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Summary:
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The first season's work has elucidated the changes that take place in the early stages after planting, especially during the first half of the first rotation. It has also identified the parts of pasture vegetation that are being modified by afforestation in South-west Scotland.
Key-Words: AFFORESTATION; LAND-USE; UPLANDS; VEGETATION-CHANGES; VEGETATION-CLASSIFICATION

ITE Project 368, Interim report for the year 1975-6

QUANTITATIVE CHANGES IN THE FLORA OF THE UPLANDS FOLLOWING AFFORESTATION

Contents

		Page
1.	Background	1
2.	Objectives	1
3.	Area of study	1
4.	Stratification	2
5.	Sampling method	3
6.	Strategy of analysis	6
7.	Classification of semi-natural vegetation	7
8.	Environmental ordination and classification	12
9.	Changes in species composition over the course of the rotation	16
10.	Differences in soil and other environmental characteristics over the rotation (K. L. Bocock and J. K. Adamson)	30A
11.	Effect of streams, roads and rides	31
References		37

Appendix 1. Project plan (7 pages)

Appendix 2. Sample recording sheets (5 pages)

Appendix 3. Vegetation types of unplanted stands (14 pages)

Appendix 4. Procedures adopted for preparation and analysis of soil samples (4 pages)

Fig. 1 Map of Southern Uplands of Scotland

Fig. 2. Enlarged map of western section of study area

Figs. 3-9. Ordination of stands by multiple discriminant analysis

Fig. 10. Mean numbers of species per plot, summarized by age class

Figs. 11-12. Mean cover-abundance of selected species, summarized by age class

Figs. 13-14. Species numbers in special habitats compared with those in regular plots

Fig. 15. Environmental variables for the nine groups of unafforested sites.

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Summary

In summer 1975 an area of approximately 1900 km^2 was sampled in South-west Scotland. Attention was confined to hill grazing and coniferous vegetation, the aim being to determine floristic changes following afforestation.

Indirect changes may result from the cessation of grazing, but in South-west Scotland afforestation has so far reduced, rather than eliminated, grazing on the higher hill pastures. Effects could not be quantified with the limited data available. Within planted forests changes were much greater, or were profound and progressive.

The older plantings were almost exclusively on sites that would now be regarded as too good for afforestation. An environmentally based classification of stand types was constructed and the vegetation of different age classes studied within each. As a precursor of the environmental classification, the vegetation of unafforested stands was also classified. With a few exceptions, the hill vegetation of South-west Scotland corresponded closely to that which has already been described for similar altitudes in the highlands. Heather moor was scarce, occupying only about 4 per cent of the total.

When a site is planted, vegetation changes follow a characteristic pattern. First the smaller plants of grass pasture decrease and the coarser species increase, then as the crop canopy closes increasing shade eliminates most of the higher plants; bryophytes may increase at this stage or if the canopy is really dense then they may die. Finally the crop is thinned; ferns, bryophytes and other woodland plants may achieve relatively high cover.

Within an afforested area roads, rides, streams, lakesides and walls may provide habitats for various plants. Streams and roads were found to be the most important. Rides, on the other hand, often had a very high cover, some one or two species, but little else.

The first season's work has elucidated the changes that take place in the early stages after planting, especially during the first half of the first rotation. It has also identified the parts of pasture vegetation that are being modified by afforestation in South-west Scotland. Two main gaps need to be filled during next season. The first is in our knowledge of older planting, of clear felling and of the second rotation. The second is in the quantification of the effect of streams, roads and rides which provide refuge for light-demanding plants during the thicket stage. To study these effects, attention will be shifted during 1976 from Scotland to Wales where there is a higher proportion of older plantings.

1. Background

The background is not repeated here, as it is stated clearly in the project plan (Appendix 1).

2. Objectives

It is convenient to have the objectives stated here. They are repeated verbatim from the contract between N.C.C. and N.E.R.C., General conditions of contract governing research commissioned by N.C.C. from N.E.R.C., Appendix A, Impact of land-use on Nature Conservation interest.

To describe in quantitative terms the effects of afforestation on the wildlife and ecosystems of Upland Britain, with special reference to the following:-

1. The extent and characteristics of land afforested at various periods in the past, and the land still available for afforestation.

2. The fate of wildlife (native plants) present on the land prior to afforestation.

3. The changes which take place in plantations from planting to the felling of the final crop.

4. The wildlife found in subsidiary habitats within plantations.

5. The changes which may occur on land in the vicinity of plantations where grazing patterns are changed by afforestation.

6. To determine the main features of floristic succession during the crop rotation, in relation to differences of soil types, aspect and planted crop species.

3. Area of study

At the request of N.C.C., the 1975 sampling programme was concentrated on the Southern Uplands of Scotland. Fig. 1 shows the area studied and the sites sampled. Because of its special wildlife interest, sampling was particularly concentrated on the tract of land between Newton Stewart, New Galloway and Dalmellington. This is shown in greater detail in Fig. 2. The special features of this western area are the granite hills and bogs of the region between the Rhinns of Kells and the Merrick, and of the Cairnsmore of Fleet.

4. Stratification

4.1 The basic sampling units, referred to as sites, were Ordnance Survey 1 km grid squares. Initially all such squares in the study area were considered, and a list made of those which were depicted on the 1:50,000 maps as containing substantial proportions (more than ⅛ of the total area) of unimproved land and/or coniferous plantations.* Each square was then classified with respect to the following five criteria:-

(1) The altitude at the centre of the square. Four classes were distinguished: below 230 m, 230-380 m, 380-460 m, 460-760 m.

(2) The general steepness of the ground. The measure used here was the maximum number of 50 ft. contour lines intersected by a straight line through the centre of the square. There were three classes: 0 to 4, 5 to 9, and more than 9.

(3) The occurrence of granite as a parent material. Two classes: present and absent.

(4) The proportion of the square afforested. Two classes: 0 to ¼ and above ¼.

(5) The position of the square in relation to the east-west axis of the study area. Two classes: a western block between grid eastings 23 and 28, and an eastern block between eastings 28 and 33.

*This was estimated by use of a transparent overlay marked with a circle of diameter equivalent to 1 km and partitioned into eight equal segments.

4.2 In combination, the classes give rise to a possible 96 strata (4 x 3 x 2 x 2 x 2), of which in practice only 63 were represented. The others did no exist. The final selection of sites was made using random numbers with the constraint that one site from each stratum should be included. A few further sites were added at the field-work stage when it was realised that forest stands from the earliest plantings were not represented (four further sites), and that lakes in afforested areas were inadequately covered (two further sites). These were termed "specials".

5. Sampling method

5.1 The method was designed in the hope that complete recording of a site could be accomplished by a pair of recorders in a single day. Sampling was initially to be at six fixed locations within each 1 km square, supplemented by locations on linear features (roads, rides, streams, lake shores, walls etc.). The former were determined by the use of a regular pattern marked on a template, and the latter by intersections between the diagonals of the square and linear features; each type of feature being sampled only once. In practice it was found that even after several days' experience with the routine, the full quota of plots could not always be covered. The target was accordingly modified so that linear samples should substitute for, rather than supplement, regular ones; thereby keeping the target at six plots for all sites. Where selection of plots, either for exclusions or inclusions, was necessary, random numbers were used for the purpose. All the points finally selected for sampling were marked on either a 2½ inch series map or sometimes on a forest map, before going into the field.

5.2 Sampling was by means of a quadrat of the type used by Shaw and Bunce (1971) in their National Woodlands Classification. This consists essentially of a central post with four radiating strings representing the diagonals of a square. The ends of these strings are also fastened to posts which form the corners of a square of area 200 m^2. In addition, coloured markers at intervals along the strings demarcate concentric squares of 4 m^2, 25 m^2, 50 m^2 and 100 m^2. In setting up the quadrat, the central post was positioned so that it coincided as accurately as possible with the sampling point marked on the map. The quadrat was orientated in a standard way on a compass bearing for all regular plots, and in the case of linear features with one of its sides (what would normally have been its south side) placed along the feature. The toss of a coin decided which side of the feature was to be sampled.

5.3 The first items recorded were those making up the block of information on the left-hand side of page 1 of the recording form (see Appendix 2). The only measurements involved were those of aspect (with a compass), and slope (with a hypsometer - in degrees or percent).

5.4 The species search was initially directed to the central 2 x 2 m square, moving around the four segments in turn. Each record from this square was then struck off the species list on page 1, and the figure 1 entered against it to indicate its square of origin. This procedure was repeated in turn for each of the concentric squares, and where new records were encountered, marked with the appropriate square identifying code (2 to 5). In the case of samples on linear features, the zone associated with the feature, but outside the quadrat was also recorded, code number 6 being used as an identifier. The species recorded included all phanerogams, pteridophytes and bryophytes, together with terricolous lichens (mostly Cladonia species) and some corticolous lichens. Saxicolous lichens were generally omitted because of taxonomic difficulties. Species not on the list were written in by hand. Species encountered only in habitats other than the soil, were recorded with habitat code numbers (rock = 2, stump = 3, fallen timber = 4, epiphyte = 5, aquatic = 6).

5.5 Estimates of species cover (page 2 of the recording form) were obtained from ten placements of a wire 30 x 30 cm quadrat in standard positions. Only species with cover estimated at greater than about 5% were recorded, although in general the attempt was made to keep the total figure at or near 100%. The exceptions to this arose when trees or tall bracken were present, in which case these were treated separately. There are therefore instances of total cover values up to 200%. Measurements of maximum vegetation height (excluding inflorescences) were also made on each of the cover quadrats, and entered in the first row of the table on page 2 of the recording form.

5.6 At the bottom of the page 2 table were entered (where applicable) the DBH measurements for all, or more usually, a known proportion of the trees on the plot.

5.7 The third page of the recording form relates to a variety of observations concerned with the general nature of the plot - its tree crop, its physical features and its management.

5.8 The fourth page of the recording form relates to soils. Almost all the information here was obtained from a soil pit dug at, or very close to, the centre of the plot. This was about 30 cm square, and up to a maximum of 30 cm deep (less if stones made a hole of this depth impracticable). Layers within the profile were distinguished on colour and/or texture, and the main features of each layer recorded separately. The items recorded were thickness, colour (five classes), presence of mottling, texture (organic plus four particulate classes), stoniness (three classes), moisture on sampling (four classes), presence of earthworms, and presence of an iron pan. In the early stages of the field work it became apparent that inconsistencies were arising in relation to the recording of L, F and H layers. It was difficult to distinguish L from F material, and H layers were being confused with humic layers on the soil proper. A simplified procedure was therefore adopted quite early on, by which the L and F layers were combined for both descriptive and sampling purposes; and the H layer, where it occurred in collectable quantity, was regarded as the uppermost of the soil-proper layers. The occurrence of roots in most samples was recorded in the laboratory during the preparation of the soils for chemical analysis. Soil samples were taken from each layer described (about 400 g), and packed into carefully labelled polythene bags. These were to be used later for measurements of pH, loss-on-ignition, and a variety of chemical factors, as well as for the purpose of checking some of the field assessments.

6. Strategy of analysis

6.1 The main purpose of the survey was to determine the effects of afforestation on the flora. The simplest and crudest method of analysis would be to take all stands of a given age, and to prepare mean species compositions of the ground flora in the various age classes. By the end of the field season it was clear that such an approach would be almost meaningless. For the crude approach to work, the planted areas would have, on average, to resemble the unplanted areas in their site characteristics. This they manifestly did not. In the older plantings, foresters had preferred loamy soils; in the younger plantings there has perhaps been a preference for deep peat, as this is easy to plough. There has always been a preference for lower altitudes: plantings over 400 m were few, and most of those that we examined had grown poorly.

6.2 The difference in average site characteristics of the various age classes is almost inevitable; any system of analysis must take account of it. The best way to surmount the difficulty is to produce a classification of the plots based on environmental features that can readily be observed and which will not vary as a result of planting. A problem arises immediately, as many obvious and important environmental characteristics of unplanted areas are drastically and irrevocably altered by the foresters' ground preparation. For instance, a flushed peat may largely dry out as a result of deep ploughing.

6.3 Nevertheless, even a crude environmental classification can help to reduce the non-comparability of the planted and unplanted samples. A crude classification, indeed, was all that we could hope for given the very limited soil sampling in each plot. The problem was: how to produce the best - albeit crude - environmental classification given our data.

6.4 From the point of view of a plant ecologist, the best environmental classification is that which agrees most closely with the vegetation. Numerical methods for exploring the vegetation-environment relation are still not perfect. However, numerical methods for classifying the vegetation have recently been developed by one of us (M.O. Hill - see Hill, Bunce and Shaw, 1975). We now have sufficient experience of these methods to apply them with some confidence.

6.5 The general plan of the analysis has therefore been to proceed in five stages, as follows.

(i) Classify the semi-natural vegetation types (Section 7 below).

(ii) Using the vegetation classification as a basis, ordinate the environmental data by multiple discriminant analysis, confining attention to variables that are not expected to vary too much in response to changes in land use (Section 8 below).

(iii) Classify the stands according to their environment, by dividing up the environmental ordination diagram (latter half of Section 8).

(iv) Describe the change in vegetation during the crop rotation, each description being confined to a relatively limited range of environmental types, as defined by the classes of the environmental classification (Section 9).

(v) Examine and describe the environmental differences between differing age classes and floristic groups (Section 10).

7. Classification of semi-natural vegetation

7.1 As we wished to compare the semi-natural vegetation with that occurring in planted forests, we used a large (200 m^2) quadrat size. Previous investigations in upland Scotland (e.g. McVean and Ratcliffe, 1962) have frequently used a 4 m^2 quadrat - which is much smaller. Nevertheless, in the interests of comprehensibility we were determined to achieve some compatibility between our own vegetation classification and those previously published (notably McVean and Ratcliffe, 1962; King and Nicholson, 1964; and Birks, 1973). This led to difficulties which took us some time to surmount.

7.2 As a first attempt to achieve compatibility, our own species lists were combined into a single data set along with synthetic lists of species abstracted from published sources. The aim was to classify our own lists in accordance with existing schemes, and to encourage an adherence to these schemes, the synthetic data were multiplied by repeating them three times. The lists were then classified by a numerical technique, "indicator species analysis" (Hill, Bunce and Shaw, 1975). Regrettably, repetition of the synthetic data had led to a number of spurious species associations. (If any list of species repeats itself sufficiently often, then it must by definition count as an association.) A second classification was therefore attempted, but this time not repeating the synthetic species lists. The resulting classification was examined in detail, to see whether it was suitable for our purposes.

7.3 Though some of the broad outlines were acceptable, the resulting classification had two defects. It did not agree well with the published vegetation types, and it was clearly influenced by heterogeneity within some of our large quadrats. To achieve compatibility, we required a way of reducing the influence of within-plot variability. So the data were classified a third time, this time paying attention to the abundance of the species within our quadrats. The new classification was acceptable; it agreed well with the previously published vegetation types, and it had overcome the problem of heterogeneity by concentrating on the dominant, not the subordinate, vegetation in our quadrats.

7.4 Of necessity the various classifications took time. There was a heavy input of computer programming. Interpretation is not quick, even after the machine has made its calculations. Nevertheless, we thought it worthwhile to ensure that we had a firm phytosociological basis on which to build; and our computer programs are likely to be useful in other contexts. The price we have paid, however, is an appreciable delay to our programme of work.

7.5 The 19 semi-natural vegetation types are summarised in Appendix 3. At the outset we were not sure how far it would be possible to integrate our results with the Zurich-Montpellier scheme adopted by Birks (1973). In the event agreement was good, so we have modified the Braun-Blanquet hierarchy only slightly, where our data demanded it.

7.6 We must emphasise that we have used the Braun-Blanquet scheme purely as a matter of convenience, and not from any conviction that it is best. We did not adopt a standard Braun-Blanquet system of data collection; in our context subjective sampling would have been quite inappropriate. The Braun-Blanquet hierarchy merely provided us with a convenient pre-existing framework into which to fit our results. Our data were obtained by an objective system of sampling, and were analysed by an objective numerical method. Indeed, the only way in which our classification may have been influenced by previous workers' preconceptions is that we included 34 summary species lists (with mean domin numbers) from previously published data. These were intended as markers, to tell us where other authors' groups would key out in our hierarchy. As the data set included 190 of our own lists, the influence of other authors' preconceptions on our own findings must have been minimal.

7.7 It will be observed that the Braun-Blanquet scheme necessitates a considerable rearrangement of the end groups. This is inevitable, as any classification of vegetation involves the drawing of lines of demarcation which - unless special precautions are taken - are bound to differ from lines of demarcation used by other authors. For example, western Molinia communities, "Molinietum atlanticum", occur on both sides of the first division in our hierarchy. On inspection it becomes clear that the computer has not been "stupid" in allowing this to happen. The first division separates heaths and bogs from grasslands and marsh. Molinia communities are often transitional between these two types, and the separation of Molinia communities at the outset into a heathy type and a marshy type is quite consistent with the main division. When, later, the groups have to be slotted into a pre-existing framework, the different lines of demarcation implicit in the pre-existing scheme demand a recombination of some of the borderline groups that had been separated at the first division of the computer hierarchy.

Table 1. Estimated area (km^2) of semi-natural vegetation and of afforestation. The four categories are: Gr - western granite; W - western non-granite; E - eastern (i.e. east of O.S. National Grid easting 28); Tot - total.

	Gr	W	E	Tot	%
1. Sphagneto-Juncetum effusi	-	90	80	170	13
2. Molinietum atlanticum	12	170	3	185	14
a. myricosum	12	66	2		
b. agrostidosum	-	55	-		
c. juncosum	-	49	1		
3. Molinieto-Callunetum	38	32	-	70	5
a. typicum	11	-	-		
b. moliniosum	27	32	-		
4. Calluneto-Eriophoretum	-	137	143	280	20
a. typicum	-	104	90		
b. moliniosum	-	33	53		
5. Nardus str.-Vacc. myrt.	4	23	-	27	2
a. typicum	3	18	-		
b. low altitude facies	1	5	-		
6. Nardo-Juncetum squarrosi	4	48	116	168	12
a. nardosum	-	18	66		
b. juncosum	2	26	50		
c. nartheciosum	2	4	-		
7. Agrosto-Festucetum	-	102	111	213	16
a. typicum	-	96	91		
b. callunosum	-	6	10		
c. flushed	-	-	10		
8. Festuco-Molinietum	1	46	159	206	15
a. typicum	1	16	122		
b. pteridosum	-	30	37		
9. Callunetum vulgaris	10	28	10	48	4
Total unplanted upland	69	676	622	1367	101
Planted within afforested areas	45	306	164	515	
Unplanted within afforested areas	18	33	5	56	
Area afforested	63	339	169	571	
% of total afforested	47	33	21	29	

7.8 The areas occupied by the various vegetation types are given in Table 1. The estimates were made by taking the proportional occurrence of each type in the standard (i.e. non-roadside, non-streamside) positions of the 1 km squares in each stratum, and sharing out the area of the stratum accordingly. For example, the stratum coded 00000 (low altitude, flat, non-granite, non-forest, western) occupied 148 km^2. The six quadrats sampled from it were classified as:

Molinietum atlanticum myricosum	2
Molinietum atlanticum agrostidosum	2
Agrosto-Festucetum	2.

Each of these types was therefore accorded an estimated area of $\frac{1}{3}(148) = 49.3$ km^2 in stratum 00000. Adding up the estimated area of each vegetation type across the strata, it was possible to get an overall unbiased estimate of the area occupied by each type.

7.9 Estimation of an appropriate standard error has not been possible, as our sampling programme included only one kilometre square from each stratum. It is possible, however, to get some idea of the reliability of the estimates, by looking at the terms which have been added up to obtain the totals. For example, the estimated area of Agrosto-Festucetum typicum is derived by adding together terms

$$49 + 4 + 32 + 85 + 11 + 6 = 187.$$

Clearly, one term - 85 - is dominant, but equally clearly a sufficient number of terms have gone into the total that it is not likely to be out by more than a factor of 2 at the worst, and probably less. On the other hand, the estimated area of Molinietum atlanticum juncosum is derived by adding together terms

$$49 + 1 = 50.$$

(All other occurrences were in special habitats such as streamsides.) Clearly this estimate is much less reliable, and could be totally misleading. This particular type is certainly not very common, but it could be substantially rarer or commoner than the estimate suggests. This is, however, the most extreme example, and for the most part the estimates can be regarded as right to within about a factor of 2 for the smaller categories and about 1.5 for the larger categories.

7.10 Notwithstanding the uncertainty of the estimates, some inferences can be made with reasonable confidence.

(1) There is less vegetational variation on the granite than on the shales. At lower altitudes on the granite, Molinietum atlanticum, Molinieto-Callunetum and Callunetum vulgaris are overwhelmingly predominant. At higher altitudes, Nardus communities - Nardo-Juncetum squarrosi and Nardus stricta-Vaccinium myrtillus - prevail. The granite accounts for a considerable proportion of the total area of Molinieto-Callunetum, this being an important type in the basin between the Rhinns of Kells and the Merrick. Planting has been particularly extensive on the granite, presumably owing to the poor quality of the land as pasture.

