above 1200 ft. to make any valid deductions as to the type of woodland which would occur there is grazing were to cease. It is likely that tree growth would be less vigorous at this elevation than lower down the slopes, due to the more rigorous climate and the generally more acidic soil (see Appendix 1), but that a fairly continuous cover of birch and rowan would develop, disappearing at some undetermined altitude depending partly on the amount of grazing by deer and other animals.

At the other end of the environmental spectrum, there were a number of fairly fertile, level, low-lying sites, only one of which was wooded. Most such sites form relatively good quality pasture and the one wooded site of this type was a broadleaved plantation containing hornbeam (Carpinus betulus) and larch (Larix decidua) in addition to species native to this region. It is unlikely, however, that many areas of this type would be taken out of agricultural usage, so a lack of information on this land type may not be very important.

Conclusions

This study has not given any results which could not have been forecast intuitively by a competent ecologist, but it has attempted to deal objectively with the information that could be collected in the space of 5 or 6 weeks' field work.

On the basis of the available evidence, it would appear that most of the land below 1200 ft (366 metres) would be covered by mixed woodland of oak, ash, sycamore, rowan, elm, birch, etc., within the area studied, if grazing animals were to be removed. Above that elevation there would probably be a more open type of woodland consisting predominantly of birch and rowan, but insufficient evidence is available to delineate the exact limits of this, or its exact structure or floristic composition.

As far as the analysis of data is concerned, it is evident that the inclusion of variables which are of minor importance can confuse the analysis, and, as far as possible, the selection of environmental variables should be restricted to those which can be shown to be of importance to the matter being studied.

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Appendix 1.

Correlation coefficients between 12 environmental variables at 108 sites.

	Slope	°from 200°	Aspect/slope	Alt.	Soil depth: Mean	Soil depth: Max.	Soil depth: Min.	Soil depth: Max-Min.	L.O.I.	pH	Diffs. in slope	Diffs. in aspect
Slope	1.0	- .10	+ .20	+ .22	- .43	-.35	- .44	+ .03	+ .12	- .25	- .30	+ .36
°from 200°		1.0	- .83	+ .19	+ .09	+.07	+ .09	- .01	+ .05	- .28	+ .20	+ .05
Aspect/slope			1.0	- .07	- .07	-.09	- .06	- .04	+ .05	+ .14	- .15	- .09
Altitude				1.0	+ .05	+.02	+ .03	- .01	+ .07	- .23	- .16	+ .03
Soil depth: Mean					1.0	+.90	+ .88	+ .17	+ .13	+ .06	+ .01	- .25
Soil depth: Max.						1.0	+ .63	+ .56	-	+ .02	+ .07	- .13
Soil depth: Min.							1.0	- .30	+ .29	+ .08	- .05	- .29
Soil depth: Max-Min.								1.0	- .30	- .06	+ .13	+ .16
Loss on Ignition									1.0	- .33	- .16	-
pH of soil										1.0	+ .11	- .06
Diff. in slope											1.0	+ .06
Diff. in aspect												1.0

Coefficients of ± 0.19 are significant for probabilities of 0.05

Coefficients of ± 0.25 are significant for probabilities of 0.01

Correlation coefficients between principal components, numbers of species, etc., based on 12 environmental variables.

	Principal components 1	2	3	4	5	Canopy ± 0 or 100%	Ht. of trees	Ht. of herb-age	% bracken	% trees	Species "values" 70 x 70m	Species numbers 70 x 70m
1 (shallow soil)	1.0	-	-	-	-	.09	.18	- .28	.17	.07	.10	.15
2 (aspect)		1.0	-	-	-	.16	.10	.05	.23	.11	.11	- .08
3 (high L.O.I. little variation in slope)			1.0	-	-	.08	- .18	.01	.09	- .01	.04	- .29
4 (much variation in depth)				1.0	-	.08	- .02	- .20	.09	.08	.02	- .10
5 (low altitude, high LOI)					1.0	.08	.23	- .04	.11	.24	.08	.24
Tree canopy ± 0 or 100% (max. 50)						1.0	.59	.19	.18	.53	- .08	.19
Height of trees							1.0	.22	.08	.78	- .10	.32
Height of herbage								1.0	- .12	.17	- .12	- .04
% bracken									1.0	- .10	.05	.01
% tree canopy										1.0	- .18	.17
Species "values" in 70 x 70 m plots											1.0	.56
Species numbers in 70 x 70 m plots												1.0

Coefficients of ± 0.19 are significant for probabilities of 0.05

Coefficients of ± 0.25 are significant for probabilities of 0.01

APPENDIX 2.

Relative values of species occurring in .003% to 100% of the squares in the Atlas of the British Flora, calculated from the formula:-

$$\text{Value} = \frac{1}{\left(e^{-.000676\, y^2 + .1613\, y - .1606}\right)^{.64} \times C}$$

where e = 2.71828

y = % occurrence

C = a constant, .002754.

.003	402.3	.03	401.2	1	363.1	34	19.84	67	2.78
.006	402.2	.06	399.9	2	327.9	35	18.44	68	2.66
.009	402.0	.09	398.7	3	296.4	36	17.15	69	2.55
.012	401.9	.12	397.5	4	268.1	37	15.96	70	2.44
.015	401.8	.15	396.2	5	242.8	38	14.87	71	2.34
.018	401.7	.18	395.0	6	220.0	39	13.87	72	2.24
.021	401.5	.21	393.8	7	199.5	40	12.94	73	2.15
.024	401.4	.24	392.6	8	181.1	41	12.09	74	2.07
.027	401.3	.27	391.4	9	164.6	42	11.30	75	1.99
		.30	390.2	10	149.7	43	10.57	76	1.92
		.33	389.0	11	136.2	44	9.90	77	1.85
		.36	387.8	12	124.1	45	9.28	78	1.78
		.39	386.6	13	113.1	46	8.71	79	1.72
		.42	385.4	14	103.2	47	8.18	80	1.66
		.45	384.2	15	94.29	48	7.68	81	1.61
		.48	383.0	16	86.19	49	7.23	82	1.56
		.51	381.8	17	78.85	50	6.80	83	1.51
		.54	380.6	18	72.20	51	6.41	84	1.46
		.57	379.5	19	66.17	52	6.05	85	1.42
		.60	378.3	20	60.70	53	5.71	86	1.38
		.63	377.1	21	55.72	54	5.39	87	1.34
		.66	376.0	22	51.20	55	5.10	88	1.30
		.69	374.8	23	47.09	56	4.82	89	1.27
		.72	373.7	24	43.34	57	4.57	90	1.23
		.75	372.5	25	39.93	58	4.33	91	1.20
		.78	371.4	26	36.82	59	4.11	92	1.18
		.81	370.2	27	33.97	60	3.90	93	1.15
		.84	369.1	28	31.38	61	3.71	94	1.12
		.87	368.0	29	29.01	62	3.53	95	1.10
		.90	366.8	30	26.84	63	3.36	96	1.08
		.93	365.7	31	24.86	64	3.20	97	1.06
		.96	364.6	32	23.04	65	3.05	98	1.04
		.99	363.5	33	21.37	66	2.91	99	1.02
								100	1.00

MAP 1. LOCATION OF STUDY AREA.