(2) Three vegetation types are exclusively western - Molinietum atlanticum, Molinieto-Callunetum and Nardus stricta-Vaccinium myrtillus. The few eastern occurrences of Molinietum atlanticum were from the granite near Dalbeattie, and do not therefore invalidate the generalization, as this is very close to the sea.

(3) Sphagneto-Juncetum effusi, Agrosto-Festucetum and Callunetum vulgaris are neither eastern nor western.

(4) Calluneto-Eriophoretum and Nardo-Juncetum squarrosi show a distinct eastern tendency but are not absent in the west. Festuco-Molinietum is strongly eastern. In the west it is represented mainly by the fern-rich variant "pteridosum". However, the "pteridosum" variant is rather doubtfully lumped with the Festuco-Molinietum in any case. If more samples were available, it might preferably be raised to an association Pterido-Molinietum, being a biotic derivative of flushed oceanic woodland on steep banks.

8. Environmental ordination and classification

8.1 The next stage of the analys., was to ordinate the stands using variables that would be likely to remain fairly constant even when land use alters. In this way it should be possible to trace the changes that have occurred, confining attention to a relatively limited range of environments. The following variables were selected for the purpose:-

1. A 0/1 variable specifying whether the stand was from the east or the west of the area
2. A 0/1 variable specifying whether the stand was on granite or not
3. Altitude in metres
4. Slope in degrees
5. cos (aspect - $\pi/4$) x sin (slope)
6. Cover of rock %
7. Stoniness of lowest horizon (field record)
8. Weighted mean pH of all layers
9. Loss-on-ignition of horizon at 10 cm
10. Loss-on-ignition of horizon at 30 cm.

8.2 Multiple discriminant analysis is a method of ordination which is mathematically similar to principal component analysis, but with the important difference that it requires a pre-existing classification as an input. Given the prior classification, the purpose of the ordination is to find linear combinations of the data variables which concentrate the existing classification as effectively as possible. In other words, the prior classification is used as a touchstone by which to evaluate the "goodness" of variables. A variable which has little or no relation to the prior classification is "bad"; one which is closely related to it is "good". Given this criterion of goodness, multiple discriminant analysis is a technique for finding the "best" linear combinations of the variables. (For further details see Sneath and Sokal, 1973, pp. 406-8.)

8.3 In the present context, the phytosociology presented in Appendix 3 provided a convenient prior classification to be used as input to the multiple discriminant analysis. Logically this meant that the ordination amounted to a search for synthetic environmental variables which were as closely related to the variation in the undisturbed vegetation as possible. This was more appropriate than principal component analysis, which would have been concerned only with summarising the environmental variables, without regard to the vegetation. The prior classification applies only to the undisturbed plots. However, the variables derived in the environmental ordination are merely linear combinations of the data variables. As such they can be generalised to afforested plots.

8.4 The ordination of the unafforested plots is given in Fig. 3, and its generalisation to the afforested plots is given in Fig. 4. In Fig. 3, the centres of gravity of the vegetation types are indicated, and these give a clear idea of the general interpretation of the ordination. Broadly speaking, lower altitude plots occur on the left of the diagram and high altitude plots on the right. The better soils are at the top of the diagram, and the worse soils at the bottom. Comparison with Fig. 4 shows that there is an evident concentration of afforestation at the lower altitudes.

8.5 Figs. 5-8 show the distribution of the various vegetation types in more detail. Clearly the ordination has succeeded in concentrating some of the types better than others. In Fig. 7, types 3a and 3b for example (Molinieto-Callunetum), are fairly well concentrated towards the bottom left of the diagram. Type 9 (Callunetum vulgaris), however, is widely scattered, and does not seem to be restricted to a limited range of environments (Fig. 8). There are two possible explanations for this: either that the relevant environmental factors have not been included in our analysis, or that the vegetation type really can arise in a wide variety of environments, being determined more by management than by intrinsic site factors.

8.6 The ordination diagram, Fig. 9, is divided into 9 categories. The progress of vegetational change in these categories after planting is the topic of Section 9 below. Table 2 gives estimates of the area occupied by the categories, derived in the same way as Table 1 (cf. paragraph 7.8 above). There is a slight discrepancy between the totals in the two tables. This is due to the fact that the special 1 km squares were excluded from the calculations presented here, but were included in those presented above. The discrepancies are immaterial to any conclusions, and can be ignored. Four points are worth noting here.

Table 2. Estimated area (km^2) of environmental categories 1-9 (cf. Fig. 9). The columns are: Gr - western granite; W - western non-granite; E - eastern (i.e. east of O.S. National Grid easting 28); Tot - total; % - per cent of total area occupied by this category.

		Gr	W	E	Tot	%
1.	Unplanted	-	126	15	141	
	Planted	-	34	48	82	
	Total	-	160	63	223	12
2.	Unplanted	-	95	246	341	
	Planted	-	58	2	60	
	Total	-	153	248	401	21
3.	Unplanted	-	13	106	119	
	Planted	-	31	-	31	
	Total	-	44	106	150	8
4.	Unplanted	-	99	2	101	
	Planted	-	42	5	47	
	Total	-	141	7	148	8
5.	Unplanted	6	281	193	480	
	Planted	-	171	135	306	
	Total	6	452	328	786	41
6.	Unplanted	6	30	34	70	
	Planted	-	9	-	9	
	Total	6	39	34	79	4
7.	Unplanted	12	-	4	16	
	Planted	36	-	-	36	
	Total	48	-	4	52	3
8.	Unplanted	36	-	-	36	
	Planted	28	-	-	28	
	Total	64	-	-	64	3
9.	Unplanted	10	-	-	10	
	Planted	1	-	-	1	
	Total	11	-	-	11	1
Unplanted		70	644	600	1314	
Planted		65	345	190	600	
Total		135	989	790	1914	101

(1) The granite is mainly confined to categories 7, 8 and 9. The two lower altitude categories (7 and 8) are extensively planted.

(2) Categories 1 and 2 are predominantly on better soils and often support Agrosto-Festucetum. Many of the older plantings are in these categories, but younger plantings are not extensive, as the land is suitable for pasture.

(3) Category 5, the central and most neutral in its characteristics, accounts for more than half the total area of planting.

(4) The higher altitude categories, 3, 6 and 9 account for a negligible percentage of the total planting.

9. Changes in species composition over the course of the rotation

9.1 First the trends within the environmental groups are summarised separately. Then the general trends are considered.

Group 1

Unplanted. 12 stands. Unplanted stands approximate to Agrosto-Festucetum. The five most frequent species were Agrostis canina, Anthoxanthum odoratum, Festuca ovina, Galium saxatile and Potentilla erecta; but Agrostis tenuis, Molinia caerulea and Pteridium aquilinum often had high cover.

0-10 years. 1 stand. Apart from noting that the stand was species-rich, with a large complement both of higher plants and bryophytes, there is little to be said about this age class.

10-20 years. 3 stands. Molinia caerulea is the only flowering plant remaining with appreciable cover, though Deschampsia flexuosa, Galium saxatile, Juncus effusus and Vaccinium myrtillus persist in two out of the three stands. The four most prominent bryophytes are Hypnum ericetorum, Plagiothecium undulatum, Polytrichum commune/formosum and Lophocolea cuspidata.

20-30 years. 4 stands. The two most prominent plants are Agrostis tenuis and Lophocolea cuspidata, but total cover is low. Also present but with even less cover are A. canina, Anthoxanthum odoratum, Dryopteris dilatata, Galium saxatile and Holcus lanatus.

30-45 years. 3 stands. The three most prominent plants are Holcus lanatus, Oxalis acetosella and Lophocolea cuspidata, with Agrostis tenuis, Hypnum ericetorum and Plagiothecium undulatum close behind them.

45-60 years. 5 stands. There is now a good cover of flowering plants, with Agrostis canina, A. tenuis, Deschampsia cespitosa, Galium saxatile, Holcus lanatus and Oxalis acetosella most prominent. Lophocolea cuspidata is present in all stands but with low cover. A wide variety of woodland plants are present but without any one having high constancy - e.g. Digitalis purpurea, Pteridium aquilinum, Rubus idaeus and Viola riviniana.

Several species of flowering plants have persisted more or less throughout the rotation, notably Agrostis spp., Anthoxanthum odoratum, Galium saxatile, Holcus lanatus and Potentilla erecta.

Group 2

Unplanted. 23 stands. These approximate to Agrosto-Festucetum. The five most prominent species are Agrostis tenuis, Anthoxanthum odoratum, Festuca ovina, Galium saxatile and Nardus stricta.

0-10 years. 2 stands. The four most prominent species are Agrostis canina, A. tenuis, Calluna vulgaris and Deschampsia flexuosa. With so small a sample it is hard to be sure that there has been a real shift, but Calluna increases in other groups after cessation of grazing, and is likely to have done so here also. Characteristic bryophyte invaders have appeared, notably Campylopus flexuosus, C. pyriformis, Ceratodon purpureus, Leptodontium flexifolium and Pohlia nutans.

10-20 years. 3 stands. Deschampsia flexuosa and Galium saxatile are now the most prominent species, but are present only with low cover. Anthoxanthum odoratum, Calluna vulgaris and Vaccinium myrtillus are present in even smaller quantity. The three principal bryophytes are Campylopus flexuosus, Hypnum ericetorum and Rhytidiadelphus squarrosus, but they are not very abundant.

20-30 years. 4 stands. The most prominent species is now the moss Hypnum ericetorum, followed by the flowering plants Deschampsia flexuosa, Molinia caerulea and Vaccinium myrtillus, which persist in small quantity. Plagiothecium undulatum and Calypogeia muellerana are present in 3 out of the 4 stands.

Group 4

Unplanted. 10 stands. These correspond closely to Molinietum atlanticum, with Molinia caerulea having a mean domin number of 7.7.

0-10 years. 3 stands. The main early change is a great increase in the abundance of Calluna vulgaris, so that dominance is shifted from nearly pure Molinia to a mixture of Calluna and Molinia. There is also an increase in species of disturbed ground, mainly bryophytes and lichens such as Cladonia chlorophaea, C. floerkeana, Dicranella heteromalla, Pohlia nutans and Polytrichum aloides.

10-20 years. 5 stands. Calluna and Molinia persist as dominants though with reduced vigour. Shade-bearing bryophytes such as Dicranum scoparium, Hypnum ericetorum, Polytrichum commune and Lophocolea cuspidata have become more prominent.

20-30 years. 7 stands. The dominant species are now mainly bryophytes, notably Dicranum scoparium, Hypnum ericetorum, Isopterygium elegans, Mnium hornum, Plagiothecium undulatum and Lophocolea cuspidata. Deschampsia flexuosa is the principal non-bryophyte survivor, with some persistence also of Agrostis canina, Blechnum spicant, Molinia caerulea and Vaccinium myrtillus.

40 years. 1 stand. The floristic composition of the stand is consistent with the hypothesis of a general trend towards species enrichment, but the stand also contained a stream, which provided habitats for additional species.

Group 5

Unplanted. 33 stands. Before planting no one species is strongly dominant in this rather heterogeneous group. Calluna vulgaris, Deschampsia flexuosa, Molinia caerulea, Potentilla erecta, Vaccinium myrtillus and Polytrichum commune are common and often prominent species. Some of the stands in this group belong to the Calluneto-Eriophoretum, but there is a strong admixture of other types.

0-10 years. 11 stands. Calluna, Deschampsia and Molinia increase relative to the other species. The increase of Calluna and Molinia may be a response mainly to disturbance and cessation of grazing, but fertilizer applications almost certainly play a part in the increase of Deschampsia. In some places it had increased markedly in swathes resulting from aerial pllication of fertilizer. With these exceptions, changes at this stage are few, though there is a small but evident increase in bryophytes of disturbed ground.

10-20 years. 11 stands. Calluna and Molinia remain prominent, but not Deschampsia. Bryophytes, notably Hypnum ericetorum, Plagiothecium undulatum and Pleurozium schreberi have become more prominent as higher plants decline; but the bryophytes are only slightly more abundant than in unplanted plots.

20-30 years. 5 stands. Mosses are now dominant, the chief species being Hypnum ericetorum and Plagiothecium undulatum. Plagiothecium has markedly increased, and is now the most prominent species. Deschampsia flexuosa, Molinia caerulea and Vaccinium myrtillus persist, but only patchily and with low cover. Calluna vulgaris has almost vanished.

Group 7

Unplanted. 9 stands. Calluna vulgaris and Molinia caerulea are the main dominants, and the group is transitional between the Molinieto-Callunetum and Molinietum atlanticum.

0-10 years. 1 stand. With only one stand available it is necessary to be cautious, but trends appear very similar to those in Group 4; that is to say that there is a large increase in Calluna and an invasion of species associated with disturbance. Among the invaders are Chamaenerion angustifolium, Cladonia chlorophaea, C. floerkeana, Lecidia granulosa, Campylopus pyriformis, Leptodontium flexifolium and Pohlia nutans.

20-30 years. 4 stands. Hypnum ericetorum is now the most prominent species, with Calluna, Molinia and Myrica persisting in some stands with low cover. The bryophytes Calypogeia fissa, Cephalozia bicuspidata and Mnium hornum are frequent but not abundant.

Group 8

Unplanted. 28 stands. These approximate to the Molinieto-Callunetum. The four most prominent plants before planting are Calluna vulgaris, Erica tetralix, Molinia caerulea and Trichophorum cespitosum.

0-10 years. 3 stands. Calluna and Molinia remain the most prominent species, and there are numerous cryptogamic invaders, including Cladonia coccifera, C. floerkeana, Lecidia granulosa, Campylopus flexuosus, C. introflexus, Dicranella heteromalla, Pohlia nutans and Polytrichum aurantiacum.

10-20 years. 6 stands. Calluna and Molinia still have high cover; Erica tetralix persists but with low cover; Trichophorum cespitosum has vanished. Of the invaders at the earlier stage only the shade-tolerant Campylopus flexuosus, Dicranella heteromalla and Pohlia nutans persist with appreciable frequency. Other shade-tolerant bryophytes are coming into prominence, notably Hypnum ericetorum and the leafy liverworts Calypogeia fissa and Cephalozia bicuspidata.

20-30 years. 2 stands. Flowering plants are very much reduced. Deschampsia flexuosa, Molinia caerulea and Vaccinium myrtillus persist with very low cover. The four most abundant species are now bryophytes, the mosses Plagiothecium undulatum and Rhytidiadelphus loreus and the leafy liverworts Calypogeia muellerana and Cephalozia bicuspidata.

9.2 Fig. 10 shows the mean number of species per stand for each environmental group plotted through the age classes. The numerals below the columns give the number of plots on which the means are based. Although some categories are severely undersampled, some clear similarities and differences between the responses of different groups do emerge.

9.3 Probably the most marked feature is the general decline in species numbers up to about 30 years after planting. Five very common species that disappear rapidly are Festuca ovina, Juncus squarrosus, Nardus stricta, Narthecium ossifragum and Trichophorum cespitosum. Slightly less common species that also soon disappear are Carex panicea, C. pilulifera, Empetrum nigrum, Cladonia impexa and Rhacomitrium lanuginosum. These plants decline so rapidly that their frequency is much reduced within ten years of planting. The reason is doubtless the same for all of them, namely that they are intolerant of shade, and are of small stature and slow growth. Ploughing, fertilisation and cessation of grazing favour larger and more competitive plants, notably Agrostis spp., Calluna vulgaris, Deschampsia flexuosa, Galium saxatile and Molinia caerulea.

9.4 The initial loss of small and slow-growing phanerogams is to some extent offset by the invasion of bryophyte colonists. Five of the commonest are Atrichum undulatum, Campylopus flexuosus, C. pyriformis, Dicranella heteromalla and Pohlia nutans, but there are numerous others. Lichens also may become prominent, particularly Cladonia species such as C. chlorophaea, C. coccifera and C. floerkeana. Flowering plants, however, do not invade effectively at this stage. This is almost certainly due to difficulties of dispersal, as Chamaenerion angustifolium - which is the only flowering plant to appear at all frequently - has exceptionally effective dispersal by wind.

9.5 The earlier changes are mainly the result of disturbance, fertilisation and cessation of grazing. After about ten years the crop begins to have an increasing effect, and there is a progressive loss of grass and shrub species as shade intensifies and the canopy closes. Some plants that had survived the initial disturbance fairly effectively - e.g. Erica tetralix and

Eriophorum angustifolium - now disappear rapidly. The flowering plants that had benefitted at the previous stage, however, die out only slowly, and a few individuals normally persist throughout the rotation, in small gaps or on rocky knolls.

9.6 Unlike the flowering plants that had initially benefitted, many of the early cryptogamic invaders are relatively light-demanding "weeds", which soon vanish. By chance four out of the five commonest invading bryophytes (Atrichum undulatum, Campylopus flexuosus, Dicranella heteromalla, Pohlia nutans) are also shade-tolerant, and may persist when the canopy closes. Many of the others, however, (Campylopus introflexus, Ceratodon purpureus, Leptodontium flexifolium, Polytrichum aurantiacum, P. juniperinum) disappear, as do the Cladonia species. Meanwhile, many shade-tolerant but non-weedy bryophytes are increasing as shade becomes too intense for growth of higher plants. The most notably increasing species are Hypnum ericetorum, Plagiothecium undulatum and Lophocolea cuspidata. Eventually, all three are normally present; but there is a marked preference of Lophocolea for the better soils at the earlier stages, and of Plagiothecium for the worse soils. In the case of Plagiothecium, which only rarely produces sporophytes, invasion may be delayed for many years on sites where it did not previously occur.

9.7 As a result of the persistence of many species in small gaps, and of the increase of several bryophytes, the total loss of species-richness is much less than might be expected. The overall means in Fig. 11 (top diagram) show that the lowest value is reached in the 20-30 year age class, and that it represents a reduction of only 38% below the figure for unplanted plots. Considering that some really dense thickets really do sustain a few species - even the bryophytes may be killed - the reduction of species number in the majority of stands must be small indeed. (Total plant cover does of course always drop.)

9.8 In the oldest plantings (i.e. in those exceeding 30 years), species numbers increase. This happened in both groups (1 and 4) for which data are available. Most stands of this age have been thinned, at which point conditions suddenly become favourable for the establishment of phanerogams and ferns. Hitherto most vascular plants have been mere survivors from an earlier non-woodland community. The invaders after thinning are woodland plants. Typical of these are Athyrium filix-femina, Digitalis purpurea, Dryopteris dilatata, D. filix-mas, Oxalis acetosella, Rubus fruticosus, R. idaeus and Viola riviniana. The restriction of these older plantings to the better soils makes inference difficult, but it seems quite possible that species diversity in the oldest plantings may exceed that of the original vegetation on the site.

9.9 Figs. 11 and 12 show the trends in species abundance for selected species, averaged across all plantable environmental categories for which data are available. For example the figures (mean domin numbers) for Calluna vulgaris were derived as follows:-

Environmental category	Unplanted	Post 1970	1965 -69	1955 -64	1945 -54	1930 -44	Pre 1930
1	2.8	5.0	-	1.3	0	0	1.0
2	0.8	4.0	-	3.3	1.5	-	-
4	2.9	6.5	7.0	3.0	0	2.0	-
5	3.3	4.2	-	2.9	1.2	-	-
7	3.7	9.0	-	-	2.5	-	-
8	4.8	3.0	6.5	6.1	1.0	-	-
Mean	3.0	5.3	6.8	3.3	1.0	1.0	1.0

Blanks indicate no data. It can be seen that the means are much more reliable for some planting dates than for others. Thus the mean for 1945-54 is taken across all plantable environmental categories, whereas the mean for 1930-44 is based on only two environmental categories, viz. 1 and 4. Consequently, the apparent increase of Agrostis tenuis in the older age classes of Fig. 11 may be much exaggerated. Categories 1 and 4 are the two most favourable categories for Agrostis tenuis before planting. This is an unsatisfactory situation; but given the difference between the site characteristics of old and young plantings, there was no way of avoiding it in the present context.

9.10 The stages of the succession may therefore be summarised as follows.

0-10 years. Elimination of small and slow-growing plants of open pasture; increase of rank and fast-growing species; invasion of bryophyte and lichen "weeds", especially on the sides of furrows.

10-30 years. Progressive decrease of flowering plant cover as canopy closes; elimination of a few further flowering plant species, but the majority persisting patchily in gaps; increase of shade-tolerant bryophytes so that they may achieve high cover; elimination of many of the cryptogamic "weeds" that had invaded at the previous stage. Where the crop is really successful, shade may become so intense that the initial increase of shade-tolerant bryophytes is reversed, and almost all autotrophs vanish from the forest floor.

30-60 years. Increase of woodland plants following thinning; maintenance or re-establishment of high bryophyte cover. Ferns undoubtedly invade at this stage (prothalli are often visible in thickets), but flowering plants may be mainly those that had survived in gaps and on rides. The events following clear fellings have not been recorded.

9.11 Finally it is worth drawing attention to Tables 3 and 4 which list the principal species and their preferences. These results, while suggestive, must be treated with caution, as they refer to the preferences of the species without regard to the differences in site characteristics of planted and unplanted stands, and without regard to whether the plots were on roads, streams etc. From the commoner species, it is clear that the net effect of afforestation is to encourage bryophytes at the expense of higher plants, while overall species numbers change little. From the rare species (4-9 occurrences) it might well appear that forestry has much increased the overall species complement. When the rarer species are examined in more detail, however, it is clear that most of them are lowland plants of relatively good soils. Their apparent preferences for afforested stands may reflect merely the fact that we sampled some forests on potentially good agricultural land, whereas such land was not sampled when unafforested.

Table 3. Increases and decreases in response to afforestation (species with four or more occurrences only). Analysis of results by taxonomic category and life form. A species is counted as "preferring unplanted" if its chance of occurrence in the afforested plots was at least twice that in the forested, and vice-versa. For an explanation of the apparent increase of rare species in the afforested areas see text.

	Shrub/ Tree	Dwarf shrub	Monocot	Dicot	Pteridophyte	Lichen	Bryophyte	Total
100 or more occurrences								
Neutral	-	3	9	2	-	-	11	25
Preferring unplanted	-	-	5	-	-	-	-	5
Preferring planted	-	-	-	-	-	-	3	3
50-99 occurrences								
Neutral	-	2	7	3	1	2	11	26
Preferring unplanted	-	1	2	-	-	1	1	5
Preferring planted	-	-	-	-	1	1	6	8
20-49 occurrences								
Neutral	-	-	3	10	2	2	7	24
Preferring unplanted	-	-	2	5	1	3	5	16
Preferring planted	-	-	1	4	1	-	10	16
10-19 occurrences								
Neutral	1	-	2	12	-	-	8	23
Preferring unplanted	-	1	5	2	-	1	5	14
Preferring planted	3	1	-	2	1	2	7	16
4-9 occurrences								
Neutral	1	1	-	9	-	3	18	32
Preferring unplanted	-	-	3	4	3	4	5	19
Preferring planted	3	1	2	17	-	2	11	36

Table 4. Commoner species, arranged according to their preference for forested or unafforested areas. A species is counted as "favouring planted" if it was at least twice as likely to occur in the afforested plots as in the unafforested. A species is counted as "favouring unplanted" if it was at least twice as likely to occur in the unafforested plots as in the forest plots. The remaining species are designated "neutral".

Common species (100 or more occurrences out of a total of 361 plots)

Neutral. Agrostis canina, A. tenuis, Anthoxanthum odoratum, Calluna vulgaris, Deschampsia flexuosa, Erica tetralix, Eriophorum angustifolium, Galium saxatile, Holcus lanatus, Juncus effusus, Luzula multiflora, Molinia caerulea, Potentilla erecta, Vaccinium myrtillus, Campylopus flexuosus, Dicranum scoparium, Hypnum ericetorum, Pleurozium schreberi, Polytrichum commune, Rhytidiadelphus loreus, R. squarrosus, Sphagnum papillosum, S. plumulosum, S. recurvum, Calypogeia fissa.

Favouring unplanted. Festuca ovina, Juncus squarrosus, Nardus stricta, Narthecium ossifragum, Trichophorum cespitosum.

Favouring planted. Dicranella heteromalla, Plagiothecium undulatum, Lophocolea cuspidata.

Frequent species (50-99 occurrences)

Neutral. Blechnum spicant, Carex binervis, C. echinata, C. nigra, Cirsium palustre, Deschampsia cespitosa, Erica cinerea, Eriophorum vaginatum, Juncus acutiflorus, J. bulbosus, Myrica gale, Rumex acetosa, Viola palustris, Cladonia coccifera, C. chlorophaea, Hylocomium splendens, Pseudoscleropodium purum, Rhacomitrium heterostichum, Sphagnum auriculatum, S. capillaceum, S. palustre, Thuidium tamariscinum, Diplophyllum albicans, Lophozia ventricosa, Odontoschisma sphagni, Pellia epiphylla.

Favouring unplanted. Carex panicea, C. pilulifera, Empetrum nigrum, Cladonia impexa, Rhacomitrium lanuginosum.

Favouring planted. Dryopteris dilatata, Parmelia physodes, Atrichum undulatum, Campylopus pyriformis, Mnium hornum, Pohlia nutans, Calypogeia muellerana, Cephalozia bicuspidata.

Fairly frequent species (20-49 occurrences)

Neutral. Campanula rotundifolia, Carex demissa, Cerastium holosteoides, Epilobium palustre, Festuca rubra, Galium palustre, Juncus conglomeratus, Plantago lanceolata, Prunella vulgaris, Pteridium aquilinum, Ranunculus repens, Sagina procumbens, Succisa pratensis, Thelypteris limbosperma, Viola riviniana, Cladonia floerkeana, C. subcervicornis, Aulacomnium palustre, Leucobryum glaucum, Mnium punctatum, Polytrichum alpestre, Nardia scalaris, Ptilidium ciliare, Scapania undulata.

<u>Favouring unplanted</u>. Drosera rotundifolia, Euphrasia spp., Lycopodium selago, Poa pratensis, Polygala serpyllifolia, Ranunculus acris, Sieglingia decumbens, Trifolium repens, Cladonia arbuscula.

<u>Favouring planted</u>. Athyrium filix-femina, Chamaenerion angustifolium, Digitalis purpurea, Holcus mollis, Oxalis acetosella, Rumex acetosella, Campylopus introflexus, Ceratodon purpureus, Ditrichum heteromallum, Eurhynchium praelongum, Isopterygium [illegible]ans, Polytrichum aloides, P. juniperinum, P. piliferum, P. u[illegible]gerum, Cephalozia connivens.

<u>Occasional species</u> (10-19 occurrences)

<u>Neutral</u>. Achillea millefolium, A. ptarmica, Cardamine pratensis, Dactylis glomerata, Hypericum pulchrum, Lathyrus pratensis, Leontodon autumnalis, Lysimachia nemorum, Myosotis secunda, Pedicularis sylvatica, Poa annua, Ranunculus flammula, Salix aurita, Stellaria alsine, Veronica officinalis, Bryum pseudotriquetrum, Dichodontium pellucidum, Dicranella palustris, Mnium undulatum, Oligotrichum hercynicum, Rhacomitrium aciculare, Pellia neesiana, Scapania irrigua.

<u>Favouring unplanted</u>. Carex bigelowii, C. rostrata, Cynosurus cristatus, Dactylorhiza maculata, Luzula sylvatica, Pinguicula vulgaris, Thymus drucei, Vaccinium vitis-idaea, Cladonia furcata, Acrocladium cuspidatum, Andreaea rothii, A. rupestris, Mylia taylori, Pleurozia purpurea.

<u>Favouring planted</u>. Betula pubescens, Cardamine flexuosa, Dryopteris filix-mas, Rubus fruticosus, Salix caprea, Sorbus aucuparia, Taraxacum officinale, Peltigera polydactyla, Icmadophila ericetorum, Brachythecium rutabulum, Dicranum majus, Hypnum cupressiforme var. cupressiforme, Leptodontium flexifolium, Polytrichum aurantiacum, Lepidozia reptans, Marsupella emarginata.

<u>Rare species</u> (4-9 occurrences)

<u>Neutral</u>. Chrysosplenium oppositifolium, Cirsium vulgare, Crataegus monogyna, Epilobium montanum, Filipendula ulmaria, Galium verum, Geum rivale, Linum catharticum, Lotus uliginosus, Oxycoccus palustris, Plantago major, Cladonia gracilis, Lecidia granulosa, Peltigera canina, Acrocladium stramineum, Brachythecium plumosum, Bryum pallens, Climacium dendroides, Ctenidium molluscum, Dicranella rufescens, Eurhynchium riparioides, Fissidens taxifolius, Hyocomium flagellare, Polytrichum alpinum, Sphagnum cuspidatum, S. fimbriatum, S. magellanicum, S. teres, Lepidozia trichoclados, Mylia anomala, Riccardia pinguis, Scapania gracilis.

<u>Favouring unplanted</u>. Anemone nemorosa, Briza media, Carex pulicaris, Carum verticillatum, Cryptogramma crispa, Galium uliginosum, Lycopodium alpinum, Montia fontana, Phragmites communis, Selaginella selaginelloides, Cetraria islandica, Cladonia bellidiflora, Sphaerophorus fragilis, S. globosus, Andreaea alpina, Brachythecium rivulare, Breutelia chrysocoma, Anastrepta orcadensis, Scapania nemorosa.

Favouring planted. Ajuga reptans, Alnus glutinosa, Angelica sylvestris, Arrhenatherum elatius, Centaurea nigra, Fraxinus excelsior, Galium aparine, Hieracium pilosella, Hypochaeris radicata, Lotus corniculatus, Luzula pilosa, Primula vulgaris, Rubus idaeus, Rumex obtusifolius, Salix cinerea, Senecia jacobea, Stellaria graminea, Teucrium scorodonia, Tussilago farfara, Urtica dioica, Valeriana officinalis, Veronica chamaedris, V. serpyllifolia, Cladonia polydactyla, Cetraria glauca, Dicranella cerviculata, Dicranoweisia cirrata, Drepanocladus fluitans, Fontinalis antipyretica, Funaria hygrometrica, Grimmia doniana, Hookeria lucens, Hygrohypnum ochraceum, Plagiothecium denticulatum, Calypogeia trichomanis, Solenostoma crenulatum.

10. Differences in soil and other environmental characteristics over the rotation. (K. L. Bocock and J. K. Adamson)

10.1 Soil and other environmental characteristics such as slope, altitude and aspect were examined to provide bases other than the flora for classification and comparison of our sample plots, for comparison of our plots with areas described and/or planted by the Forestry Commission and for examination of soil changes with afforestation. We considered that the results of the latter together with other data on the environment and on the flora of an area would allow prediction of changes in flora following afforestation.

10.2 A full assessment of the value of the soil and other environmental characteristics measured in 1975-76, in relation to the requirements for the sampling programme in 1976-77 will be completed and reported on before the 1976-77 field-work begins. Figs. 15, Table 7 and the notes below give a first description of the environmental characteristics of the nine environmental groups created by sub-division of the ordination diagram (para. 8.6 above and Fig. 9) and indicate changes in some of the characteristics with afforestation.

10.3 Although the variability within each of nine groups is great several trends are evident across the groups (Fig. 15). Groups three, six and nine, corresponding approximately to respectively Sphagneto-Juncetum effusi, Nardo-Juncetum squarrosi plus Nardo-Vaccinietum myrtilli and Callunetum vulgaris occur at the highest altitudes and have medium ratings for drainage, moisture content, organic matter (L.O.I.), texture, stoniness, nitrogen and phosphorus contents. LF material tends to accumulate on these sites largely because of slow decomposition and the acidity of all layers tends to be higher than at a lower altitude.

10.4 The range of mean pH across the nine groups is not great, within-group variability is large (Fig. 15), so differences between groups are apparently not significant. On the average the least acid soils occur in groups one (Agrosto-Festucetum), two (Agrosto-Festucetum plus Festuco-Molinietum plus some Sphagno-Juncetum effusi) and four (Molinietum atlanticum).

10.5 As expected, the least organic and stoniest soils at moderate altitude, groups one and two, carry Agrosto-Festucetum. The most organic soils occur at low to moderate altitude in groups four (Molinietum atlanticum), five (Calluneto eriophoretum plus Molinietum atlanticum plus representative plots of several other vegetation types), seven (mainly Callunetum eriophoretum vulgaris) and eight (mainly Molinieto callunetum). The above conclusions are based not only on loss-on-ignition values but also on the completely independent field estimates of organic matter content and texture (Fig. 15).

10.6 The nitrogen and phosphorus data require further analysis. The nitrogen data for the LF layer show no clear trend but, for uppermost layer below the LF, highest values occur for groups four, five, seven and eight, which have the most organic soils. Exactly the opposite trend occurs for phosphorus both in layer one and in the LF. Expression of these data on an ash-free basis, or a volume basis using the established loss-on-ignition/bulk density relationship, may further clarify these results.

10.7 Preliminary examination of environmental characteristics of the 19 vegetation groups derived by classification of floristic data for unafforested plots indicated some clear differences between plots. However, these differences tended to become somewhat blurred by fusion of some of the 19 groups to give nine vegetation groups (Paras. 7.5-7.7 above) and blurred even further by recombination of the sites into nine environmental groups using the vegetation classification and ordination (Section 8 above).

10.8 Differences in environmental characteristics with age of stand, which parallel differences in the flora indicated in Section 9, are listed in Table 7. Variability of the data is similar to that for the nine vegetation groups (Fig. 15). Although sub-division of the ordination diagram (Fig. 9), created groups which were less variable environmentally than the whole data sets for unafforested sites and subsequently for afforested sites, a within-group association between age of stand and altitude is evident with older stands occurring at the lower altitude. The older stands in a group also tend slightly to be on more mineral-rich soils than the younger stands and this is supported by the assessments of texture. Stoniness shows no trend with age of stand.

10.9 Weighted mean pH for the whole soil profile showed no trend so pHs of the LF layer and of the uppermost underlying layer were examined as these were expected to be more responsive to the influence of the trees. The main tendency is for a rise in pH, especially in the LF layer, in the first ten years after afforestation followed by a gradual fall (Table 7). The pH changes, if they are significant, are slight and may be explainable in terms of removal of grazing with increased supply of grassy and herbaceous plant remains to the soil surface followed by build-up of LF layer with age of stand (Table 7) but interpretation is complicated by differences in altitude and associated variables between unplanted and planted sub-groups of sites.

10.10 Trends in total nitrogen and phosphorus content with age of stand are not apparent but re-expression of the data on an ash-free or volume basis (see para 10.6 above), may be revealing and valuable in relation to nutrient availability and vegetation composition. Clarification of the contribution of roots to the total nitrogen and total phosphorus is required but the root data have not yet been analysed.

11. Effect of streams, roads and rides

11.1 Linear features such as streams, roads and rides are clearly of importance as a reservoir of native flora, particularly during the thicket stage. For this reason, data from these habitats were recorded in addition to the standard positions in each 1 km square (cf. paragraph 5.1). But in the event there were only just enough regular plots to make satisfactory quantitative summaries, and the treatment of the linear features is of necessity somewhat sketchy. Further work is required to elucidate their quantitative significance.

The stream habitat

11.2 The following observations refer to the scatter diagrams (Fig. 13) in which the species complements of several categories of streams (afforested, non-afforested, wide and narrow) are plotted against the mean species complements of plots within the same 1 km square but containing no linear features, and carrying a tree crop of approximately the same age class. Several points should be noted.

(i) Streams in general add considerably to the species-richness of a site. Increases of 60% are typical.

(ii) There was no consistent difference in species-richness between afforested and non-afforested streamsides.

(iii) The width of the planting gap did not apparently influence species-richness. Unfortunately, data are lacking for narrow gaps in the older age classes, so that the general statement cannot be assumed to be true in forests older than 25 years. It is notable that two out of three streamsides recorded with planting gaps of 2 m or less in 22-year-old plantings had species complements close to their non-stream afforested counterparts.

(iv) The effects of planting date on species-richness are difficult to disentangle from the effects due to variation in planting gap; but if attention is again confined to those plots with planting gaps of 2 m or less, some inferences are possible. While the species complement shows no clear relationship to planting date, there is only one plot having more than 50 species. This compares with nine such plots in the wide planting gap and unplanted categories.

11.3 Table 5 summarises the species that appear to be preferential to streams, i.e. those which are at least 2.5 times as frequent in a streamside category as in the data as a whole. Inevitably some of these occurrences must be due to chance; but when these lists are compared with comparable lists (paragraph 11.8) for rides, it is clear that the number of occurrences due to chance must be small, and that streamsides really do provide a habitat for a large number of special species. Table 5 suggests a number of tentative conclusions.

(i) Wide streams are considerably richer than narrow ones.

(ii) Narrow streams have their species-richness reduced under afforestation.

(iii) The species complement of wide streams is not greatly reduced by planting. Species preferential to wide streamsides both in planted and unplanted areas include Carex echinata, Cirsium palustre, Deschampsia cespitosa, Epilobium palustre, Plantago lanceolata, Ranunculus acris, Succisa pratensis, Viola palustris, Atrichum undulatum, Diplophyllum albicans and Pellia epipylla.

The forest road habitat

11.4 A comparison of forest road samples with those taken from the same 1 km squares but in regular plots lacking linear features (Fig. 14) shows that in almost every case the species complements are greater by forest roads. The most extreme cases of species enrichment occur in the earlier plantings - i.e. pre 1954 - although there are several instances of early plantings where the increase is small or zero. Increases in the 10-20 year age classes are fairly consistently in the range 0 to 90%. The greatest percentage increase, about 600%, applies to two plantings in the 20-30 year age class.

11.5 The construction of a road introduces at least two habitats not otherwise common in the plantations we examined: exposures of mineral (as opposed to peat) soils, and the hard-packed gravelly surface of the road itself. Bryophytes are important pioneer plants on both, with species such as *Ceratodon purpureus*, *Oligotrichum hercynicum*, *Polytrichum aloides* and *P. urnigerum* developing appreciable cover.

11.6 Table 6 summarises the species that appear to be preferential to roads, i.e. those that are at least 2.5 times as frequent in a roadside category as in the data as a whole, and which occur in 34% or more of the stands in their age class. Of the three age-class categories, two contained too few plots (4 and 3) to make generalisations possible. The post 1945 planting category contains 15 plots, an adequate number; but few of the preferential species occur with any regularity. Only two, *Sagina procumbens* and *Polytri hum urnigerum* occured in more than four of the plots. The reasons for the absence of a well marked road community are not clear. Perhaps the mineral exposures are potentially suitable for a rather large number of species, so that the assemblage appearing at any one site is - at least in the earlier stages after the construction of the road - merely the result of chance immigration.

The ride habitat

11.7 The scatter diagram (Fig. 13) shows the relation between the species complements found in rides and those found in regular plots of the same age class in the same 1 km square. Here there is a marked difference from streams and roads, in that at first rides differ hardly at all from the rest of the forest. There is some indication that in the 20-30 year age classes the rides are beginning to gain over the regular forest plots. But the evidence is not conclusive, and it is clear that up to about 30 years the species losses in the two habitats are more or less keeping pace with one another. The species lost from rides are often the same as those lost from regular habitats, with *Anthoxanthum odoratum*, *Festuca ovina* and *Nardus stricta* being particularly affected. Rides differ from forest plots mainly in the degree to which the surviving species dominate the vegetation. *Calluna vulgaris*, *Deschampsia flexuosa*, *Holcus lanatus* and *Molinia caerulea* often attain very high cover value in rides.

11.8 The list of preferential species for rides is very short compared with that for roads and streams, and contains only one species with more than a single occurrence in the thirteen plots. This was the liverwort *Ptitidium ciliare*, which occurred four times.

The lakeside habitat

11.9 A scatter diagram is given in Fig. 14, and indicates that stands of high species-richness sometimes occur by lakes. The small size of the sample precludes any firm conclusions. The overall list of preferential species is quite long (70 species), but most of these have only a single occurrence. The following occurred in three or more of the six plots: *Caltha palustris*, *Myrica gale*, *Ranunculus flammula*, *Cephalozia connivens* and *Odontoschisma sphagni*.

The wall habitat

11.10 *Rhacomitrium heterostichum* was the only preferential species with more than four occurrences out of 13 plots. In general, walls had little influence on species composition, and their main significance in plantations is that rides are often positioned along them.

Table 5. Species preferential to streamside categories. A wide stream is one that exceeds 2 m. A species is counted as preferential to a category if it occurs in at least 34% of the stands in the category, and is at least 2.5 times as likely to occur in the category as in the sample at large.

(i) Wide unplanted (3 plots)

Carex echinata, Cirsium palustre, Dactylorhiza maculata, Deschampsia cespitosa, Epilobium palustre, Hypericum pulchrum, Hypochaeris radicata, Juncus acutiflorus, Plantago lanceolata, Prunella vulgaris, Pteridium aquilinum, Ranunculus acris, R. flammula, Succisa pratensis, Trifolium repens, Viola palustris, V. riviniana, Atrichum undulatum, Cephalozia bicuspidata, Diplophyllum albicans, Pellia epiphylla.

(ii) Wide planted (6 plots)

Achillea millefolium, Carex echinata, Cirsium palustre, Deschampsia cespitosa, Digitalis purpurea, Epilobium palustre, Holcus mollis, Oxalis acetosella, Plantago lanceolata, Rannunculus acris, R. repens, Rumex acetosa, Succisa pratensis, Viola palustris, Atrichum undulatum, Polytrichum aloides, Pseudoscleropodium purum, Diplophyllum albicans, Pellia epiphylla, P. neesiana.