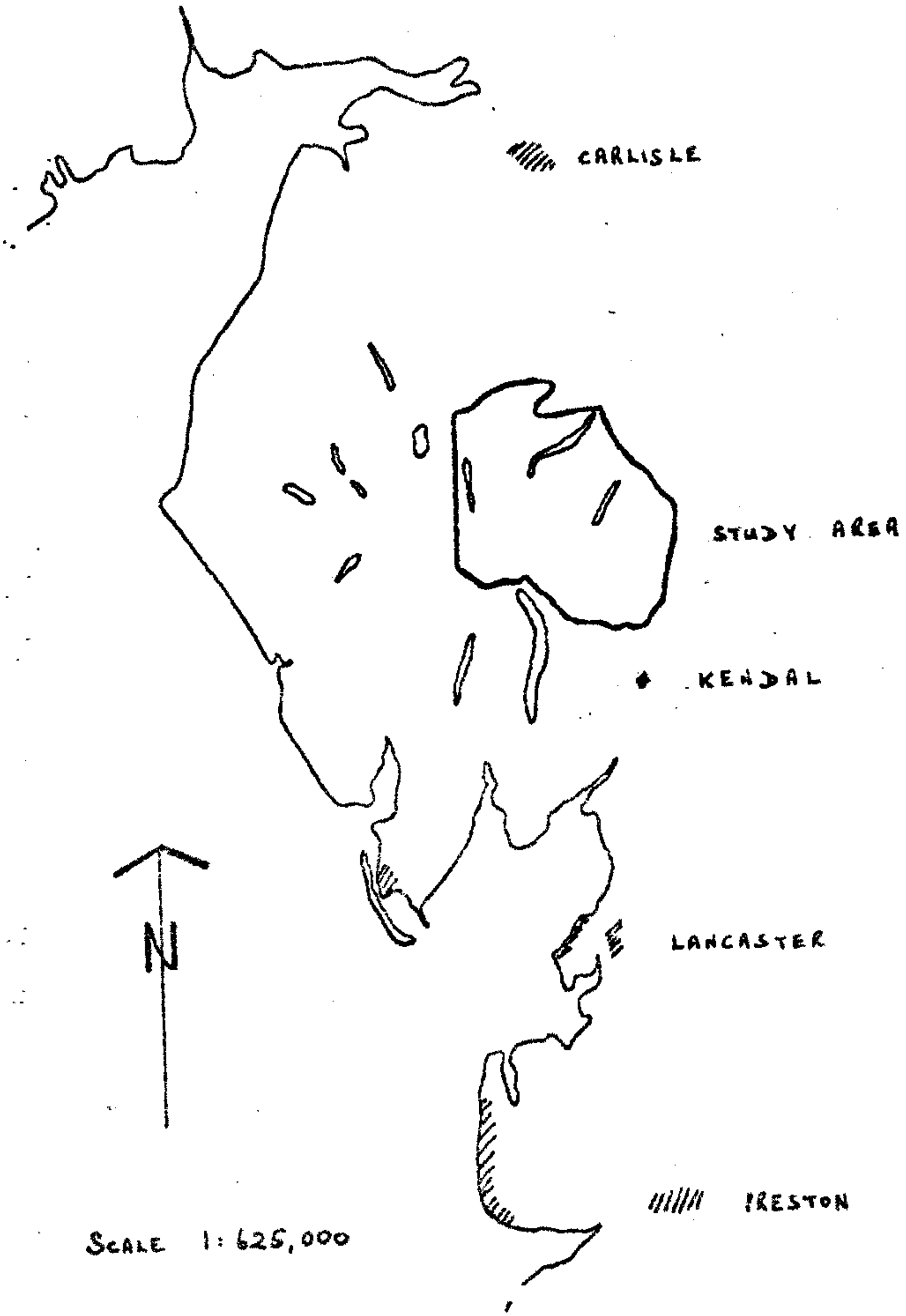


Fig. 1. Numbers of Plant Species in 104 Sample Sites.

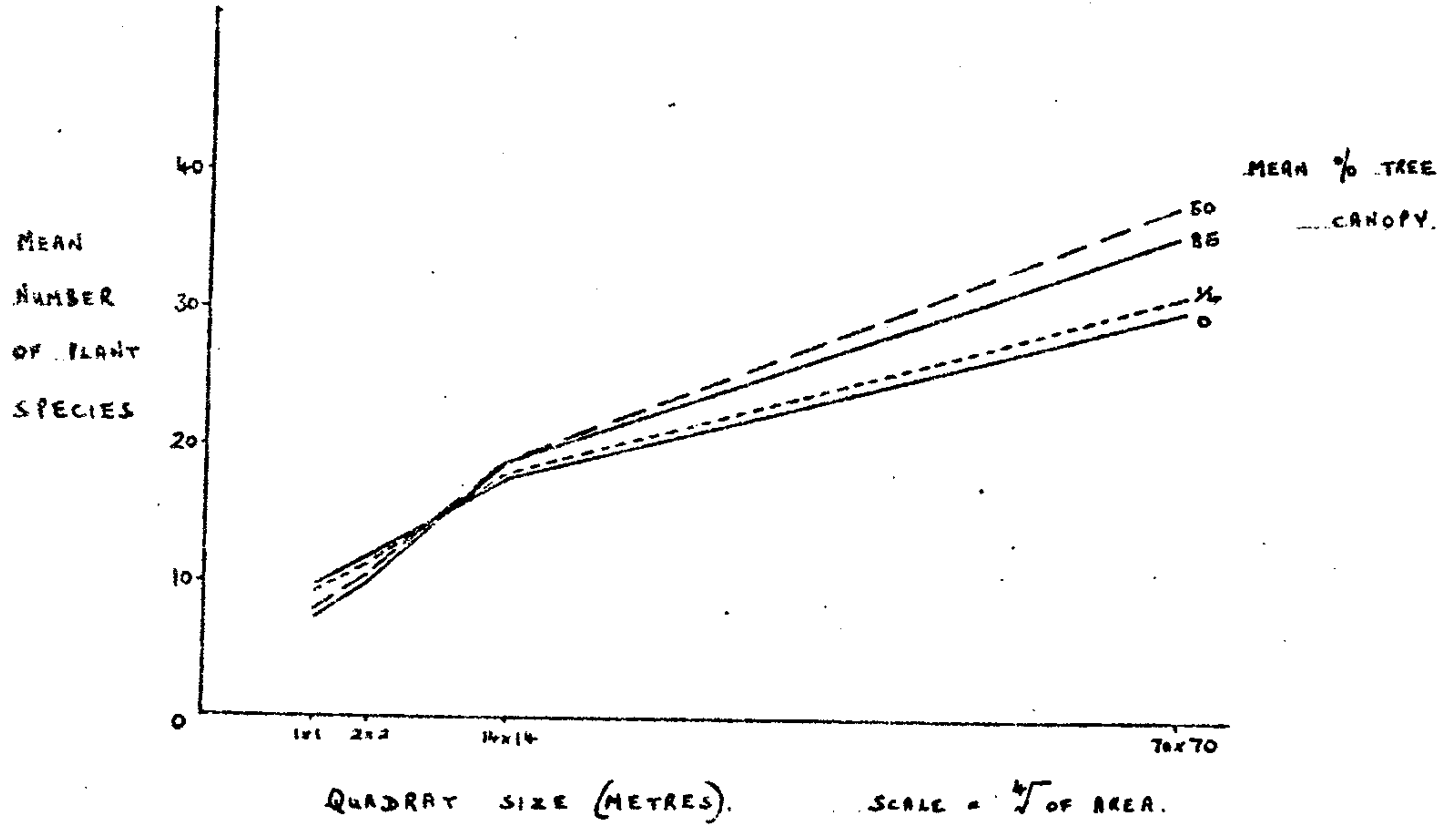


FIG. 2. NUMBERS OF PLANT SPECIES IN 5 SAMPLE SITES.