(iii) Narrow unplanted (21 plots)

Epilobium palustre, Festuca rubra, Ranunculus repens, Rumex acetosa, Trifolium repens, Philonotis fontana, Pellia epiphylla, Scarpania undulata.

(iv) Narrow planted (10 plots)

Hylocomium splendens, Pellia epiphylla, Scapania undulata.

Table 6. Species preferential to road categories. A species is counted as preferential to a category if it occurs in at least 34% of the stands in the category, and is at least 2.5 times as likely to occur in the category as in the sample at large.

(i) Pre-1945 planting (3 plots)

Arrhenatherum elatius, Centaurea nigra, Chamaenerion angustifolium, Cirsium palustre, Deschampsia flexuosa, Digitalis purpurea, Dryopteris dilatata, D. filix-mas, Galium palustre, Holcus lanatus, Juncus effusus, Oxalis acetosella, Poa annua, Ranunculus repens, Rubus fruticosus, R. idaeus, Rumex acetosella, R. acetosa, Viola riviniana, Thuidium tamariscinum, Lophocolea cuspidata.

(ii) Post 1945 planting (15 plots)

Polytrichum urnigerum.

(iii) Unplanted (4 plots)

Achillea ptarmica, Carex panicea, C. pilulifera, Cirsium palustre, Epilobium palustre, Juncus acutiflorus, J. bulbosus, Plantago major, Prunella vulgaris, Pteridium aquilinum, Ranunculus acris, Rumex acetosa, Sagina procumbens, Senecio jacobaea, Taraxacum officinale, Trifolium repens, Tussilago farfara, Veronica officinalis, Cladonia chlorophaea, C. impexa, Atrichum undulatum, Ceratodon purpureus, Philonotis fontana, Polytrichum urnigerum.

REFERENCES

Birks, H.J.B. (1973). Past and Present Vegetation of the Isle of Skye. Cambridge University Press, London.

Hill, M.O., Bunce, R.G.H. and Shaw, M.W. (1975). Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. J. Ecol. 63, 597-613.

McVean, D.N. and Ratcliffe, D.A. (1962). Plant Communities of the Scottish Highlands. H.M.S.O., London.

King, J. and Nicholson, I.A. (1964). Grasslands of the forest and sub-alpine zones. In The Vegetation of Scotland (ed. by J.H. Burnett), pp. 168-231. Oliver & Boyd, Edinburgh.

Shaw, M.W. and Bunce, R.G.H. (1971). National Woodlands Classification, Handbook of Field Methods. Merlewood Research Station, Grange-over-Sands, Cumbria. (unpublished).

Sheath, P.H.A. and Sokal, R.R. (1973). Numerical Taxonomy. Freeman, San Francisco.

APPENDIX 1

Project Plan   Project No. ITE [illegible]

PART OF THE PROJECT GROUP 398
THE EFFECTS ON UPLAND ECOSYSTEMS OF DIFFERING LAND USES

Project Group:
Leader : K. L. Bocock

QUANTITATIVE CHANGES IN THE FLORA OF THE UPLANDS FOLLOWING AFFORESTATION

Summary objective: Quantitative examination of the changes in flora over the period from afforesting open upland to felling of the mature crop, in particular following coniferous afforestation

Project leader : M. O. Hill

Draft 9 July 1975 by M. O. Hill and K. L. Bocock

Background

The upland zone, that is the area above the predominantly arable valley bottoms and plains, occupies about one third of the total land area of Britain. Below the climatic tree-line in the zone, in Wales, the Borders, the southern Scottish Uplands and parts of the Scottish Highlands, economic and social factors have encouraged large-scale commercial afforestation with conifers of many former hill sheep-walks. The current national and world shortage of timber is likely to encourage further afforestation, particularly if modifications to the tax system do not remove financial incentives for private forestry.

The effects of changes in land-use and management on the flora of the uplands are of considerable interest to the NCC in relation to its defined remit. However, these effects have been inadequately described and are often poorly understood.

Recent and current work by the FC and NC/ITE is providing some relevant information. The present project, which will be funded by the NCC, is designed to throw light on the effects of different types of afforestation on the flora of upland areas. It will be linked as closely as possible with monitoring of the effects of afforestation (ITE 9), survey of commercial forests in north-west England (ITE 13), study of effects of birch (ITE 90), and the Gisburn afforestation experiment (ITE 367). It will also be linked with a study of effects of the new forests on populations of song-birds which is the objective of a separate NCC contract involving Dr. I. Newton (ITE) and Dr. J. Lockie (Department of Forestry and Natural Resources, Edinburgh) in a supervisory role and D. Moss or another as a graduate research worker. As part of the project, liaison will be maintained with FC research staff who are currently examining differences in flora and soils between sitka spruce plots <u>within</u> compartments matched in all respects except age.

In the rotation of a forest crop there is a corresponding cycle in the ground flora. The stages of the cycle need to be known, as do the differences resulting from differing site characteristics and regimes of management. Moreover, even in heavily afforested areas, there is always a certain proportion of the ground which is unplanted. From the wildlife point of view, the unplanted ground, though less in extent, may be equally or more important than the planted. Hence, quantitative data on unplanted areas within forests are as relevant as data from planted areas. When these data are avilable, together with data on the vegetation which the forests have replaced, it should be possible to take a balanced view of the effect of afforestation on the flora.

Objectives

i) To compare site characteristics of present and past plantings

ii) To determine the semi-natural floristic composition of the types of area which are being planted up.

iii) To compare this with the floristic composition of comparable areas which are currently managed as forests.

iv) To identify and estimate the abundance of the main habitat features associated with floristic diversity in the unafforested areas - e.g. streams, rock outcrops, bogs, marshes.

v) To identify and estimate the abundance of the main habitat features associated with floristic variety in the forested area - e.g. roads, rides, picnic sites and unplanted areas; and to examine what becomes of the habitat features which had been associated with floristic variety before afforestation.

vi) To determine the main features of floristic succession during the crop rotation, in relation to differences of soil type, aspect and planted crop species.

vii) To identify problems of species biological interest which become apparent during the course of the investigation - e.g. mode of dispersal and establishment of higher plants and bryophytes within afforested areas.

viii) To identify priorities for continuing work on the effects of afforestation.

Criteria for Success

i) Preparation of a report summarising changes in types of area planted.

ii) Availability of data on the overall range of variation and floristics of the unplanted areas.

iii) Availability of data on the overall range of variation and floristics of the planted areas.

iv) Availability of data on the nature and abundance of special habitat features within the unafforested area.

v) Availability of data on the nature and abundance of special habitat features within the planted area, and on the fate of former special habitat features which are lost.

vi) Availability of data which cover the main phases of the crop rotation.

vii) Preparation of a report stating the main biological problems which are raised by the survey.

Methods

The following notes are intended as a first indication of the methods which will be used in this project. They will be modified and expanded as required during the planning and early field work stages.

Sampling scheme

The abundance of floristic types and of habitat categories can be estimated only by objective methods of sampling. A system of stratification ensures economy of effort, and will be used. Objectives (i), (ii) and (iii) require sampling to be extensive. Aims (iv) and (v) require sampling which is restricted so as to concentrate on particular features of interest. For (iv), the use of Ordnance Survey maps is appropriate. For (v), the use of modern forestry maps is necessary.

To satisfy the needs of the NCC for information about effects of afforestation in particular parts of the southern uplands and yet to examine the region as objectively as possible, an area of interest, defined by Ordnance Survey National Grid lines and including the major upland areas of interest to the NCC, has first been defined. This extends from about Newton Stewart/Glen Trool in the west to the Tweedsmuir/Moffat area in the east and covers a total area of about 4600 km^2 (Fig.). 1 km^2 squares in this area will be sub-sampled on the basis of underlying rock (granite/non-granite), slope (3 strata), altitude (3 or 4 strata) and forest cover (3 strata). Only squares containing a high percentage (> c. 80 per cent) of forest or bracken, heath and rough grass-land (see 1" O.S. maps) will be considered usable in this project. Each 1 km^2 area selected will be surveyed by examining in detail large quadrats (plots) and transects across special features (streams, forest roads, etc.), the latter at points selected during a standard walk across the area.

About 70 x 1 km^2, including 400-500 plots, will be examined in this year. Tree species, tree age-class and soil will not be considered as bases for stratification but the proposed approach is expected to cover all age-classes, soils and the main tree species and trends with age, soil or species should emerge during the data analysis. 1 km^2 squares will be chosen so as to maintain a balance between grazed and ungrazed non-forest areas.

Large quadrat (plot) size

200 m^2 quadrat was used in the survey of semi-natural woodlands (ITE 1) and in the Shetland Survey (ITE 47) and it is proposed to use this size in coppice studies (ITE 366). 100 m^2 quadrat size was used in the N.W. commercial forest survey (ITE 13). A field trial conducted with Dr. S. D. Ward of ITE Bangor indicated that there is no special objection to using a 200 m^2 quadrat in coniferous plantations, except perhaps that it is inconveniently large when the forest is in the thicket stage. Because the 200 m^2 quadrat will give a more representative portion of an area, than will the 100 m^2 quadrat, particularly in mature forest, and because 200 m^2 is now preferred more frequently within the Institute than other quadrat sizes, the 200 m^2 size has been selected for this project.

Recording abundance of flora

Shaw (ITE 13) used a semi-quantitative local frequency measure of abundance. Bunce and Shaw (ITE 1) used visual estimates of cover. In a dense plantation it is not very easy to estimate cover over a large area such as 200 m^2. Even in a stand where the trees are well spaced, estimation of the cover, e.g. of the bryophyte species, is difficult. Dr. S. D. Ward and M. O. Hill experimented with placing a 0.25 m^2 quadrat in 25 systematically placed positions within the large 200 m^2 quadrat, and visually estimating cover within the small quadrat at each of its 25 situations. The results were highly encouraging. Cover of bryophyte species, and of brashings, logs and stumps could be estimated with confidence within the smaller quadrats. Cover for the 200 m^2 quadrat was simply the average of that in the smaller quadrats. There was no indication that estimating local frequencies would have been any quicker. The great advantage of cover is that it is an absolute measure, quite independent of any particular method of sampling.

From analysis of the results of initial trials we concluded that 10 small quadrats per plot will be adequate before canopy closure and 20 after closure. Shrubs, such as Ulex and Myrica, rocks and rock-dwelling species will always be recorded at all stations.

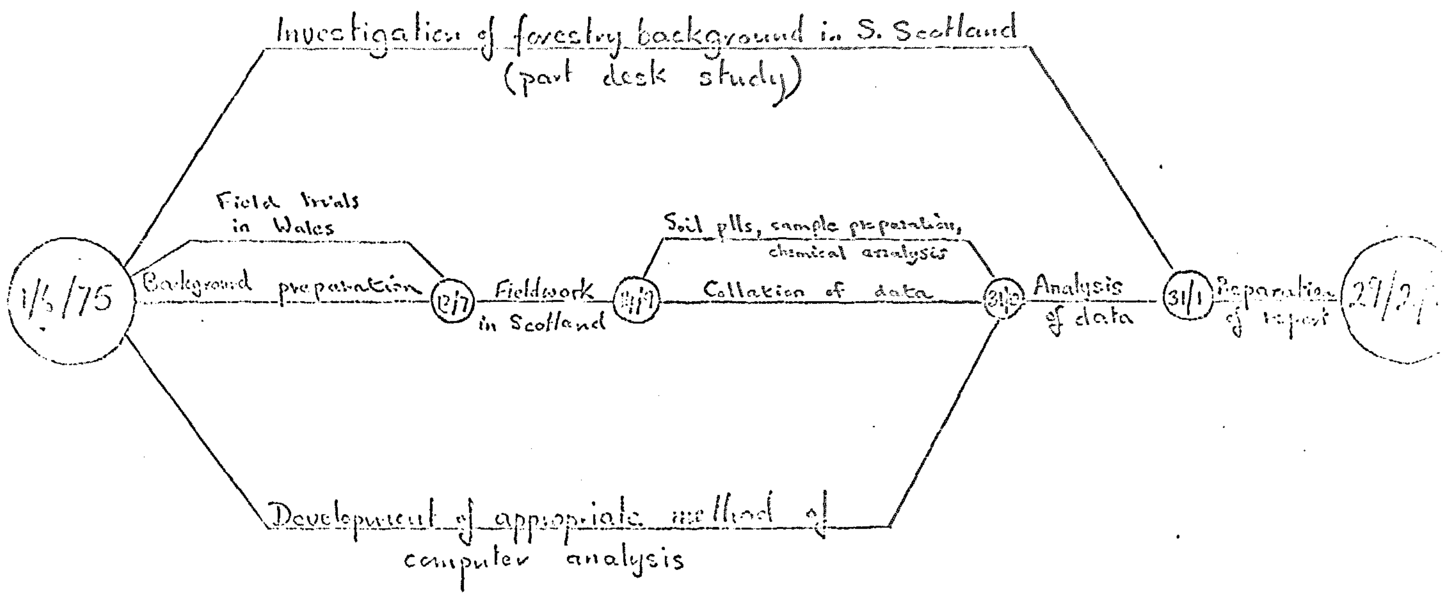
Special habitats

Species lists from stumps and rocks are to be made, but these will be listed separately from the ground flora proper. In coniferous woodland the distinction between stumps and brashings is often a small one, in that they support similar species. Nevertheless, it is impossible to regard brashings as a separate category like stumps, as they gradually become covered with litter and bryophytes, and are then effectively part of the forest floor.

Soil description and sampling

A shallow (c. 30 cm deep) pit will be dug using a mattock and the exposed soil profile described briefly in terms of horizon thickness, colour, stoniness, rootiness, texture. Samples of the L/F layer and other upper soil horizons will be taken for laboratory examination including determination of pH, LOI, total N and total P. If, after initial field trials, it appears that identification of horizons by project staff is difficult, soil samples for analysis will be taken at 0-5 cm and, say 0-25 cm depth.

Network for Project 308



APPENDIX 2

ITE Project 368: Effects of afforestation on flora

Habitat code: Ground 1: rock 2: stump 3: fallen timber 4: epiphyte on shrub or tree 5: aquatic 6.

1			2
	3	4	
5			6

4004 (2.0)
5002 (2.?)

-1-4-5	RECORDERS
2	DAY OF MONTH
8	MONTH
22	SITE NUMBER
4985	SITE GRID REFERENCE
2201	SITE STRATUM
13	PLOT NUMBER
00	PLOT GRID REFERENCE
12.00	ALTITUDE
0	ASPECT
0	SLOPE
1630	TIME OF DAY
3	WEATHER 1 = rain 2 = drizzle 3 = dry

[Stream reduced to a running ditch — category 6 not relevant]

Achi mill 7
~~[illegible]~~ 35 1
[illegible] 42
Aira prae 42
Alnu glut 77
Ange sylv 109
Anth odor 171
Aspl tric 15?
Athy fili 211
Bell pere 231
Betu pend 239
pube 240
Blec spic 24?
~~[illegible]~~ 309 1
Calt palu 310
Camp rotu 322
Card prat 33?
Care bine 350
demi 361
~~[illegible]~~ 370 5
flac 376
host 382
nigr 393
oval 397
pauciflora 400
pilu 405
pull 408
rost 414
Cent nigr 444
Cera holo 467
Cham angu 477
Chry oppo 505
Cirs arve 515
palu 520
vulg 522
Cono maju 541
Cyno cris 557
Dact glom 607
Dact macu 610
Desc cesp 627
~~flex~~ 628 2
Digi purp 640
Dros rotu 657
Dryo dila 661
fili 664
Empe nigr 694
Endy nons 687
Epil mont 695
palu 697
Equi fluv 713
palu 697
Eric cine 725
~~tetr~~ 731 1
~~[illegible]~~ 732 2 (65)
vagi 734
Fest ovin 801
rubr 804
Fili ulma 833
Frax exce 841
Gali palu 852
~~saxa~~ 859 4
veru 866
Hier pilo 976
~~Holc lana~~ 985 5
moll 994
Hype pulc 1015
Hypo radi 1023
Junc acti 1030
~~[illegible]~~ 1035 5
bufo 1037
~~bulb~~ 1039 1
~~effu~~ 1047 (2.2?)
~~squa~~ 1075 2 (15)
Lath mont 1112
Leon autu 1129
Linu cath 1169
Loli pere 1183
Lotu corn 1197
ulig 1194
Luzu camp 1227
~~[illegible]~~ 1234 2
sylv 1209

Lych flos 1210
Lyco sela 1217
Lysi nemo 1221
Meny trif 1239
~~[illegible]~~ 1307 (320)
Mont font 1312
Myos secu 1323
Myri gale 1330
Nard stri 1344
~~[illegible]~~ 1345 4
Oxal acet 1413
Pedi sylv 1442
Ping vulg 1451
Plan lanc 1497
majo 1498
Poa annu 1495
prat 1506
triv 1507
Poly serp 1514
Pote poly 1574
~~erec~~ 1583 1
Prun vulg 1613
Pter aqui 1619
Quer petr 1638
robu 1640
Ranu acri 1642
flam 1651
repe 1660
Rhin mino 1678
Rubu frut 1723
Rume acet 1735
acetosa 1736
obtu 1748
Sagi proc 1757
Sali cine 1789
Saro scop 1822
Sene jaco 1899
Sieg decu 1915
Sile dioi 1859
Soli virg 1951
Sorb aucu 1950
Stel alsi 2007
gram 2009
medi 2011
Succ prat 2021
Tara offi 2035
Teuc scor 2046
Thel limb 2051
Thym drue 2060
Tric cesp 1859
Trif prat 2091
repe 2092
Trig palu 2102
Ulex euro 2112
Urti dioi 2126
~~Vacc myrt~~ 2135 2
viti 2138
Vero cham 2168
offi 2173
serp 2182
Viol [illegible] 2193
Viol palu 2215
rivi 2218

Cetr isla 2977
Clad arbu 2902
cocc 2905
fimb 2906
~~floe~~ 2907 4
furc 2908
grac 2909
~~[illegible]~~ 2910 2
poly 2911
squa 2912
uncl 2913
unci 2914
Corn acul 2915
Parm phys 2916
saxa 2917
Pelt cani 2918
poly 2919
Spha glob 2920

Acro cusp 3004
fasc 3004
stra 3007
Andr roth 3025
rupe 3026
~~Atri undu~~ 3040 5
Aula palu 3042
Barb [illegible] 3045
cyli 3047
fall 3048
ungu 3052
Blin acut 3069
Brac albi 3072
plum 3077
rivu 3080
ruta 3081
Breu chry 3085
Bryu alpi 3087
arge 3089
capi 3091
pall 3110
pseu 3113
Camp seri 3128
Camp stel 3136
Camp atro 3137
~~flex~~ 3139 5
pyri 3142
Cera purp 3151
Crat comm 3161
falc 3162
fili 3163
Cten moll 3165 4
~~[illegible]~~ 3166 4
palu 3167
vari 3159
Dicr cirr 3193
Dicr maju 3203
scop 3205
Ditr hete 3217
Drep exan 3223
flui 3224
revo 3226
Eurh prae 3249
ripa 3251
stri 325?
swar 3255
Fiss adia 3257
bryo 3260
osmu 3269
taxi 3274
~~[illegible]~~ 3284 5
Grim [illegible] 3291
pulv 3312
tric 3319
Hedw cili 3328
Hylo sple 3346
Hypn cupr 3351
~~[illegible]~~ 3352 5
Isop eleg 3357
Isot myos 3362
Leuc glau 3374
~~[illegible]~~ 3382 1
puno 3389
undu 3395
Phil font 3435
Plag dent 3445
[illegible] 3458
~~undu~~ 3459 2
Pleu schr 3463
~~Pohl nuta~~ 3475 5
wahl 3467
Poly aloi 3479
alpi 3480
alpi 3481
~~comm~~ 3482 1
form 3483
juni 3485
pili 3486
urni 3489
Pseu puru 3507
Rhac acic 3519
aqua 3520

Rhac cane 3521
fasc 3522
hete 3524
lanu 3525
Rhyt lore 3532
squa 3533
triq 3534
Scor scor 3541
~~Spha [illegible]~~ 3578 2
~~cusp~~ 3584 2
comp 3551
cusp 3556
fimb 3557
girg 3559
~~[illegible]~~ 3575 4
~~[illegible]~~ 3587 2
~~plum~~ 3580 2
~~recu~~ 3574 4
tene 3579
tere 3580
Tetr pell 3585
Thui [illegible] 3598
Thui tam 3599
Ulot cris 3632
Weis cont 3639

Barb floe 3695
Caly fiss 3706 2
~~[illegible]~~ 3707 1
~~Ceph bicu~~ 3714 1
conn 3716
Chil pall 3737
poly 3738
~~Dipl albi~~ 3747 4
Frul dila 3752
tama 3763
Gymn infl 3772
Lepi rept 3807
Loph cusp 3812
Loph inci 3819
~~vent~~ 3824 5
Mars emar 3834
Meta fure 3845
Myli anom 3852
tayl 3854
Nard scal 3857
Odon spha 3863
~~Pell epip~~ 3867 1
nees 3869
Plag aspl 3877
majo 3878
Ptil cili 3888
Ricc mult 3899
ping 3901
sinu 3902
Scap [illegible] 3914
Scap grac 3927
irri 3929
~~undu~~ 3935 1
Sole crem 3943
Trit quin 3960

Cover and tree record. Cover of following to be noted: 1 bare ground 2 rock, 3 stump, 4 fallen timber, 5 living wood, 6 water. Bryophytes on a special habitat do not count against its cover. E.g. the record Fallen timber 30, Hypn cupr (4) 15, Isoth myos (4) 15, means that the bryophytes Hypnum and Isothecium completely cover some fallen timber, which itself covers 30% of the quadrat under observation.