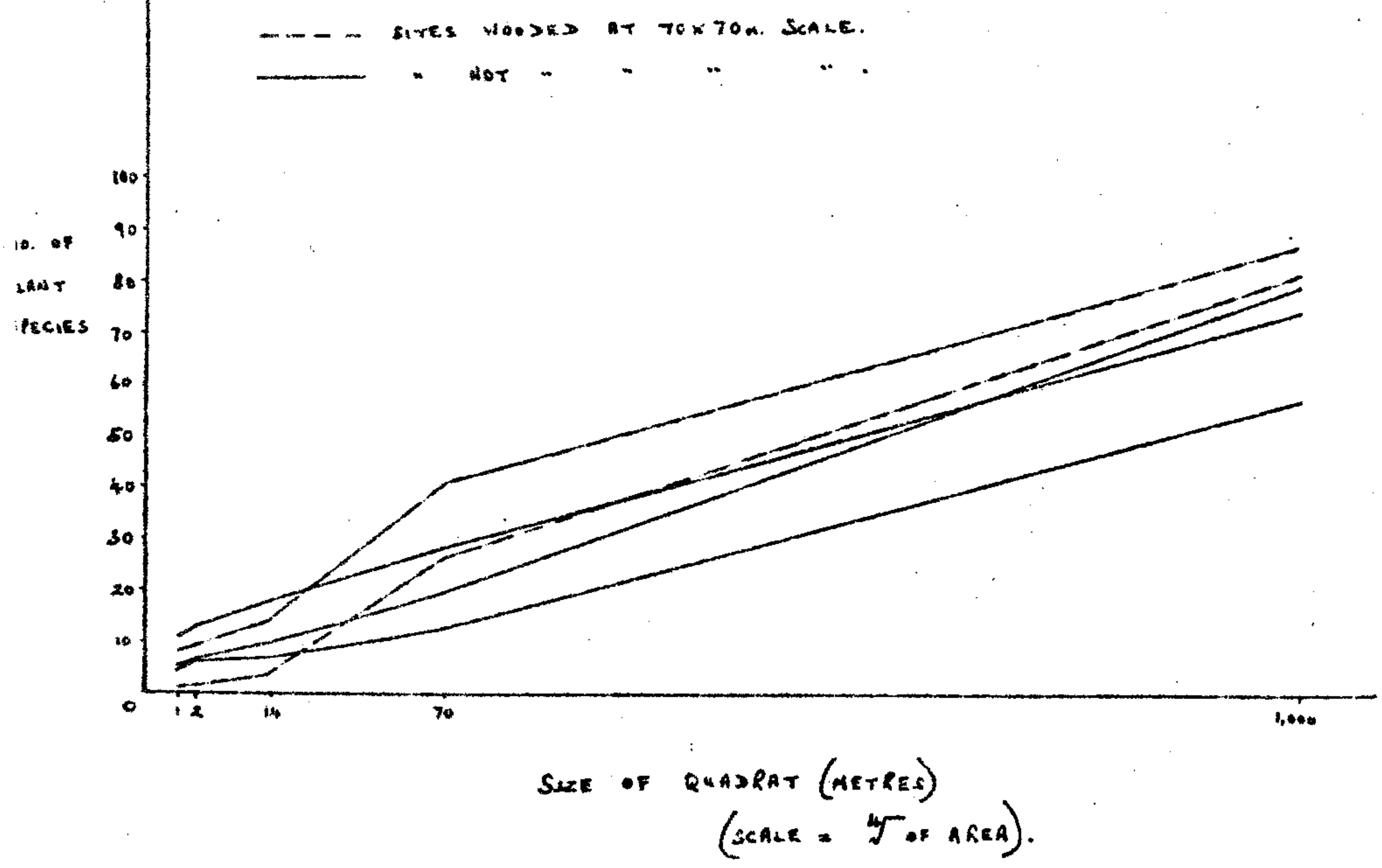
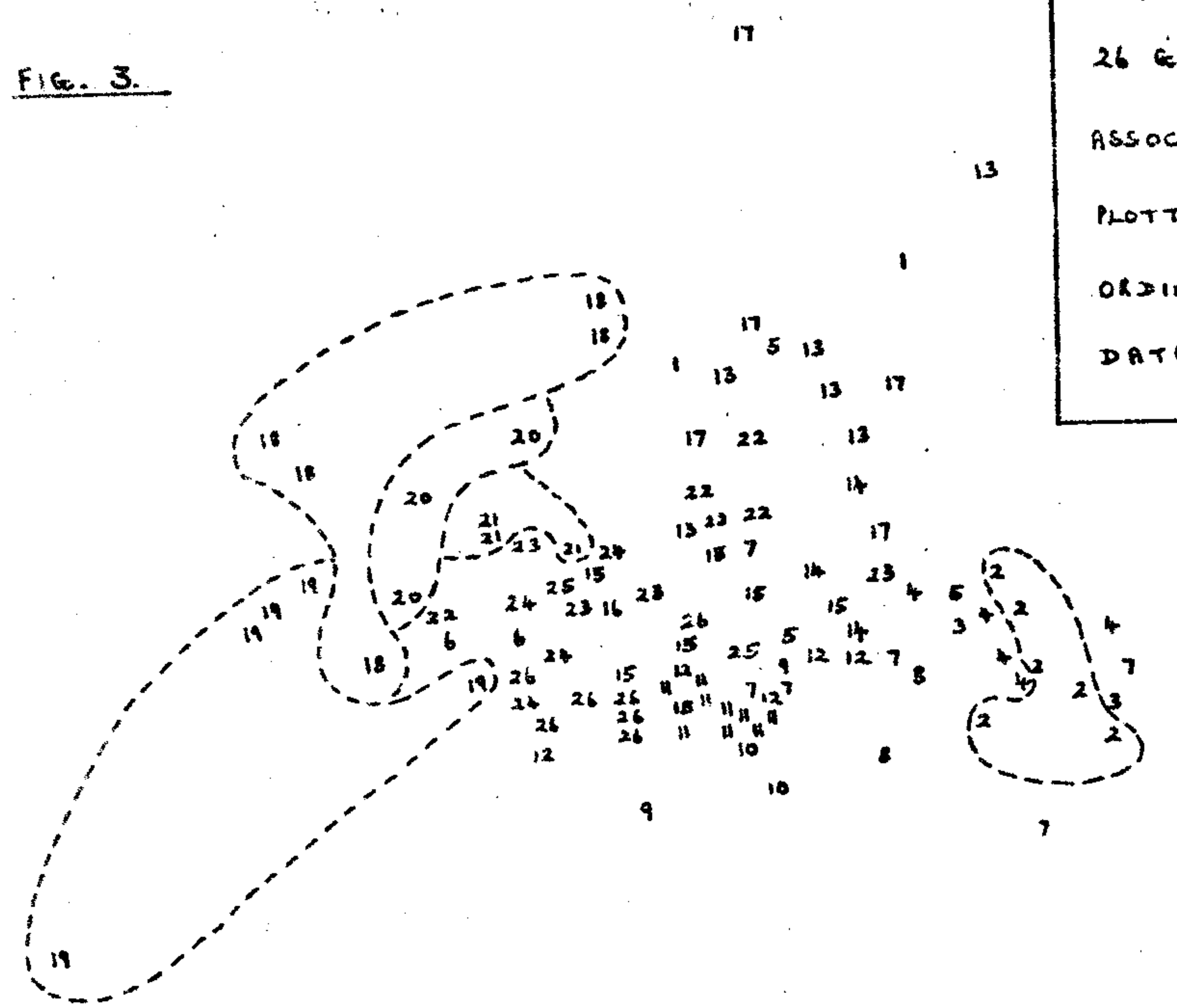


FIG. 3.



26 GROUPS OF THE FLORISTIC ASSOCIATION ANALYSIS PLOTTED ON 2 AXES OF AN ORDINATION OF THE SAME DATA.

Fig. 4

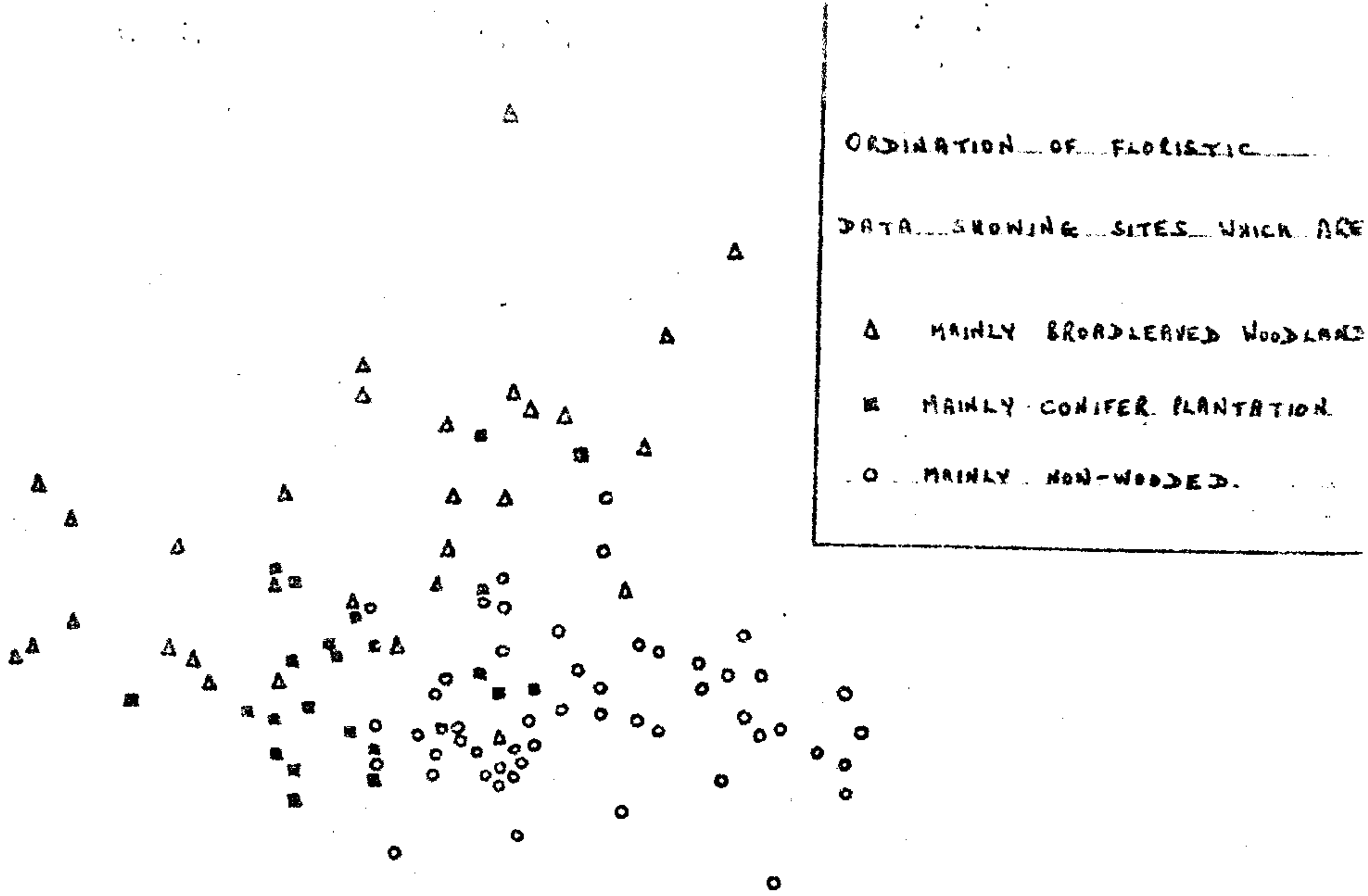
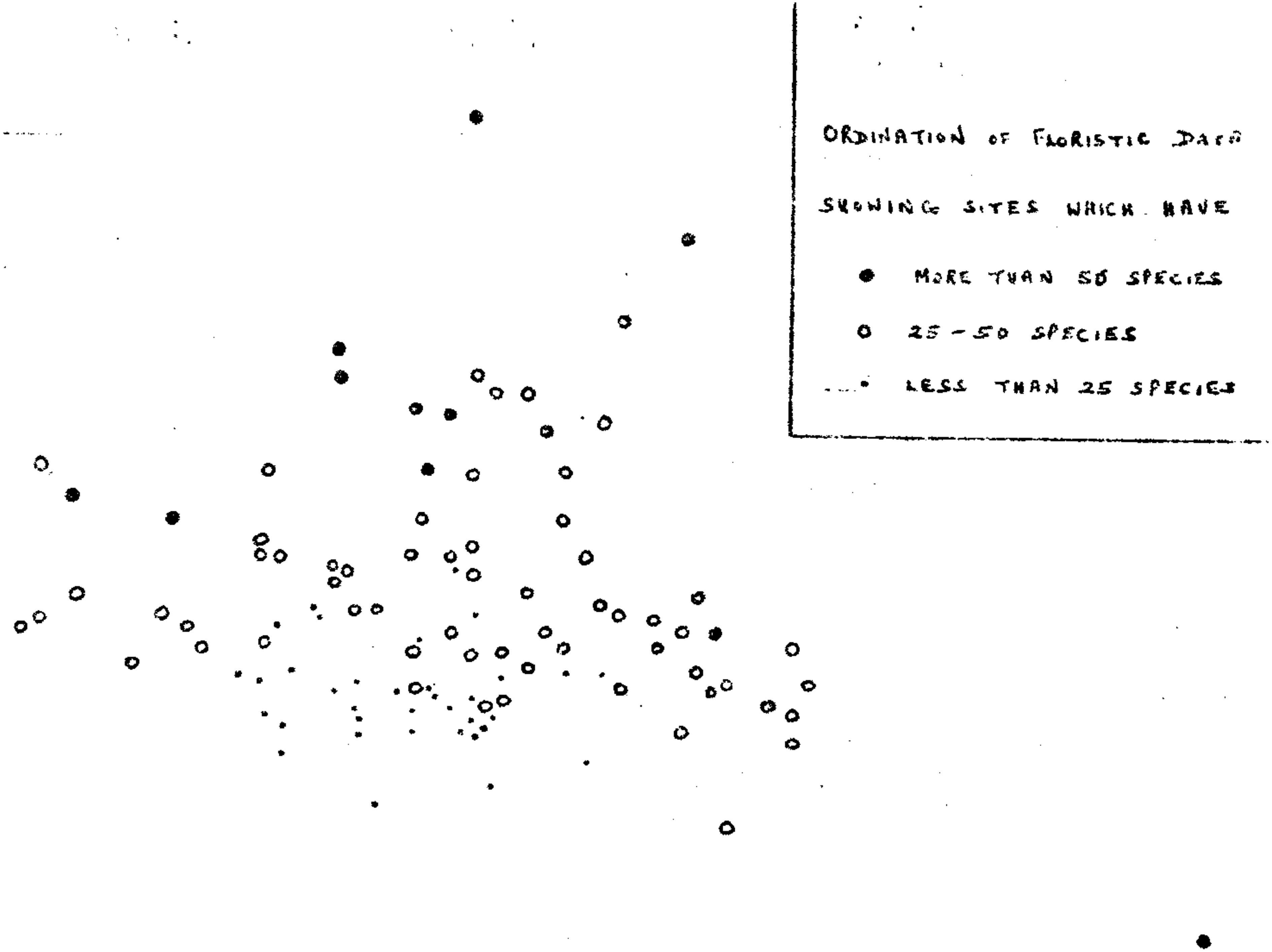