SITE NUMBER 22 PLOT NUMBER 13

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Veg. height		15		22		30		46		24		5		5		12		45		19	
Juncus squarr	15	15																			
Molinia	620	35		55		100		100		20				80		30				100	
Eriophorum angustifolium	65			45												20					
Picea sitch	500					100		100		100		100		100							
Dead	200									80		100		20							
Juncus [illegible]	100																	100			
Picea sitch	6	3	7	3	2	5															

Note: before canopy closure record cover of ground vegetation only at odd stations. Shrubs such as Ulex, Myrica to be recorded at all stations. Rocks and rock-dwelling species to be recorded at all stations.

Describe position relative to local landform. Give informal description of vegetation stating if more than one type present. Comment on whether there is recent disturbance (human or animal) resulting in invasion by specialized species or in tree regeneration. Are drainage operations leading to species elimination? If trees not present is forestry having indirect effect? Can you guess trends?

SITE NUMBER 22 PLOT NUMBER 13

(100) Trees - planted species

1 Lari lept (2) Pice sitc 3 Pice abie 4 Pinu cont
5 Pinu sylv 6 Pseu menz

(200) Trees - management etc (1=yes;0=no;no ploughing=0 furrow depth)

Height (m) 2·5 Furrow depth (cm) 23 Canopy closed? 0 Brashed? 0
Thinned? 0 Windthrow? 0 Planting date 1963 (102)

300 Trees and shrubs - regeneration ("1"= 1-5 seen; "2"= 6 or more)

Betu pend 1	Betu pube 2	Cory avel 3	Frax exce 4
Lari lept 5	Pice sitc 6	Pinu cont 7	Pinu sylv 8
Pseu menz 9	Quer petr 10	Quer robu 11	Rhod pont 12
Sali cine 13	Saro scop 14	Sorb aucu 15	Ulex euro 16

(400) Linear habitats (show on sketch map with indication of how wide and long)

1 Wall dry 2 Wall mort 3 Wall ruined 4 Fence
5 Embankment 6 Ride 7 Tarmac road 8 Rough road
9 Dry ditch (10) Wet ditch (11) Slow stream 12 Fast stream

500 Rock habitats

1 Rocks 5-50 cm 2 Boulders 3 Scree 4 Rock piles 5 Rock outcrop

600 Wet and peaty habitats (excluding streams and ditches)

1 Blanket bog 2 Flat bog 3 Marsh 4 Swamp 5 Small pool $< 1 m^2$ 6 Large pool/lake

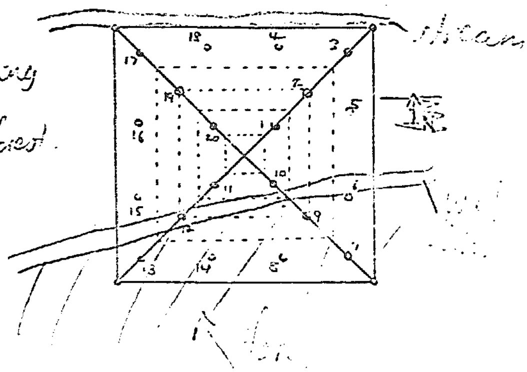
700 Human influences (excluding linear habitats)

1 Burning 2 Agric improvement 3 Mining/quarrying 4 Dumping

(800) Animals (1=living,2=dead,3=dung,4= signs such as molehills or wool)

11 Sheep 12 Goat 13 Cattle 14 Pony 15 Rabbit
16 Red deer (17) Roe deer 18 Mole 19 Frog 20 Red grouse

(950) Grazing (0) 1 2 3 4
(960) Exposure 0 (1) 2 3 4



Plot is on stream flowing through ride in sitka spruce forest. Juncus/Calluna [illegible] in ride.

SITE NO 22 PLOT NO 13 (enter with linear habitat code indicated)

Linear habitats (Road, ride, stream, lakeside, wall)
11 12 13 14 15

101 Tarmac road
102 Rough road constructed for forestry
103 Rough road not constructed for forestry
104 Ride (must be at least 5 m wide)
105 River fast (faster than 1 mph, wider than 2m)
106 River slow (slower than 1 mph, wider than 2m)
107 Stream fast (narrower than river but should be marked on map)
(108) Stream slow
109 Lakeside muddy
110 Lakeside sandy or gravelly
111 Lakeside rocky
112 Dry wall
113 Mortared wall
(114) .4 Width of habitat (m) (enter "0" if a lakeside; for streams and roads enter distance between banks or verges)
115 Height of habitat (applies only to walls)

(200) If there are planted trees within 30m of line on side of plot then ring figure and answer the following
3 Distance of trees from line (m)
2.5 Height of trees (m)
2 Species of trees (enter code numbers as under "100" on plot sheet)

(300) If there are planted trees within 30m of line on side opposite plot then ring figure and answer the following
3 Distance of trees from line (m)
2.5 Height of trees (m)
2 Species of trees

(400) Give orientiation of centre of plot facing with back to line
140

Notes on linear habitat recording
The line is defined as a road verge, ride middle, stream bank, lake margin or foot of wall. Plot is arranged so that one side coincides with line. Decide which side to place plot by tossing coin. (Does not apply to lakes) Record plot as usual, indicating zonation (if any) on sketch map. Having recorded plot, record presences and absences of any additional species up to 1 m on other side of line from plot. Include both sides of a wall. Indicate these species with the code "0" on the species presence sheet. (The aim here is to cover waterweeds, bank specialities etc.)

Notes on plot questionaire
Blanket bog is peat deeper than 60 cm spread over rolling country.
Flat bog is peat deeper than 60 cm in basins etc, where drainage is seriously impeded - no appreciable flushing.
Marsh is ground which oozes when trodden; bogs in the sense defined here need not be marshy
Swamp is flattish, has soft bottom and overflows gum boot (often has Carex rostrata, Caltha, Sphagnum etc.)
Under "animals" mention any other unwinged vertebrates
In unthinned plantations record only the central 50m^2 for tree statistics.

SIMPLIFIED SOIL RECORDING FORM

Site No	Site name		Grid Ref km E | km N	Date Day | Year
Plot No	Observer			
Profile No	Solid geology		L layer thickness (cm)	F layer thickness (cm)
Altitude (m)			L layer composition	Nature of F layer
Slope °	Site drainage			F layer composition
Aspect °	Rainfall (mm)	No of layers	H layer thickness (cm)	

Sample code
layer no
layer depth cms (start)
" " " (end)

LAYER COLOUR
Yellowish 1
Brownish 2
Reddish 3
Greyish 4
Black 5

MOTTLED
Yes 1
No 2

PREDOMINANT TEXTURE
Organic 1
Sand 2
Silt 3
Clay 4
Mixed (loam) 5

OVERALL STONINESS
Stones rare/absent 1
Moderately stony 2
Extremely stony 3

MOISTURE ON SAMPLING

Dry 1

Moist 2

Wet 3

Waterlogged 4

ROOTS

0 = absent
1 = fine (<1 mm diam.)
2 = small (1–3 mm)
3 = medium (3–10 mm)
4 = large (10–30 mm)
5 = very large (>30 mm)

Fibrous 1

Fleshy 2

Woody 3

Rhizomatous 4

Rare 5

Few 6

Common 7

Abundant 8

LARGE EARTHWORMS

Observed 1

Not observed 2

IRON PAN

Present 1

Absent 2

MAJOR SOIL GROUP (if known)

Comments

APPENDIX 5

VEGETATION TYPES OF UNPLANTED STANDS

1. Synopsis of classification, with orders and alliances
2. Hierarchy generated by indicator species analysis, showing its relation to the named groups
3. Dichotomous key to vegetation types
4. Differential tables showing the vegetation types generated by indicator species analysis

SOUTHERN UPLANDS OF SCOTLAND: SEMI-NATURAL VEGETATION TYPES

The vegetation types were derived by an indicator species analysis of releves recorded from 200 m^2 quadrats. For ease of comprehension the resulting groups are pigeonholed according to the Zurich-Montpellier system. Nomenclature follows McVean & Ratcliffe (1962) except where there is a statement to the contrary. Numbers in binary code refer to the computer-generated hierarchy.

SCHEUCHZERIO-CARICETEA

Caricion canescentis-fuscae

1. Sphagneto-Juncetum effusi (1100)
   (Juncus acutiflorus-Acrocladium cuspidatum nodum occurred a few times, but not often enough to be distinguished by the computer analysis.)
2. Molinietum atlanticum (assoc. nov.)
   a. myricosum (0010) (= Molinia-Myrica)
   b. agrostidosum (0011)
   c. juncosum (1101)

OXYCOCCO-SPHAGNETEA

Ericion tetralicis

3. Molinieto-Callunetum
   a. typicum (0001)
   b. moliniosum (0000)

Erico-Sphagnion

4. Calluneto-Eriophoretum
   a. typicum (0110)
   b. moliniosum (0111)

SALICETEA HERBACEAE

Nardeto-Caricion bigelowii

5. Nardus stricta-Vaccinium myrtillus (Birks, 1973, p. 60)
   a. typicum (1010)
   b. low altitude facies (1011)

NARDO-CALLUNETEA

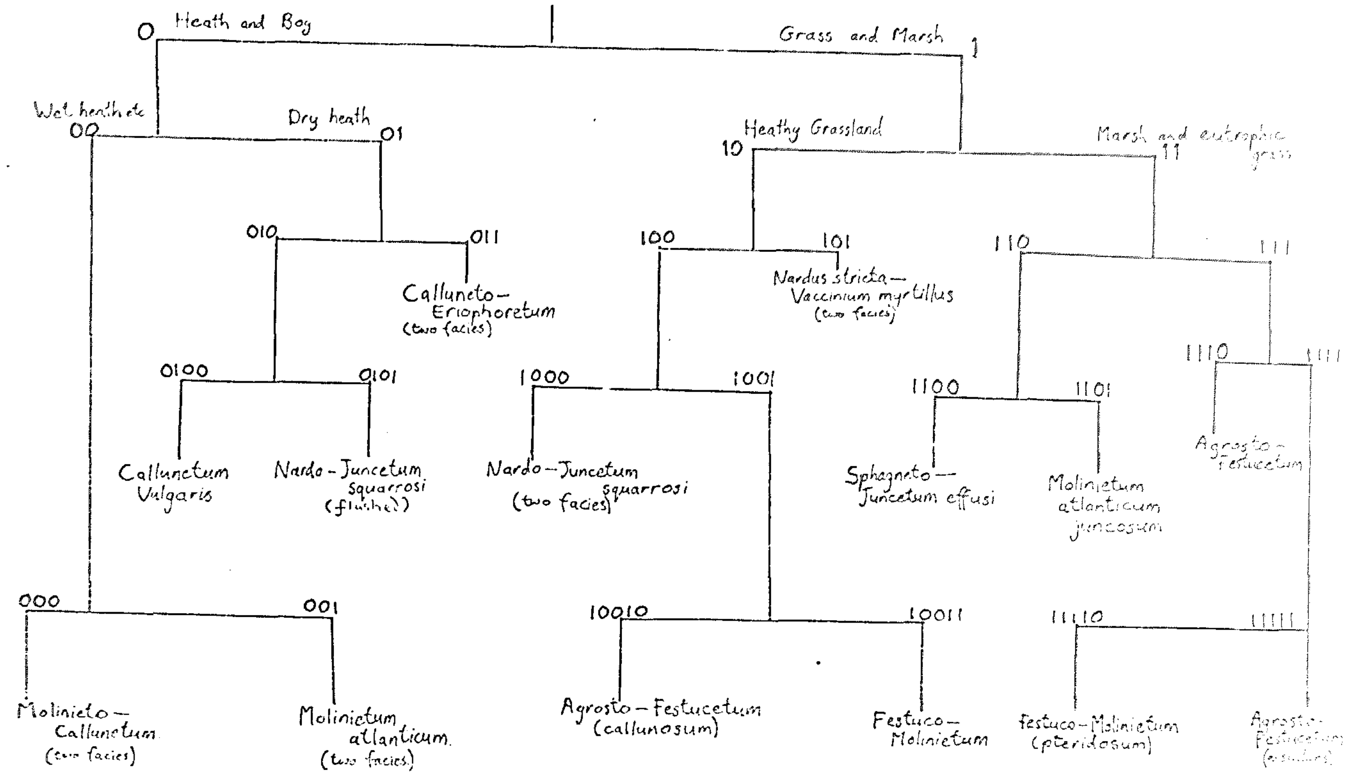
Nardo-Galion saxatilis

6. Nardo-Juncetum squarrosi (Birks, 1973, p. 124)
   a. nardosum (10000) (= Nardetum subalpinum)
   b. juncosum (10001) (= Juncetum squarrosi subalpinum)
   c. nartheciosum (0101) (includes Sphagneto-Caricetum subalpinum as a mosaic element within it)
7. Agrosto-Festucetum
   a. typicum (1110)
   b. callunosum (10001)
   c. exsudans (11111) (= herb-rich Callunetum vulgaris)
8. Festuco-Molinietum (assoc. nov.)
   a. typicum (10011) (= Molinia-Festuca-Deschampsia, King
   b. pteridosum (11110) & Nicholson, 1964, p. 216)

Ericion cinereae

9. Callunetum vulgaris (0100)

SOUTHERN UPLANDS OF SCOTLAND: SEMI-NATURAL VEGETATION TYPES ARRANGED IN HIERARCHY GENERATED BY INDICATOR SPECIES ANALYSIS



APPENDIX 3 3. Dichotomous key to vegetation types

Division *

Negative indicators (heath and bog)
Calluna vulgaris, Erica tetralix, Eriophorum angustifolium, E. vaginatum, Narthecium ossifragum, Sphagnum capillaceum (s.l., including S. rubellum).
Positive indicators (grassland and marsh)
Agrostis tenuis, Festuca ovina (5+%), Galium saxatile, Rhytidiadelphus squarrosus.

If indicator score is -1 or less then go to division *0 (heath and bog group), if 0 or more then go to division *1 (grassland and marsh group).

Species preferential to heath and bog
Calluna vulgaris, Carex echinata, Drosera rotundifolia, Erica cinerea, E. tetralix, Eriophorum angustifolium, E. vaginatum, Molinia caerulea, Myrica gale, Narthecium ossifragum, Polygala serpyllifolia, Trichophorum cespitosum, Sphagnum auriculatum, S. capillaceum S. papillosum, S. plumulosum, S. recurvum, S. tenellum, Calypogeia fissa, Odontoschisma sphagni, Calluna vulgaris (5+%), Molinia caerulea (5+%), Trichophorum cespitosum (5+%), Calluna vulgaris (25+%), Molinia caerulea (25+%).

Species preferential to grassland and marsh
Agrostis tenuis, Anthoxanthum odoratum, Carex binervis, C. pilulifera, Deschampsia cespitosa, Festuca ovina, Galium saxatile, Holcus lanatus, Luzula multiflora, Rumex acetosa, Hylocomium splendens, Pleurozium schreberi, Pseudoscleropodium purum, Rhytidiadelphus squarrosus, Lophocolea cuspidata, Agrostis canina (5+%), A. tenuis (5+%), Anthoxanthum odoratum (5+%), Deschampsia flexuosa (5+%), Festuca ovina (5+%), Galium saxatile (5+%).

Division *0

Negative indicators (wet heath, bog and Molinia moors)
Molinia caerulea (5+%), Molinia caerulea (25+%), Myrica gale, Odontoschisma sphagni
Positive indicators (dry heath, Pennine blanket bog and heathy moorland)
Calluna vulgaris (25+%), Deschampsia flexuosa, Juncus squarrosus, Vaccinium myrtillus, Dicranum scoparium, Polytrichum commune

If indicator score is -1 or less then go to division *00 (wet heath, bog and Molinia moor group), if 0 or more then go to division *01 (dry heath, pennine blanket bog and heathy moorland group).

Species preferential to wet heaths, bog and Molinia moors
Drosera rotundifolia, Erica cinerea, Juncus acutiflorus, Myrica gale, Polygala serpyllifolia, Campylopus atrovirens, Sphagnum auriculatum, Odontoschisma sphagni, Erica tetralix (5+%), Molinia caerulea (5+%), Molinia caerulea (25+%).

Species preferential to dry heaths, Pennine blanket bog and heathy moorland
Carex nigra, Deschampsia flexuosa, Empetrum nigrum, Galium saxatile, Juncus squarrosus, Luzula multiflora, Nardus stricta, Vaccinium myrtillus, Dicranum scoparium, Hylocomium splendens, Plagiothecium undulatum, Pleurozium schreberi, Polytrichum commune, Rhytidiadelphus loreus, Sphagnum recurvum, Calypogeia muellerana, Lophozia ventricosa, Eriophorum vaginatum (5+%). Juncus squarrosus (5+%). Nardus stricta (5+%), Vaccinium myrtillus (5+%), Calluna vulgaris (25+%)

Division *1

Negative indicators (heathy grasslands, i.e. Nardo-Galion saxatilis)
Calluna vulgaris (5+%). Vaccinium myrtillus, Dicranum scoparium, Hypnum ericetorum
Positive indicators (marshes and eutrophic grasslands)
Holcus lanatus, Juncus acutiflorus, J. effusus, Trifolium repens, Viola palustris, Pseudoscleropodium purum

If indicator score is -1 or less then go to division *10 (heathy grasslands), if 0 or more then go to division *11 (marshes and eutrophic grasslands)

Species preferential to heathy grasslands

Lycopodium selago, Trichophorum cespitosum, Vaccinium myrtillus, Cladonia impexa, C. uncialis, Campylopus flexuosus, Dicranum scoparium, Hypnum ericetorum, Rhacomitrium lanuginosum, Rhytidiadelphus loreus, Deschampsia flexuosa (5+%), Vaccinium myrtillus (5+%).

Species preferential to marshes and eutrophic grasslands
Campanula rotundifolia, Carex echinata, C. nigra, Cerastium holosteoides, Cirsium palustre, Deschampsia cespitosa, Epilobium palustre, Festuca rubra, Holcus lanatus, Juncus acutiflorus, J. bulbosus, J. effusus, poa pratensis, Ranunculus acris, R. repens, Rumex acetosa, Sieglingia decumbens, Succisa pratensis, Trifolium repens, Viola palustris, V. riviniana, Atrichum undulatum, Philonotis fontana, Pseudoscleropodium purum, Sphagnum palustre, S. recurvum, Thuidium tamariscinum, Euphrasia officinalis agg., Anthoxanthum odoratum (5+%), Holcus lanatus (5+%), Juncus acutiflorus (5+%).