ORDINATION OF FLORISTIC
DATA SHOWING SITES WHICH ARE
Δ MAINLY BROADLEAVED WOODLAND
■ MAINLY CONIFER PLANTATION
O MAINLY NON-WOODED.

FIG. 5.



ORDINATION OF FLORISTIC DATA
SHOWING SITES WHICH HAVE
MORE THAN 50 SPECIES
25 - 50 SPECIES
LESS THAN 25 SPECIES

FIG. 6. PLOTTED FUNCTIONS OF ENVIRONMENTAL DATA FOR 4 SITES.

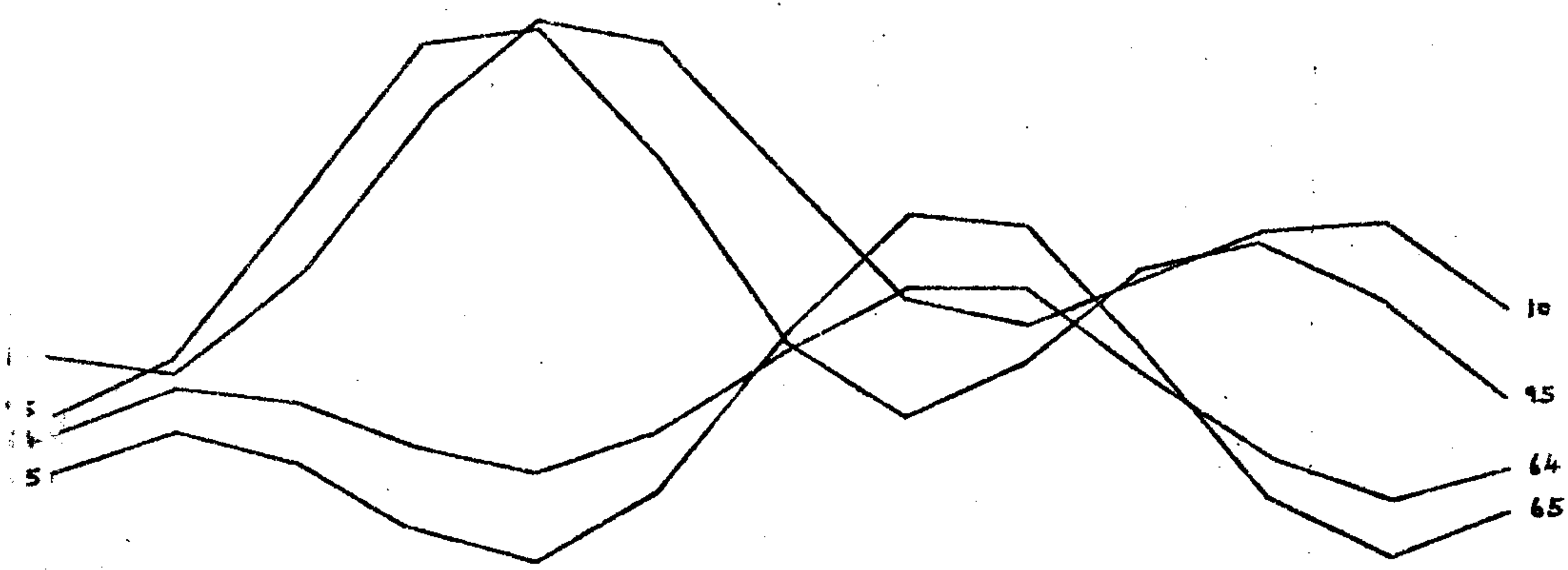


FIG. 7. PLOTTED FUNCTIONS FOR 5 SITES IN ONE GROUP OF THE FLORISTIC — ASSOCIATION ANALYSIS, USING 12 ENVIRONMENTAL VARIABLES.

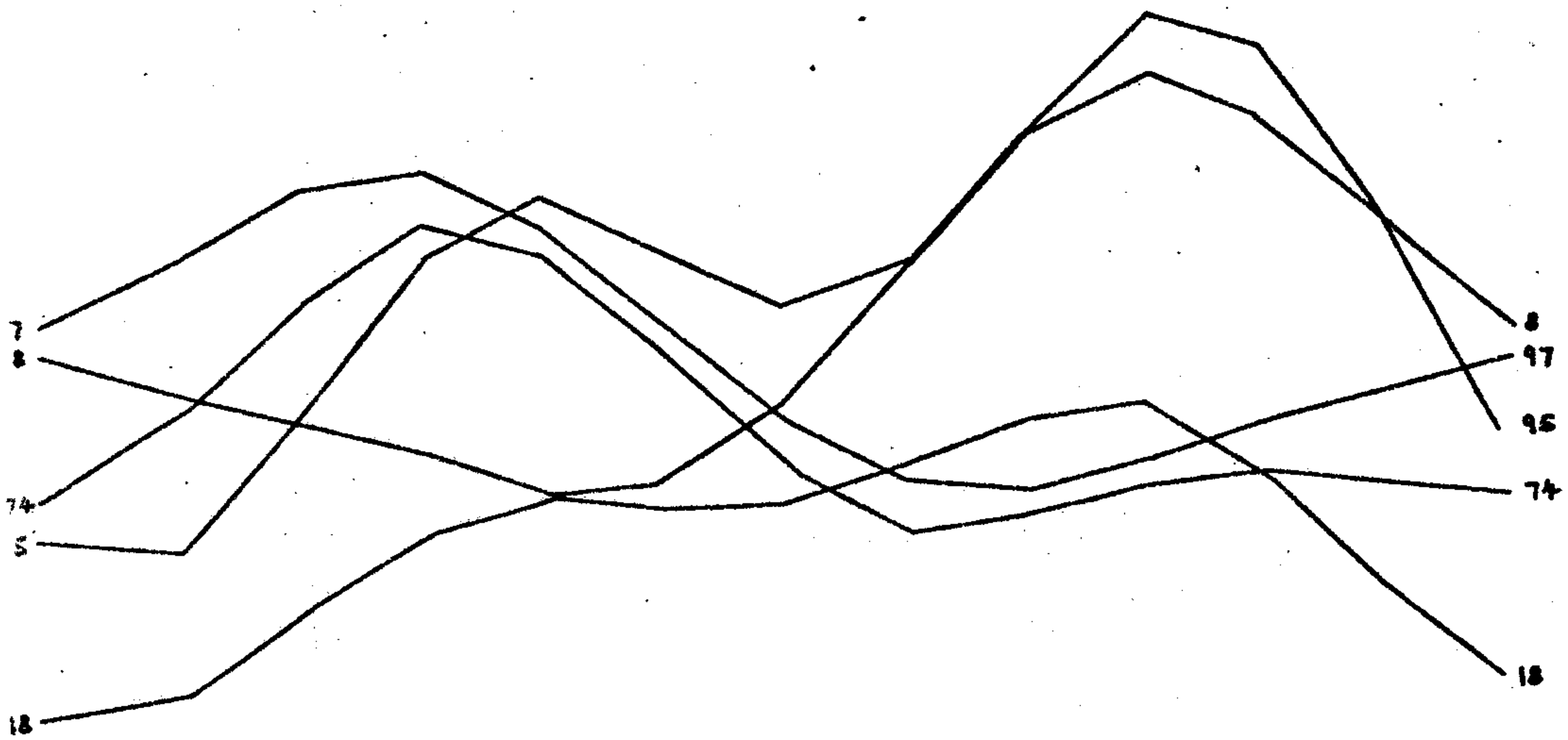


FIG. 7 PLOTTED FUNCTIONS FOR 5 SITES IN ONE GROUP OF THE FLORISTIC ASSOCIATION ANALYSIS, USING 12 ENVIRONMENTAL VARIABLES.

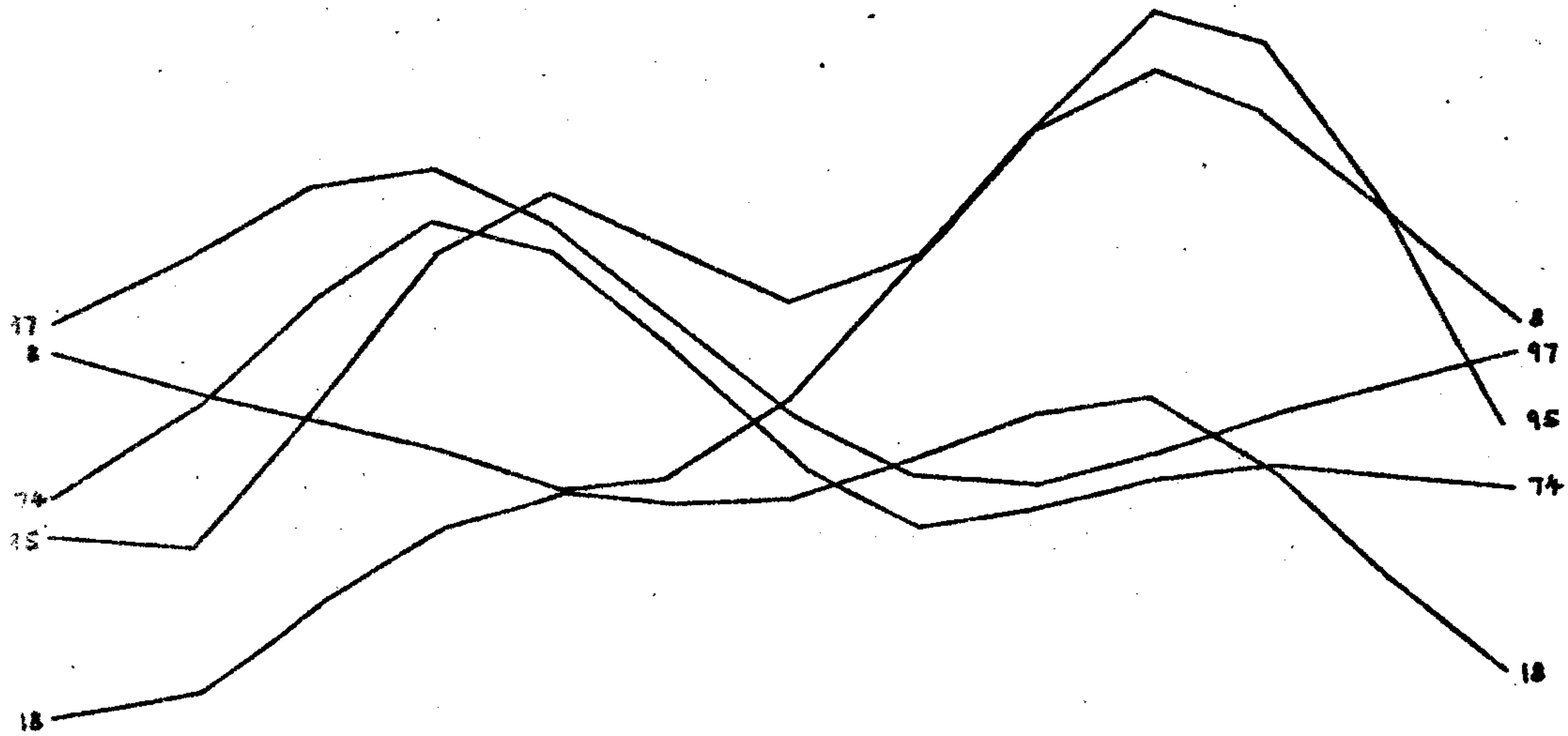


FIG. 8. PLOTTED FUNCTIONS FOR 5 SITES IN ONE GROUP OF THE FLORISTIC ASSOCIATION ANALYSIS, USING 7 ENVIRONMENTAL VARIABLES.