Group *00 Wet heat, bog and Molinia moors

Division *00

Negative indicators: Calluna vulgaris (5+%), Erica tetralix (5+%), Trichophorum cespitosum, Rhacomitrium lanuginosum, Sphagnum tenellum, Odontoschisma sphagni
Positive indicators: Agrostis canina, Carex echinata, Juncus acutiflorus, Sphagnum recurvum

If indicator score is -1 or less then go to division *000
0 or more then go to division *001

Division *000

Negative indicators: Drosera rotundifolia, Molinia caerulea (25%+), Myrica gale Campylopus atrovirens, Sphagnum auriculatum
Positive indicators: Carex panicea, Calluna vulgaris (25%+)

If indicator score is -2 or less then assign to group *0000 (Molinieto-Callunetum molinicosum)
If indicator score is -1 or more then assign to group *0001 (Molinieto-Callunetum typicum)

Division *001

Negative indicators: Myrica gale (5%+), Sphagnum plumulosum
Positive indicators: Deschampsia flexuosa, Galium saxatile, Calypogeia fissa, Lophocolea cuspidata, Polytrichum commune

If indicator score is 0 or less then assign to group *0010 (Molinietum atlanticum myricosum)
If indicator score is 1 or more then assign to group *0011 (Molinietum atlanticum agrostidosum)

Group *01 Dry heath, pennine blanket bog and heathy moorland

Division *01

Negative indicators: Nardus stricta, N. stricta (5+%)
Positive indicators: Deschampsia flexuosa (5+%), Erica tetralix, Eriophorum vaginatum, E. vaginatum (5+%), Pleurozium schreberi

If indicator score is 1 or less then go to division *010
If indicator score is 2 or more then go to division *011

Division *010

Negative indicators: Calluna vulgaris (25+%)
Positive indicators: Carex echinata, Eriophorum vaginatum, Juncus squarrosus (5+%), Narthecium ossifragum, N. ossifragum (5+%), Sphagnum auriculatum

If indicator score is 2 or less then assign to group *0100 (Callunetum vulgaris)
If indicator score is 3 or more then assign to group *0101 (Nardo-Juncetum squarrosi, exsudans)

Division *011

Negative indicators: Empetrum nigrum, Polytrichum commune (5+%)
Positive indicators: Deschampsia flexuosa (5+%), Juncus bulbosus, Luzula multiflora, Molinia caerulea (5+%), M. caerulea (25+%)

If indicator score is 1 or less then assign to group *0110 (Calluneto-Eriophoretum typicum)
If indicator score is 2 or more then assign to group *0111 (Calluneto-Eriophoretum moliniosum)

Group 10 Heathy grasslands

Division *10

Negative indicators: Agrostis tenuis (5+%), Anthoxanthum odoratum, Luzula multiflora, Trichophorum cespitosum, Rhytidiadelphus squarrosus, Lophocolea cuspidata
positive indicators: Lycopodium selago, Cladonia impexa, C. uncialis, Rhacomitrium lanuginosum

If indicator score is -1 or less then go to division *100
If indicator score is 0 or more then go to division *101

Division *100

Negative indicators: Juncus squarrosus, Nardus stricta, N. stricta (5+%), N. stricta (25+%)
positive indicators: Blechnum spicant, Molinia caerulea, M. caerulea (5+%)

If indicator score is -2 or less then go to division *1000
If indicator score is -1 or more then go to division *1001

Division *1000

Negative indicators: Nardus stricta (25+%)
Positive indicators: Carex nigra, Eriophorum angustifolium, Juncus squarrosus (5+%), Polytrichum commune (5+%), plagiothecium undulatum, Calypogeia fissa

If indicator score is 1 or less then assign to group *10000 (Nardo-Juncetum squarrosi, nardosum)
If indicator score is 2 or more then assign to group *10001 (Nardo-Juncetum squarrosi, juncosum)

Division *1001

Negative indicators: Calluna vulgaris (5+%), pteridium aquilinum
Positive indicators: Juncus squarrosus, Molinia caerulea, M. caerulea (5+%), M. caerulea (25+%), Nardus stricta

If indicator score is 1 or less then assign to group *10010 (Agrosto-Festucetum, callunosum)
If indicator score is 2 or more then assign to group *10011 (Festuco-Molinietum, typicum)

Division *101

Negative indicators: Lycopodium selago
Positive indicators: Calluna vulgaris, C. vulgaris (5+%), C. vulgaris (25+%), Erica cinerea, Narthecium ossifragum, Cladonia floerkeana

If indicator score is 2 or less then assign to group *1010 (Nardus stricta-Vaccinium myrtillus, typicum)
If indicator score is 3 or more then assign to group *1011 (Nardus stricta-Vaccinium myrtillus, low altitude)

Group 11 Marshes and eutrophic grasslands

Division *11

Negative indicators: Carex echinata, Epilobium palustre, Viola palustris, Mnium hornum, polytrichum commune
Positive indicators: Festuca ovina (5+%), pseudoscleropodium purum

If indicator score is -2 or less then go to division *110
If indicator score is -1 or more then go to division *111

Division *110

Negative indicators: Juncus effusus (5+%), philonotis fontana
Positive indicators: Molinia caerulea, M. caerulea (5+%), Myrica gale, Campylopus flexuosus, Sphagnum papillosum

If indicator score is 1 or less then assign to group *1100 (Sphagneto-Juncetum effusi)
If indicator score is 2 or more then assign to group *1101 (Molinietum atlanticum, juncosum)

Division *111

Negative indicators: Agrostis tenuis (5+%)
Positive indicators: Blechnum spicant, Oxalis acetosella, prunella vulgaris, Succisa pratensis, Thelypteris limbosperma, T. limbosperma (5+%)

If indicator score is 1 or less then assign to group *1110 (Agrosto-Festucetum, typicum)
If indicator score is 2 or more then go to division *1111

Division *1111

Negative indicators: (none)
Positive indicators: Achillea ptarmica, Briza media, Calluna vulgaris (5+%), Galium uliginosum, Linum catharticum, Ranunculus repens, Salix aurita

If indicator score is 3 or less then assign to group *11110 (Festuco-Molinietum, ptericosum)
If indicator score is 4 or more then assign to group *11111 (Agrosto-Festucetum, exsucans)

	0000 MOLINIETO-CALLUNETUM b. moliniosum		0001 MOLINIETO-CALLUNETUM a. typicum		0010 MOLINIETUM-ATLANTICUM a. myricosum		0011 MOLINIETUM-ATLANTICUM b. agrostidosum	
Call vulg	3,7	V	5.6	V	2.6	V	2.0	IV
Care panicea			1.6	V	1.3	III	1.2	III
Dros rotu	2.0	III	1.2	IV	1.7	IV		
Eric tetr	3.6	V	3.2	V	3.7	V	2.0	V
Erio angu	2.5	V	1.4	III	1.5	III		
Junc bulb					1.3	IV		
Junc squa	1.4	IV	1.0	III				
Moli caer	6.7	V	4.0	V	7.8	V	8.0	V
Nard stric			1.7	IV				
Narth ossi	3.7	V	2.7	V	2.3	V	7.2	III
Poly serp	1.0	III	1.0	III	1.3	III		
Poten erec	1.9	IV	2.4	V	2.8	V	2.9	V
Camp flex	0.8	III	1.3	IV	0.8	III		
Hyph eric	1.5	III	2.3	V	7.0	III	1.6	IV
Spha auri	1.6	IV	1.0	III	1.6	IV		
Spha capi	1.9	IV	1.5	IV	2.3	V	1.6	IV
Spha papi	2.7	IV	1.7	IV	3.3	V	1.6	III
Spha plum	1.6	IV	1.6	IV	1.8	V	1.4	III
Eric cine	1.6	IV	2.4	V	0.7	III		
Erio vagi	1.7	IV						
Tric cesp	3.4	V	3.7	V	1.5	III		
Clad impe			1.2	III				
Clad unci	0.7	III						
Camp atro	1.1	III						
Rhac lanu	1.6	IV	1.7	V				
Spha comp	0.7	III						
Spha tene	1.8	IV	1.4	IV				
Dipl albi			1.7	IV				
Odon spha	2.3	IV	1.5	IV				
Pleurozia	1.1	III						
Agro cani			1.1	IV	1.8	IV	2.9	V
Anth odor					0.7	III	2.0	IV
Care echi					2.7	V	1.4	IV
Care nigr					1.1	III		
Cact macu							1.0	III
Desc flex							2.0	IV
Epil palu							1.0	III
Fest ovin			1.0	III	0.8	III	2.0	IV
Gali saxa							2.7	V
Holc lana							1.3	III
Junc acfl					3.2	V	2.3	IV
Junc effu					0.8	III		
Luzu mult							1.6	IV
Myri gale	1.7	III			3.3	V	2.0	IV
Pter aqui					1.1	III		
Succ prat								
Vacc myrt							1.1	III
Viol palu					0.8	III	1.7	IV
Aula palu							1.2	III
Dicr scop					0.7	III		
Plag uncu							1.1	III
Poly comm							1.9	IV
Rhyt squa							1.0	III
Spha palu							2.2	IV
Spha recu					1.5	IV	1.8	IV
Caly fiss							1.3	[illegible]
Ceph bicu							1.0	III
[illegible]							[illegible]	[illegible]

	0100 CALLUNETUM-VULGARIS		0101 NARDO-JUNCETUM SQUARROSI (narthecíosum)		0110 CALLUNETO-ERIOPHORETUM a. typicum		0111 CALLUNETO-ERIOPHORETUM b. moliniosum	
Anthox odo			0.8	III				
Agros cani	2.1	IV	2.8	V	7.3	III	2.0	V
Call vulg	7.5	V	3.6	V	5.7	V	4.7	V
Carex echi			1.9	V				
Carex nigr					2.0	IV		
Desc flex	2.7	IV	2.2	V	3.2	V	3.8	V
Empe nigr	1.2	III	7.7	IV	2.0	IV		
Eric tetr	1.8	IV	7.0	III	2.6	V	2.1	V
Erio angu	1.8	III	3.0	V	2.9	V	1.8	IV
Fest ovin	1.5	III	1.6	IV	1.3	III	1.7	IV
Gali saxa	1.6	IV	1.1	III	1.3	III	2.7	V
Junc squa	2.4	V	3.5	V	2.0	IV	3.1	V
Luzul mult	0.9	III	0.8	III			2.2	V
Moli caer	2.0	III	2.0	III	1.6	III	5.4	V
Narth ossi	1.2	III	3.0	V	1.6	III		
Pote erec	2.4	V	3.0	V	1.8	IV	2.4	V
Tric cesp	3.5	V	3.6	V	4.0	V	2.4	V
Vacc myrt	3.0	V	3.0	V	3.6	V	2.2	V
Clad ompe	0.8	III						
Camp flex	0.9	III	1.2	III	1.4	IV	1.8	V
Dicr scop	1.9	IV	1.0	III	2.5	V	2.1	V
Hypn eric	2.6	V	2.0	IV	2.4	V	1.5	IV
Pleu schr	1.6	III			2.1	IV	2.0	V
Poly comm	1.2	III	2.6	V	3.2	V	2.8	V
Rhyt lore	1.7	IV	1.2	III	2.6	V	1.5	IV
Spha capi	1.3	III	2.1	V	2.9	V	2.0	V
Spha papi	1.6	IV	3.5	V	2.5	V	1.7	IV
Caly fiss			1.4	III				
Care bine	0.9	III						
Care pani	1.2	III	1.9	V				
Junc bulb			1.5	III				
Nard stri	3.2	V	4.5	V	1.7	III		
Viol palu			1.2	III				
Clad chlor	0.8	III						
Clad floc	1.0	III						
Rhac lanu	1.6	III	1.4	III				
Spha auri			1.6	III				
Spha plum			2.0	IV				
Spha tene	0.8	III						
Erio vagi			2.2	IV	4.2	V	3.7	V
Hylo sple					1.0	III		
Plag undu					1.9	IV	1.5	IV
Spha recu			1.5	III	2.2	IV	2.4	V
Caly muel					1.3	III	1.4	IV
Loph vent					1.5	III		
Junc eff							2.0	IV

	10000 NARDO-JUNCETUM SQUARROSI (nardosum)		10001 NARDO-JUNCETUM SQUARROSI (juncosum)		10010 AGROSTO-FESTUCETUM (callunosum)		10011 FESTUCO-MOLINIETUM		1010 NARDUS STRICTA VACCINIUM MYRTILLUS (typicum)		1011 NARDUS STRICTA VACCINIUM MYRTILLUS (low altitude)	
Agro cani	3.5	V	3.4	V	2.4	V	3.0	V	1.9	IV	2.7	V
Agro tenu	3.3	V	2.7	V	3.5	V	1.6	III	2.3	IV	1.2	III
Call vulg			1.5	III	5.4	V					4.7	V
Care bine	1.5	III	1.0	III			1.6	IV			2.5	V
Care pilu	1.3	III			1.5	III			2.0	IV	1.0	III
Desc flex	3.2	V	4.1	V	3.1	V	2.6	V	4.1	V	3.5	V
Fest ovin	3.6	V	3.5	V	4.1	V	3.6	V	3.6	V	2.2	IV
Gali saxa	3.3	V	3.2	V	3.5	V	2.7	V	3.4	V	2.7	V
Junc squa	2.2	IV	3.9	V			2.3	V	1.8	III		
Nard stri	6.2	V	4.0	V	1.8	III	3.4	V	3.5	V	4.7	V
Pote erec	3.0	V	2.0	IV	3.0	V	3.0	V	2.7	V	2.5	V
Tric cesp	1.9	III					2.3	IV			1.5	III
Vacc myrt	3.3	V	2.9	V	3.2	V	3.0	V	4.1	V	4.7	V
Camp flex	1.1	III			1.5	IV	1.7	IV	1.3	III	1.5	III
Dicr scop	1.6	IV	1.0	III	2.8	V			1.5	IV	2.5	V
Hylo sple					1.1	III						
Hypn eric	2.4	V	2.7	V	2.7	V	2.5	V	2.4	V	2.7	V
Pleu schr	1.6	IV	2.5	V	3.1	V	1.4	III	1.7	IV	2.5	IV
Poly comm	2.9	V	3.7	V	2.0	IV	2.0	V	2.4	V	1.7	IV
Anth odo	3.0	V	3.7	V	2.8	V	2.5	V			1.2	III
Care nigr			1.8	III								
Luzul mult	1.8	IV	2.2	V	1.7	IV	2.4	V				
Plag undu			1.7	IV								
Rhyt squa	1.8	IV	2.8	V	2.1	V	1.5	III				
Caly fiss			0.9	III								
Loph cusp			1.3	III	1.4	III						
Blec spic					1.7	IV						
Camp rotu					1.0	III						
Erica cine					2.0	III						
Moli caer					1.0	III	6.5	V				
Oxal acet					1.1	III						
Pter aqui					3.8	IV						
Rum aceto					0.8	III						
Thel limb					1.0	III						
Dich pell					1.0	III						
Pseu puru					1.1	III						
Barb floe					1.1	III						
Carex bigel									1.4	III		
Care pani							1.2	III			1.5	III
Empe nigr									1.7	III	1.7	III
Lyco selg									2.2	V		
Vacc viti									1.0	III		
Clad arbu									1.4	III		
Clad cocc									0.9	III	1.5	IV
Clad chlor											1.7	IV
Clad impe					1.1	III			2.0	IV	2.2	V
Clad unci									1.8	IV	1.7	IV
Rhac lanu									2.7	V	2.7	V
Rhyt lore									1.6	III	1.2	III

	1100		1101		1110		11110		11111	
	SPHAGNETO-JUNCETUM EFFUSI		MOLINIETUM ATLANTICUM (juncosum)		AGROSTO-FESTUCETUM (typicum)		FESTUCO-MOLINIETUM (pteridosum)		AGROSTO-FESTUCETUM (exsudans)	
Agros cani	3.9	V	3.5	V	2.6	V	3.0	V	3.0	V
Agros tenu	2.5	IV	2.1	IV	5.7	V	2.0	IV	3.8	V
Anth odo	3.4	V	3.0	V	3.3	V	3.3	V	3.8	V
Blec spic			1.0	III			2.0	V		
Carex bine			1.5	III			1.6	IV		
Care pani			2.1	V					2.8	V
Cirs palu	1.8	IV	1.8	V			1.6	IV	2.8	V
Desc cesp	1.7	III			1.4	III				
Desc flex	2.0	III			1.4	III	3.6	V		
Fest ovin	1.8	IV	2.8	V	4.5	V	4.0	V	3.6	V
Gali saxa	3.4	V	2.5	V	2.7	V	3.3	V	2.4	V
Holc lana	3.2	V	2.3	IV	2.7	[illegible]			3.2	V
Junc acfl	3.3	V	3.5	V	1.1	III			2.4	V
Junc eff	3.4	V	2.1	V	2.1	IV			1.4	III
Junc squa					1.0	III				
Luzu mult	2.0	V	2.0	V	1.5	III	1.6	IV	2.6	V
Moli caer			5.6	V	1.3	III	4.0	V	2.2	IV
Nard stri	2.2	III	1.6	III	3.1	V			2.6	V
Oxal acet							1.6	IV	1.8	III
Poa prat			1.3	III	1.3	III			1.6	III
Pote erec	2.5	V	3.0	V	2.4	V	2.6	V	3.0	V
Rume aceto	2.2	IV	1.3	III	1.7	IV				
Succ prat			1.5	III			1.6	IV	2.2	V
Trif repe	1.5	III			1.8	IV	1.3	IV	2.6	V
Vacc myrt					1.1	III	2.0	IV		
Atri undu							2.0	V	1.4	III
Hypn eric	1.0	III			1.2	III	1.6	IV	2.6	V
Pleu schr	1.3	III	1.1	III	0.9	III			2.2	IV
Rhyt squa	2.0	IV	1.5	III	2.0	IV	3.0	V	2.2	IV
Cara hola	1.2	III								
Fest rubr	2.3	IV							2.0	IV
Gali palu	1.1	III								
Ranu acri	1.0	III							1.6	IV
Ranu repe	1.1	III			1.4	III			2.4	V
Euph prae	1.0	III								
Phil font	1.2	III					1.6	IV		
Thui tama	1.4	III					1.3	IV	2.0	IV
Loph cusp	1.2	III							1.4	III
Care echi	1.9	IV	2.3	V						
Care nigr	1.4	III								
Epil palu	2.2	V	1.1	III						
Erio angu			1.3	III						
Junc bulb	1.2	III	2.0	V					1.6	IV
Junc congl	1.0	III							1.6	III
Myri gale			2.5	V						
Ranu flam			1.1	III						
Viol palu	2.2	V	2.3	V						
Camp flex			1.5	IV						
Dicr hete			1.5	IV						
Minu horn			1.0	III						
Pohl nuta			1.3	IV			1.3	IV		
Poly comm	2.9	V	2.1	V	0.9	III	2.3	V		
Spha palu	1.5	IV	1.5	IV			1.3	IV		
Spha papi			2.5	V						
Spha recu	1.4	III	1.1	III						
Achi mille							1.6	IV	1.6	III
Call vulg			1.6	III			2.0	IV	5.2	V
Care pilu									2.2	IV
Euph offic					0.9	III	1.3	IV	2.4	V
Pter aqui							4.3	IV	3.2	V
Sieg decu			1.5	III	1.3	III			2.2	IV
Thel limb							2.6	IV		
Viol rivi							1.3	IV	2.4	[illegible]
Dicr scop							1.6	IV	2.4	V
Pseu puru					1.5	III	3.0	V	[illegible]	V

Add to group 11111

Achi. pta.	1.6	IV	Lys. nim.	1.4	III
Briza.	1.6	IV	Pimp. sax.	1.4	III
Camp. rot.	2.2	V	Prun. vulg.	2.4	V
Gal. ver.	1.6	III	Salix aur.	1.6	IV
Linum cath.	1.6	IV	Thym. dru.	1.6	III
			Pell. epi.	1.4	III

Add to group 11110

Athyrium	IV	2.0	Acr. cusp.
Bryo. f.-m.	IV	1.3	Bryo. pseu.
Luz. sylv.	IV	1.3	Plag. und.
Plant. lanc.	IV	1.6	

Appendix 4

PROCEDURES ADOPTED FOR PREPARATION AND ANALYSIS OF SOIL SAMPLES

1. Storage of fresh samples

Samples were received at Merlewood in consignments of varying size and immediately put into cold storage.

Consignment No.	Name	Site numbers	Sampling dates 1975	Samples into cold storage	Samples air dried between
1	Newton Stewart I	1-12	15.7-24.7	26.7	6.8-15.8
2	Newton Stewart II	13-30	25.7-9.8	15.8	5.9-19.9
3	Dumfries	31-42	10.8-14.8	15.8	20.9-27.9
4	R.vox	45-62	25.8-4.9	5.9	28.9-19.10

Table 1. Storage dates to indicate sample freshness

N.B. Sampling dates are approximate, exact dates on field sheets. Some samples from some of sites 1-12 were in consignment 2 and therefore laboratory processing of all the samples from these particular sites was delayed. The consignment name indicates only the base used by the field workers and not the sampling district.

Samples from consignments 1 and 2 were taken from cold storage and sorted and dried in order, but consignments 3 and 4 were sorted in numerical order. Such organisation facilitates sample handling in general, and checking on sample labelling in particular.

2. Sample sorting

Fresh samples were tipped from the polythene bags into shallow aluminium or stainless steel trays (sizes from 18 x 20 cm to 25 x 31 cm). Sods were broken up and any above-ground material was discarded if it had obviously been alive prior to sample collection. Live roots greater than 1 mm in diameter were discarded (i.e. roots in categories 2 to 5 on the field sheet). Any roots which were less than 1 mm in diameter or were obviously dead were left in the sample. Large stones bigger than about 3 cm in diameter were removed. The remaining material was spread over one or more trays so that it was less than about 3 cm in depth.

Ideally, all roots should be removed from samples prior to chemical analysis. This was not possible with Project 368 samples. 1 mm diameter seemed to be a suitable lower limit for the size of roots removed, because roots larger than this could be removed with ease manually whereas the smaller roots die and begin to decompose quickly naturally and in storage, thus creating a sorting problem if we had chosen to remove them.

3. Field sheet entries

Field entries were checked in the laboratory where possible. Texture was the only characteristic which could be considered unaltered by sampling and storage so the field entry for this was the entry most frequently altered in the laboratory. The most frequent difference between field and laboratory textural diagnoses was on the question of organic matter versus silt/clay contents. Differences in assessment of colour also became apparent but the field assessment was usually taken as correct because (a) colour vision is known to differ between individuals so that a field colour assessment bears an unknown relationship to laboratory colour assessment; and (b) sample colour, particularly that of organic-rich wet samples, changes during storage.