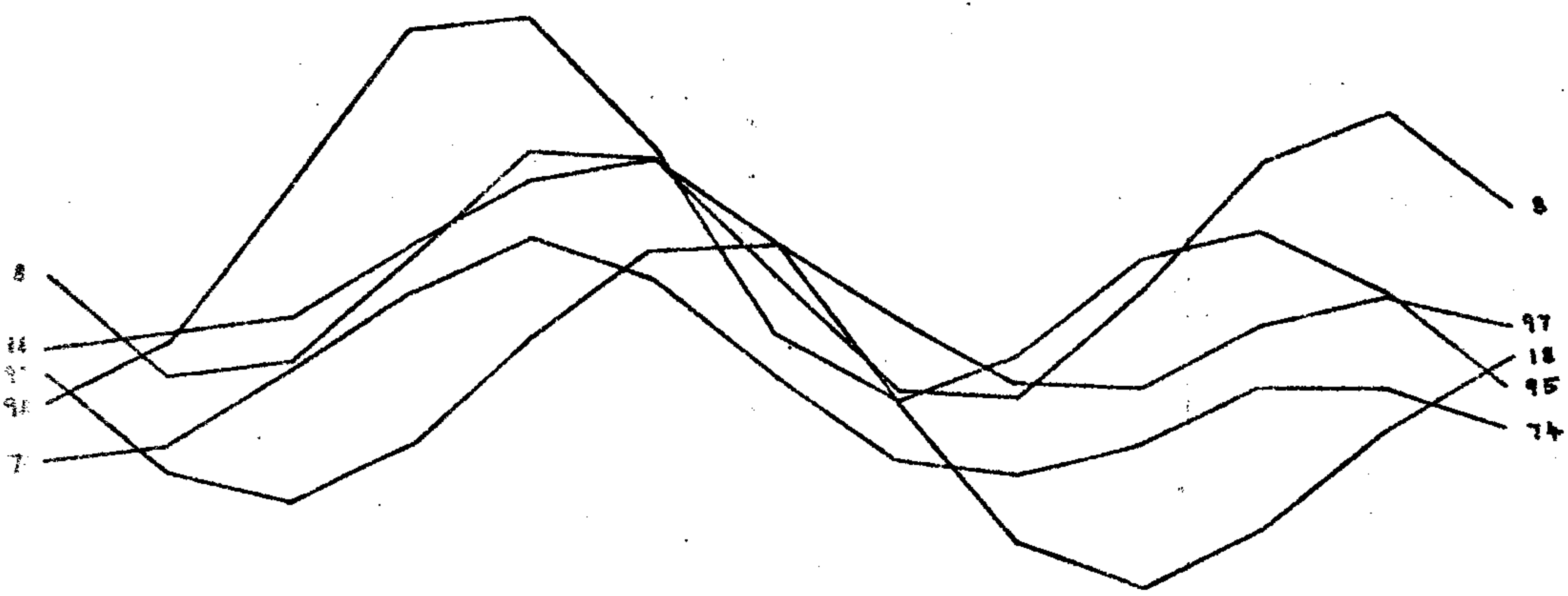
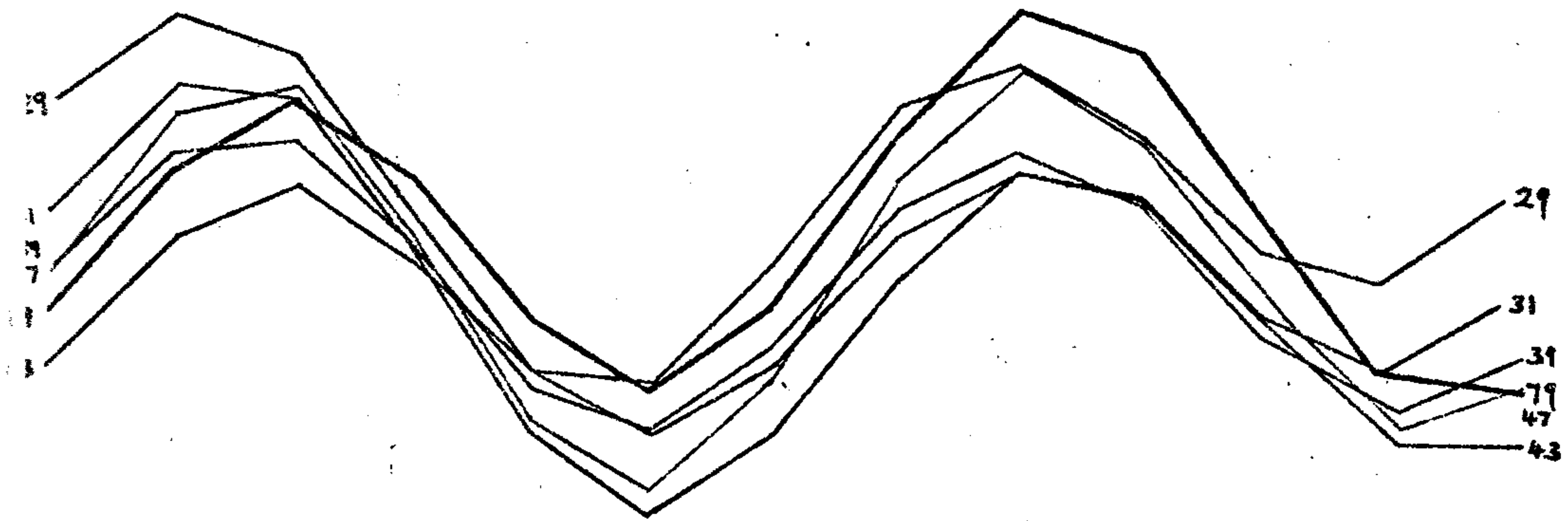
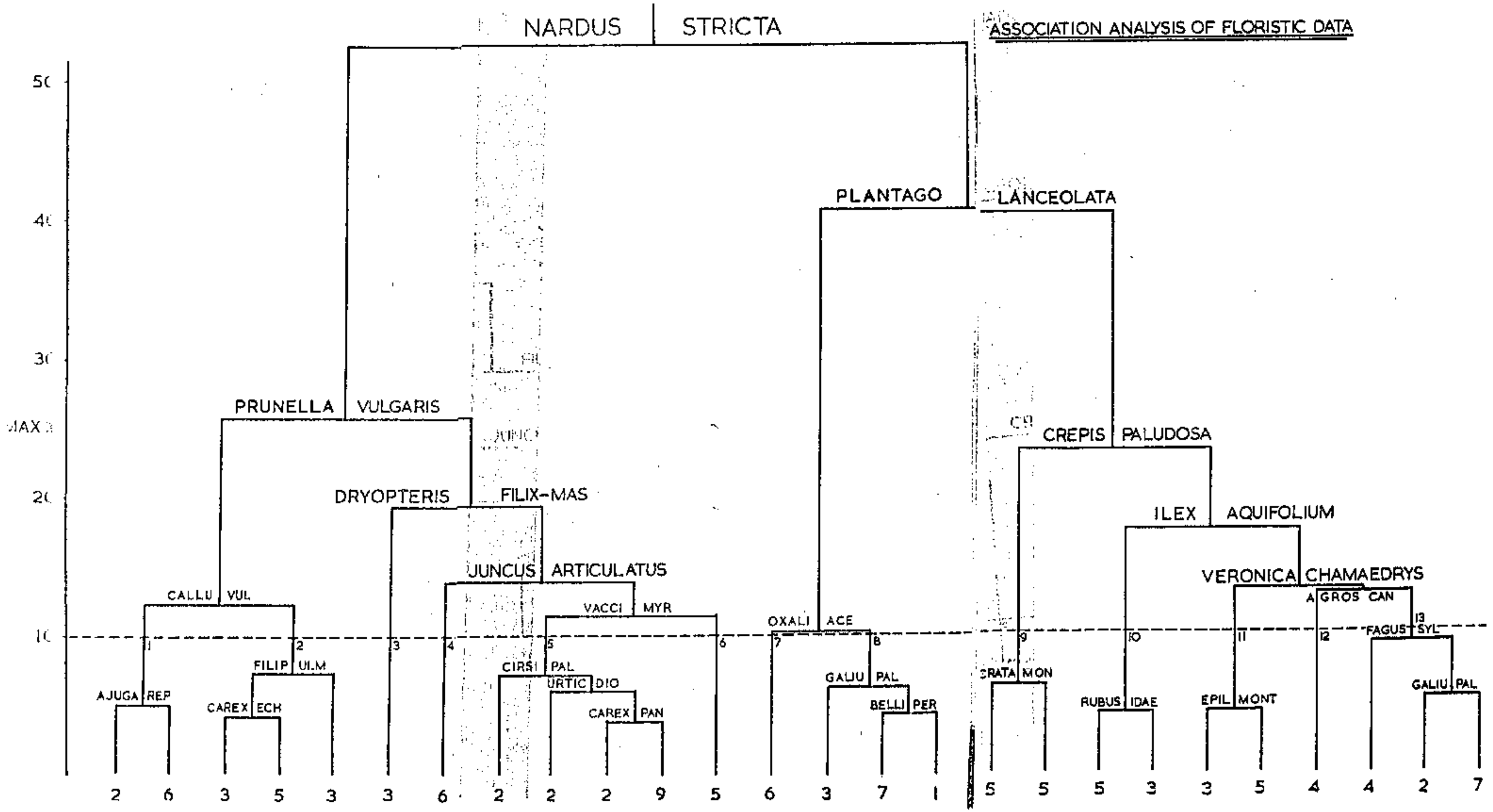