If large earthworms were observed in a numbered soil layer during sorting the appropriate field entry was altered if necessary. Other earthworms were mentioned in the comments section. The division between "small" and "large" in the laboratory was 3 cm in length, but, in field descriptions, this division was not defined clearly. In general, a field entry was altered only if the laboratory worker thought that the field-worker was out by a considerable amount or if the error was in the reverse direction to the effect of sampling and storage, e.g. storage is unlikely to make a sample wetter. When such alterations were made, the incorrect tick was not rubbed out but a large cross put over it and the new tick put in the appropriate box.

The laboratory worker also entered root information. In the early stages of sorting there was discussion and cross-reference between workers to ensure a uniform assessment of frequency and type. If an H layer had occurred in the profile and only the depth had been recorded, the other characteristics were assessed in the laboratory. This was to allow the H layer to be treated as a numbered layer during computing. Any other relevant general information was written on the sheets, usually in the comments section. Because the appropriate field sheets were not available at Merlewood at the time of sorting, sites 46 and 47 were described fully in the laboratory. These laboratory descriptions, made completely independently of the field descriptions, were found subsequently to agree well with the original field descriptions.

4. pH

Sub-samples of moist soil or LF material were taken from the corners and the middle of each tray and transferred to a 100 ml glass beaker. Sufficient sample was taken so that, after sample wetting, the beaker was about half full. Measurement was made within two days of the sample drying dates given in Table 1. 30-60 minutes before measurement, de-ionised water was added to the beaker so that, after stirring, the sample was just saturated with no standing water on its surface. This approximately 1:1 dilution by volume gave the mineral soils and peats a pasty consistency. It was often necessary to use scissors to chop the L/F samples before wetting. Note that our 1:1 dilution is different from some published so-called 1:1 dilutions which involve adding x cm depth of water to x cm depth of soil. Particularly for poorly buffered soils, it is important to add the minimal quantity of water required to give a pH reading, as in our method, if a pH near to the natural field pH is to be recorded.

Measurement was made using glass and reference electrodes in conjunction with an EIL 38B meter and a temperature compensation probe. Before beginning measurements, meter calibration was adjusted using BDH standard buffer solutions of pH 4 and pH 7. After approximately every four measurements, calibration was checked using the pH 4 buffer. Care was taken to immerse the electrodes to a uniform depth throughout calibration and measurement. On an average, about three measurements were taken per sample to ensure an accurate stable reading. Due to sample shortage, about fifty pH samples had to be returned to the appropriate main sample for drying, and subsequent chemical analysis.

5. Drying

On the day of sorting, the samples in metal trays (see 2) were put into a 1.4 m^3 Unitherm Drying Oven. Air recirculation was set at 90 per cent and temperature at 40°C. Samples were removed and bagged after 48 hours. On two occasions, the oven over-shot and the temperature reached about 65°, but in both cases this was for no more than two hours.

6. Sample grinding and sieving

About 65 per cent of samples were put through the Christie and Norris hammer mill, fitted with a 0.7 mm sieve. This machine was preferred because it was easiest and quickest to use, but its use was limited to organic-rich samples. Small organic-rich samples (about 1 per cent of all samples) were put through the Glen Creston micro-hammer mill to facilitate high retrieval. Mineral-rich samples were put through the Merlewood-built roller-sieve which consists of revolving, perforated steel drums into which are placed the sample and two heavy steel rollers. Material falling through the 2 mm perforations was saved for analysis. Roots less than 1 mm in diameter were separated from the mineral material remaining in the drum for sieving, and then chopped with scissors or put through the Glen Creston before being included for analysis. When necessary, material from all machines was sub-sampled by quartering on Bristol Board with a 30 cm ruler so that one 50 cm^3 tub could be filled with material from each sample. Remaining material was re-bagged for storage and tubs batched in groups of 25 before being submitted for analysis.

7. Approximate time spent in soil processing

Sorting, pHing and drying	85 man days
Grinding and sieving	40 man days
Total	125 man days

8. Chemical analysis

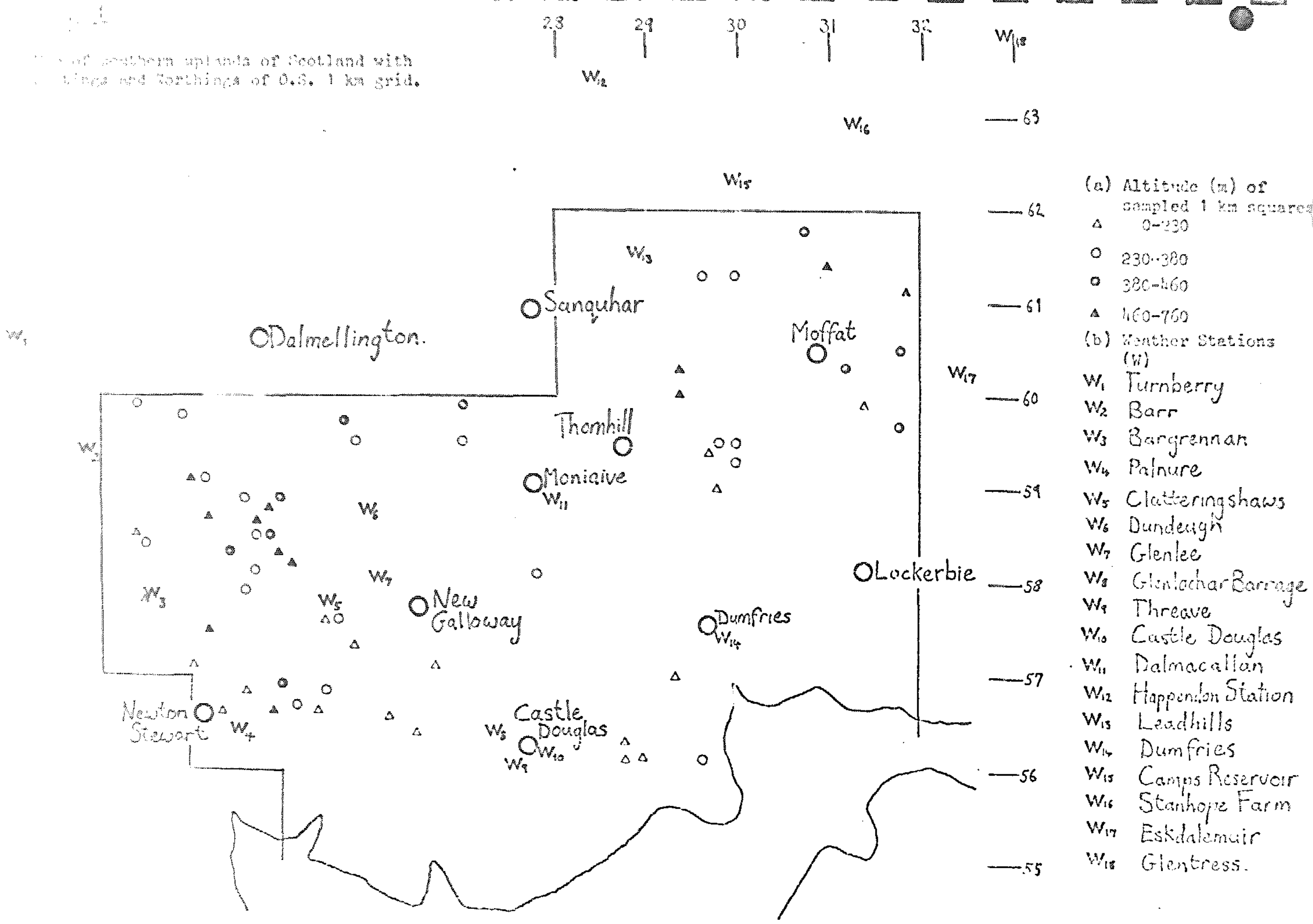
Loss on ignition was determined by ashing dried, milled and weighed sub-samples of LF material or other soil layers at 550°C for two hours. Total nitrogen was determined using a Kjeldahl digestion with mercuric oxide as a catalyst followed by a colorimetric method using indophenol blue in the Autoanalyser (Allen et al, 1974). Total phosphorus was determined using a nitric, perchloric and sulphuric acid digestion followed by an adaptation of the phosphomolybdovanadate method (Kitson and Mellon, 1944) in the Autoanalyser.

References

Allen, S. E., Grimshaw, H. M., Parkinson, J. A. and Quarmby, C. (1974) Chemical analysis of ecological materials. 192-3. Oxford-London-Edinburgh: Blackwell Scientific Publications.

Kitson, R. E. and Mellon, M. G. (1944) Ind. Engng. Chem. analyt. Edn. 16, 379.

... of southern uplands of Scotland with
... tings and Northings of O.S. 1 km grid.



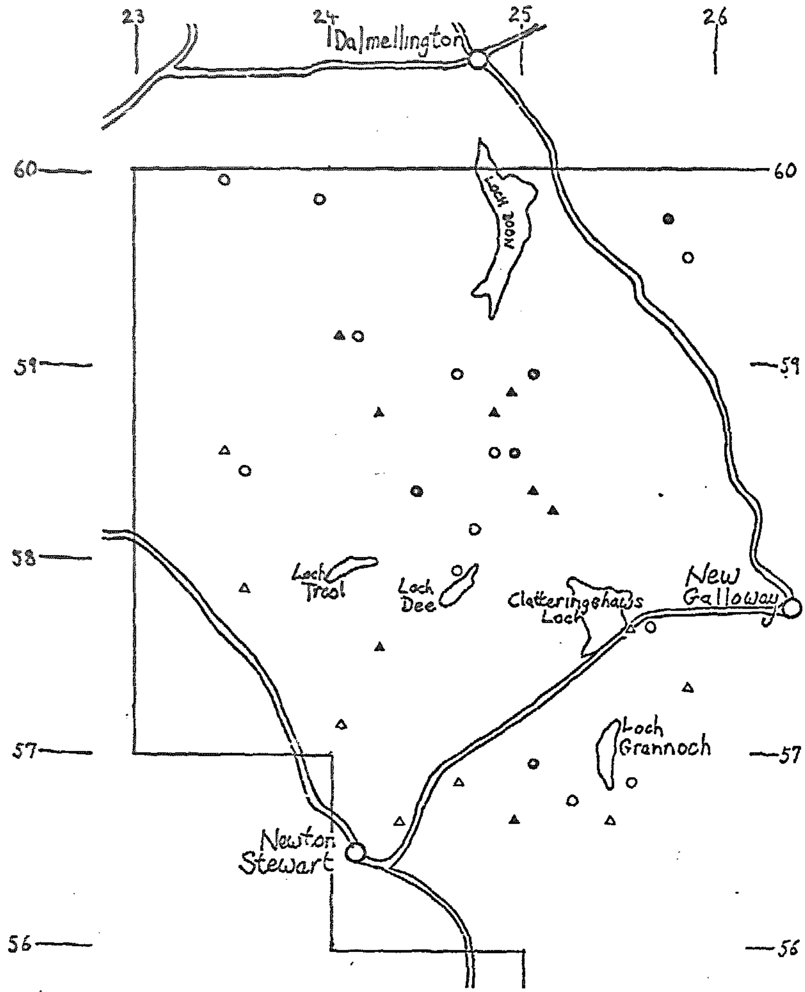


Fig. 2

Enlarged map of western section of study area in Southern Uplands of Scotland giving Eastings and Northings of O.S. 1 km grid.

Altitude (m) of sampled 1 km squares

△ 0-230

○ 230-380

◉ 380-460

▲ 460-760

Fig. 3 Ordination of unafforested stands by multiple discriminant analysis, canonical axes 1 and 2. Dotted lines refer to the environmental groups defined in Fig. 9 below. Also shown are the mean positions of the vegetation types, numbered as follows.

1. Sphagneto-Juncetum effusi
2. Molinietum atlanticum
   a. myricosum, b. agrostidosum, c. juncosum
3. Molinieto-Callunetum
   a. typicum, b. moliniosum
4. Calluneto-Eriophoretum
   a. typicum, b. moliniosum
5. Nardus stricta-Vaccinium myrtillus
   a. typicum, b. low altitude facies
6. Nardo-Juncetum squarrosi
   a. nardosum, b. juncosum, c. nartheciosum
7. Agrosto-Festucetum
   a. typicum, b. callunosum, c. exsudans
8. Festuco-Molinietum
   a. typicum, b. pteridosum
9. Callunetum vulgaris

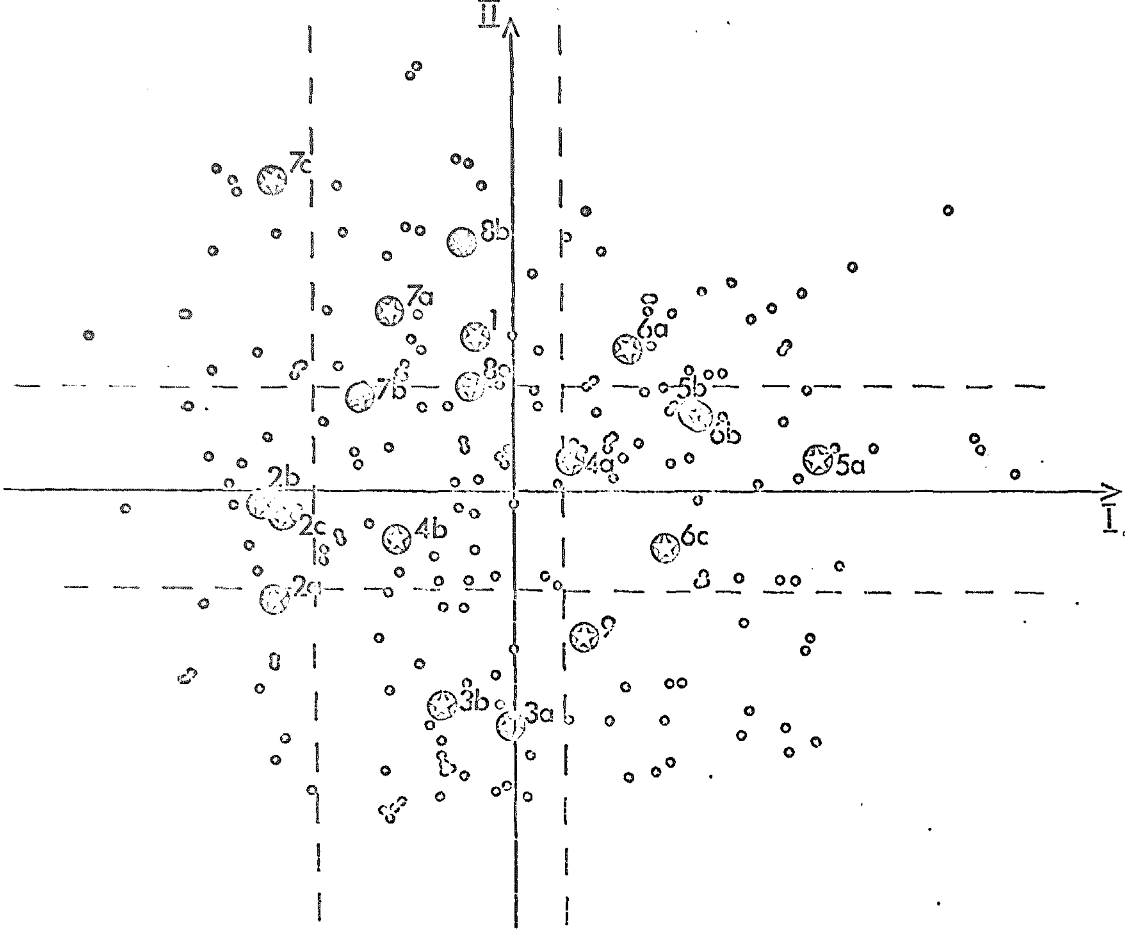


Fig. 3 (see legend on previous sheet)

Fig. 4 Afforested stands, ordination by multiple discriminant analysis. Axes and scale are as in Fig. 3

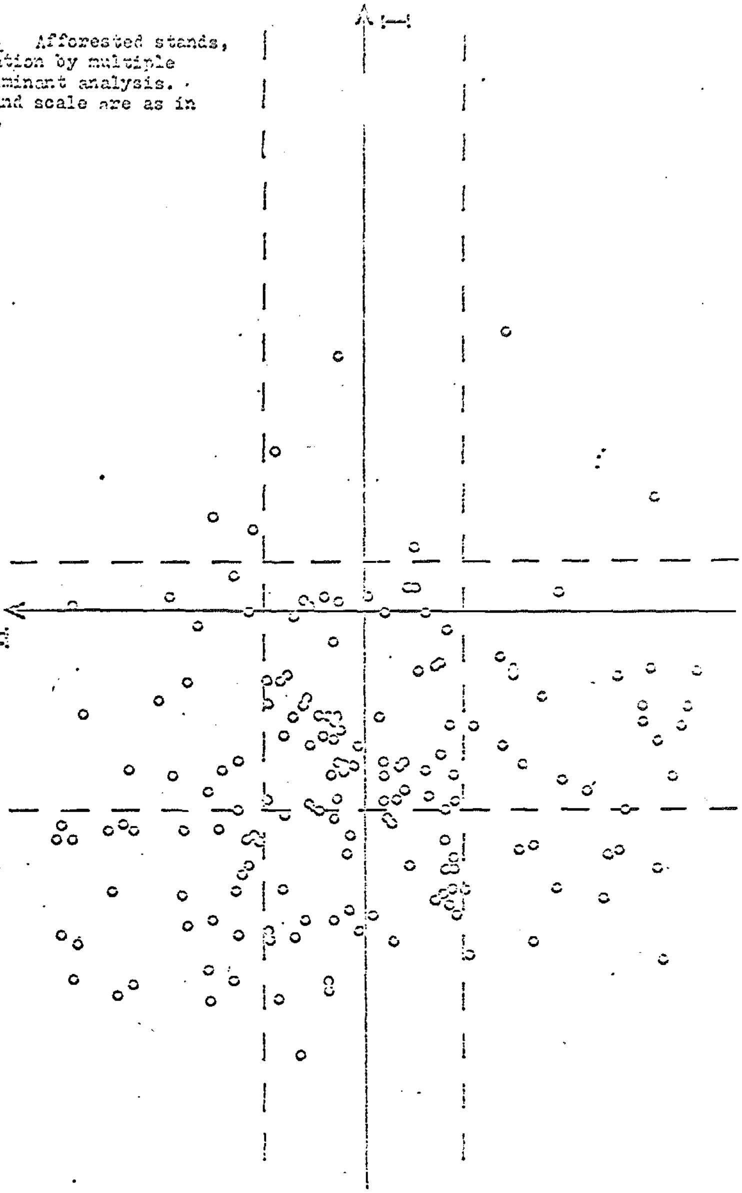


Fig. 5 Unafforested stands, ordination by multiple discriminant analysis showing scatter of points in vegetation types 1,4a and 4b. Axes, scale and numbering are as in Fig. 3

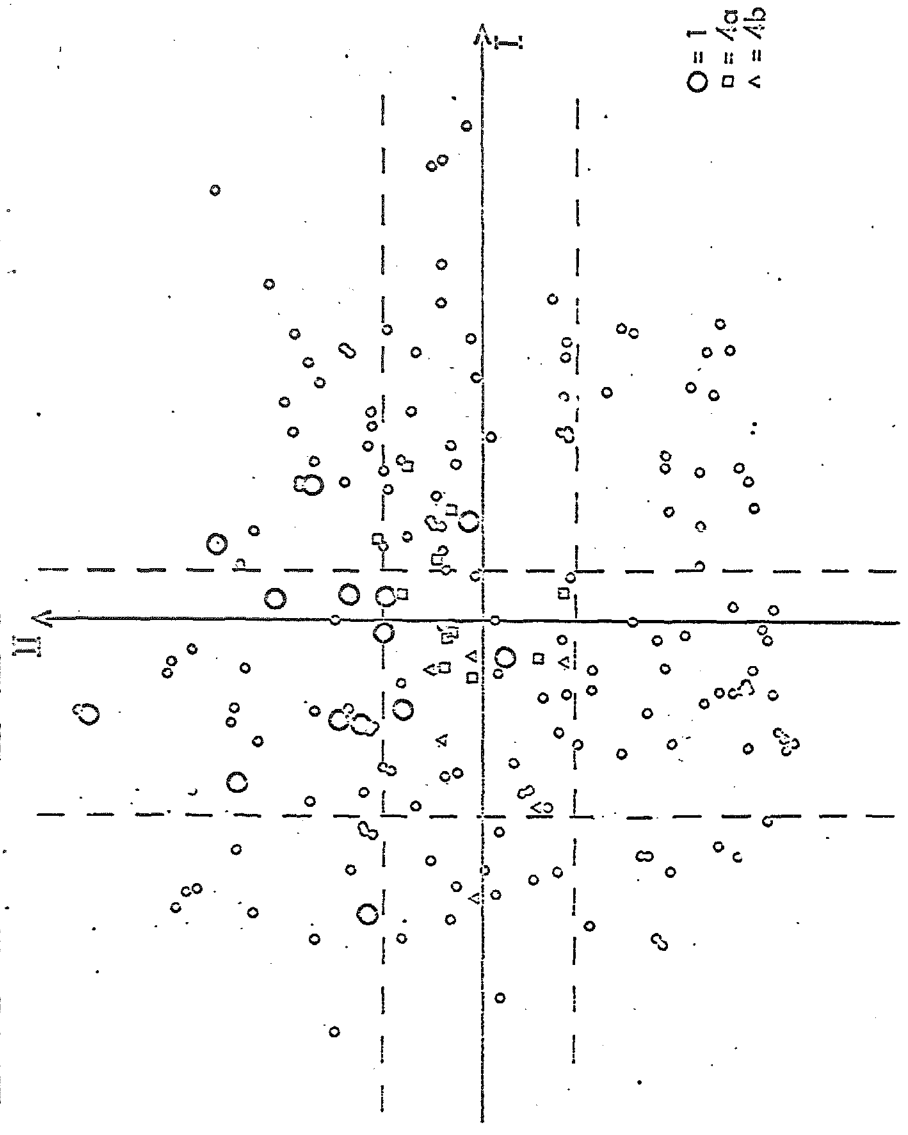


Fig. 6 Unafforested stands, ordination by multiple discriminant analysis showing scatter of points in vegetation types 2 and 5. Axes, scale and numbering are as in Fig. 5.