FIG. 9. PLOTTED FUNCTIONS FOR ONE NON-WOODED AND FIVE WOODED SITES.



Association analysis groups at χ^2 10 level.

Group	Mean number of species.	Mean "value" of site.	Mean "value" of each species at site.
1	52	584	11.2
2	42	260	6.2
3	37	317	8.6
4	34	221	6.5
5	17	140	8.2
6	21	89	4.2
7	50	216	4.3
8	29	105	3.6
9	49	271	5.5
10	37	142	3.8
11	36	180	5.0
12	30	169	5.6
13	20	111	5.6



ASSOCIATION ANALYSIS OF FLORISTIC DATA
NARDUS
STRICTA
PRUNELLA
VULGARIS
PLANTAGO
LANCEOLATA
DRYOPTERIS
FILIX-MAS
CREPIS
PALUDOSA
JUNCUS
ARTICULATUS
ILEX
AQUIFOLIUM
VERONICA
CHAMAEDRYS
CALLU
VUL
VACCI
MYR
OXALI
ACE
AGROS
CAN
FAGUS
SYL
FILIP
ULM
AJUGA
REP
CAREX
ECH
CIRSI
PAL
URTIC
DIO
CAREX
PAN
GALIU
PAL
BELLI
PER
CRATA
MON
RUBUS
IDAE
EPIL
MONT
GALIU
PAL
1 2 3 4 5 6 7 8 9 10 11 12 13
2 6 3 5 3 3 6 2 2 2 9 5 6 3 7 1 5 5 5 3 3 5 4 4 2 7

Correlation coefficients between principal components, numbers of species, etc., based on 7 environmental variables.

	Principal components, based on 7 variables 1	2	3	4	5	Canopy ± 0 or 100%	Ht. of trees	Ht. of herbage	% bracken	% trees	Species "values" 70 x 70m	Species numbers 70 x 70m
1 (steep slope, low pH)	1.0	-	-	-	-	.19	.06	- .25	.29	.11	.18	- .08
2 (shallow soil, low LOI)		1.0	-	-	-	.01	.25	- .13	.04	.02	.15	.43
3 (uniform topography, low LOI)			1.0	-	-	- .10	- .23	- .04	- .08	- .27	-	- .07
4 (low altitude, flat)				1.0	-	- .02	.10	- .10	.13	.05	.04	.18
5 (variations in aspect, deep soil, high pH)					1.0	.04	- .11	.03	- .04	- .06	.17	.23
Canopy ± 0 or 100%						1.0	.59	.19	.18	.53	- .08	.19
Ht. of trees							1.0	.22	.08	.78	- .10	.32
Ht. of herbage								1.0	- .12	.17	- .12	- .04
% bracken									1.0	- .10	.05	.01
% trees										1.0	- .18	.17
Species "values" 70 x 70 m											1.0	.56
Species numbers 70 x 70 m												1.0

Coefficients of ± 0.19 are significant for probabilities of 0.05

Coefficients of ± 0.25 are significant for probabilities of 0.01

Correlation coefficients between % bracken and tree cover, height of herbage, and environmental variables

	Ht. of herbage	% bracken	% trees	Slope	Aspect from 200°	Alt.	Mean soil depth	Variation in soil depth	L.O.I.	pH	Diff. in slope	Diff. in aspect
Herbage	1.0	- .11	.17	- .25	.20	- .01	.24	- .15	- .03	.05	.12	- .13
% bracken		1.0	- .10	.28	.13	- .08	- .12	.01	.05	- .28	- .13	.15
% trees			1.0	.06	.03	- .10	- .06	.08	.09	- .24	.09	.14
Slope				1.0	- .10	.22	- .43	.03	.12	- .24	- .30	.36
Aspect					1.0	.19	.09	-	.05	- .28	.20	.05
Alt.						1.0	.05	- .01	.07	- .23	- .16	.03
Mean soil depth							1.0	.17	.13	.05	.01	- .25
Variation in soil depth								1.0	- .31	- .07	.13	.16
L.O.I.									1.0	- .33	- .16	-
pH										1.0	.11	- .06
Diff. in slope											1.0	.06
Diff. in aspect												1.0

Coefficients of ± 0.19 are significant for probabilities of 0.05

Coefficients of ± 0.25 are significant for probabilities of 0.01