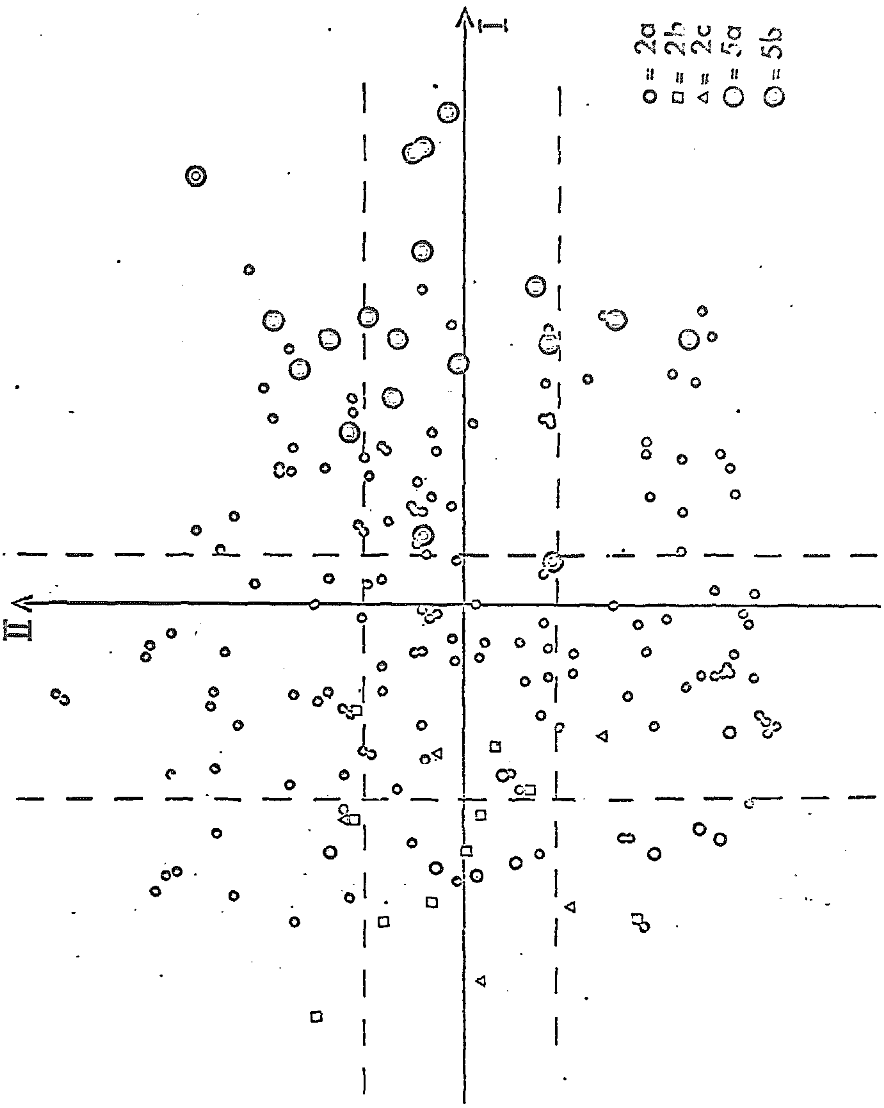


Fig. 7. Unafforested stands, ordination by multiple discriminant analysis showing scatter of points in vegetation types 3 and 7. Axes, scale and numbering are as in Fig. 3.

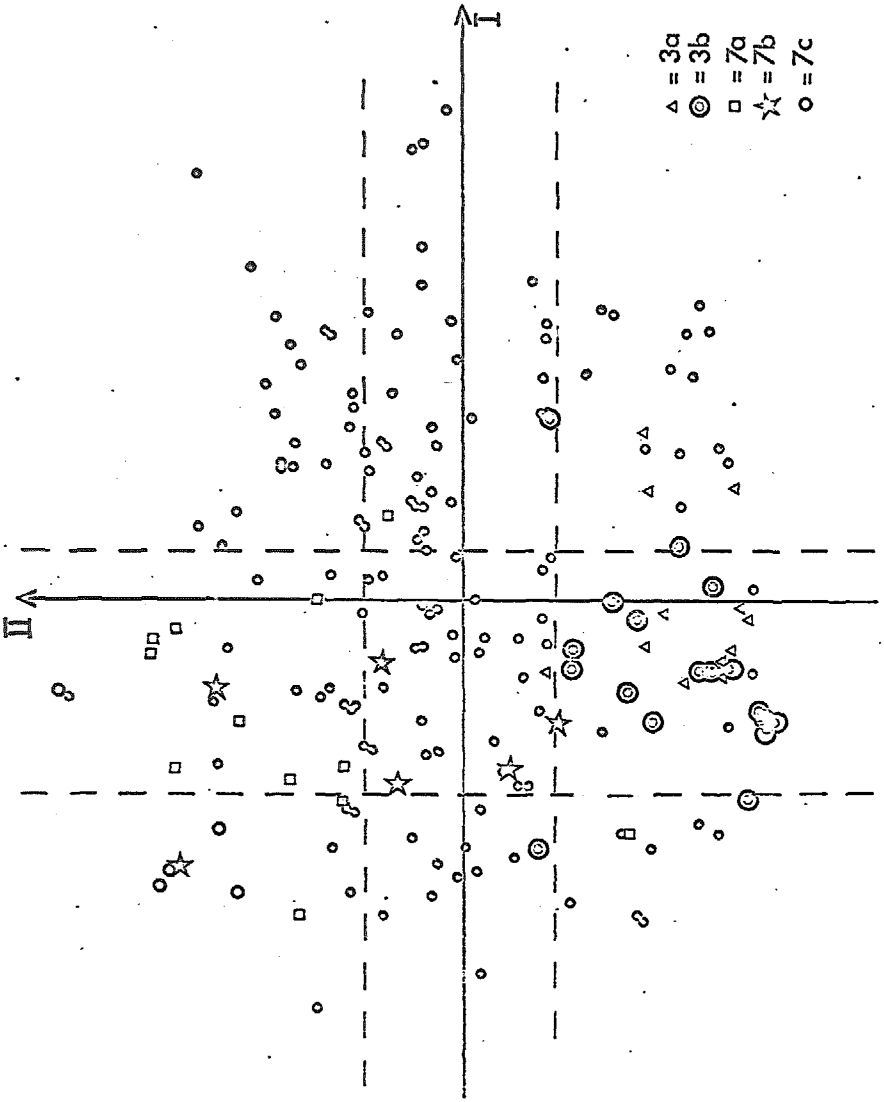


Fig. 8 Unafforested stands, ordination by multiple discriminant analysis showing scatter of points in vegetation types 6, 8 and 9 Axes, scale and numbering are as in Fig. 3.

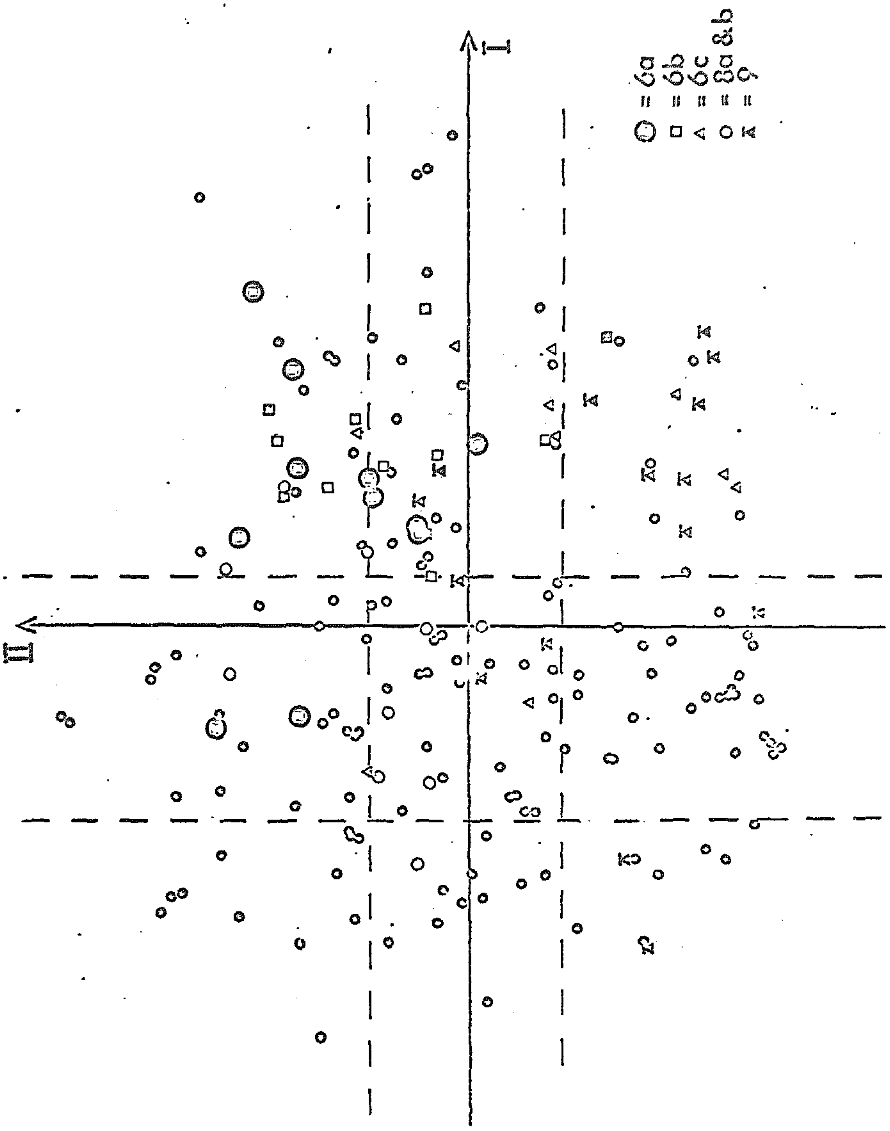


Fig. 9 Unafforested stands, demarcation of environmental types on ordination by multiple discriminant analysis, canonical axes 1 and 2. Boundaries between the nine environmental types are demarcated by dotted lines, and their relation to the vegetation types can be judged by comparison with Figs. 5-8. Numbering of environmental types is not related to that of the vegetation types.

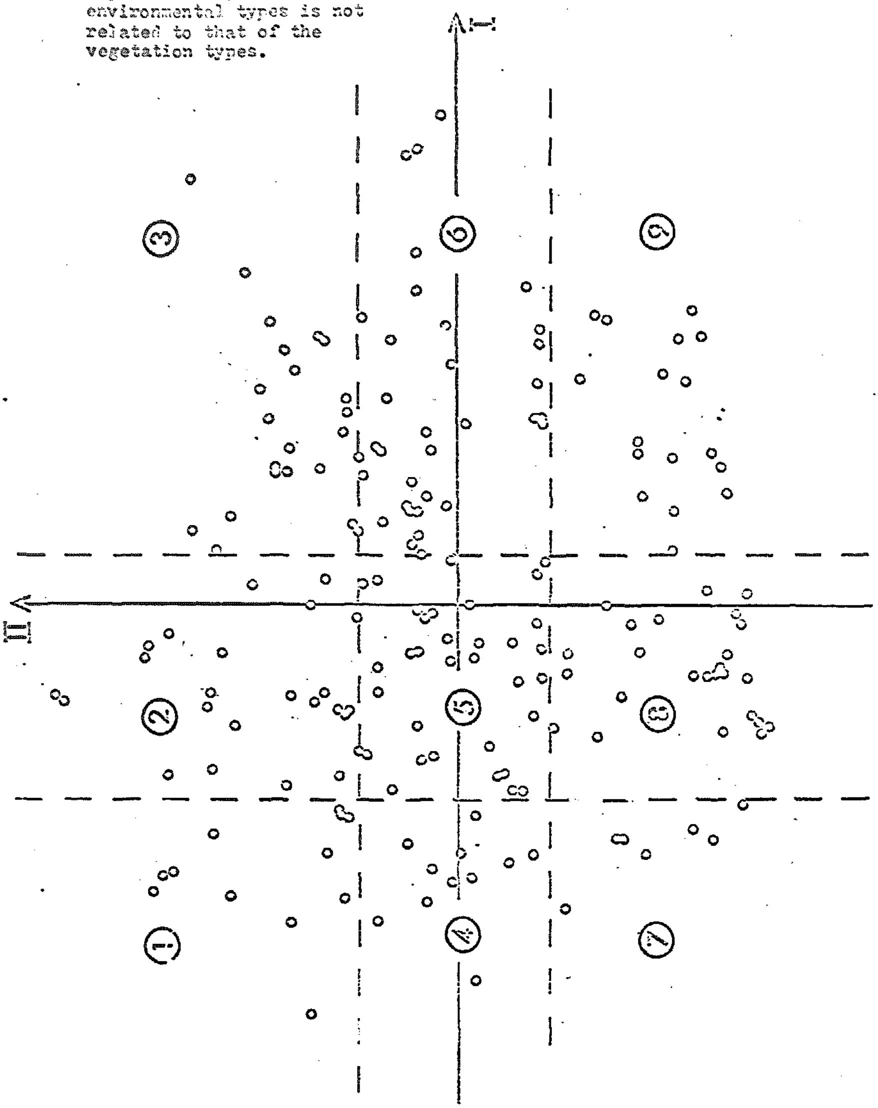


Fig. 10 Mean numbers of species per plot, summarized by environmental category and age class

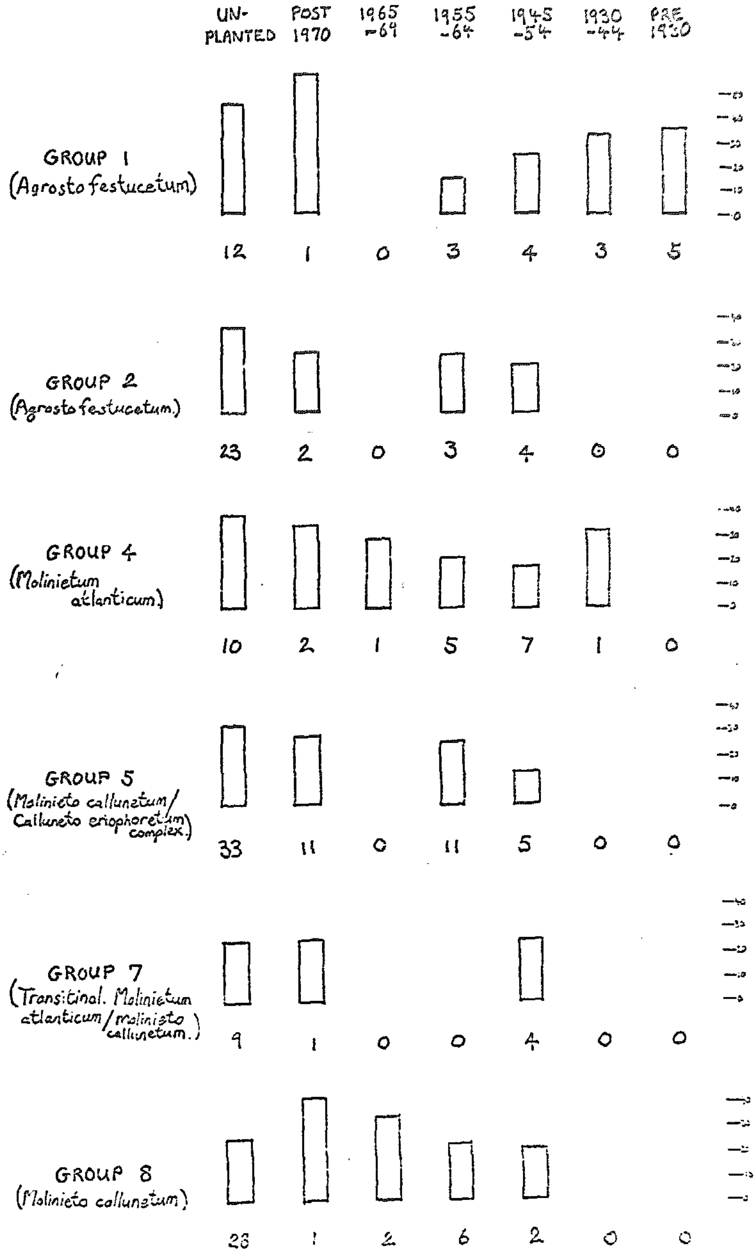


Fig. 11 Mean numbers of species per plot and mean cover-abundance (domin scale, selected species), summarized by age class

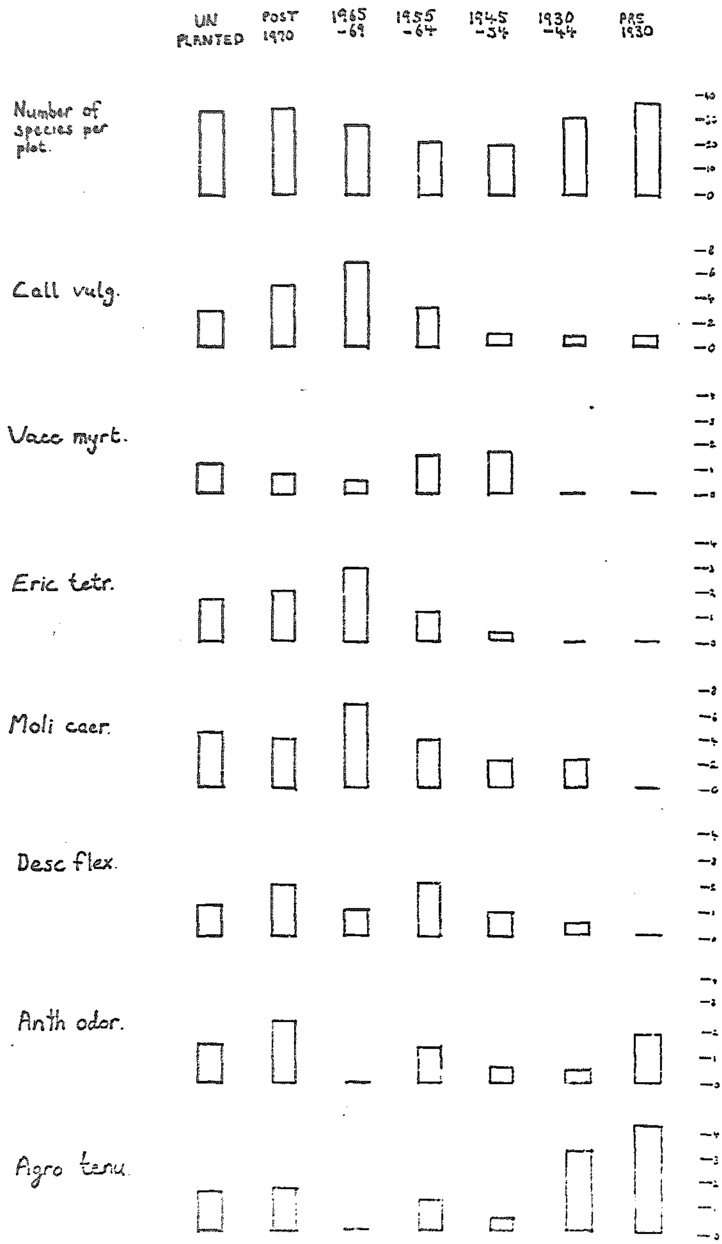


Fig. 12 Mean cover-abundance (domin scale) of selected species, summarized by age class (continuation of Fig. 11)

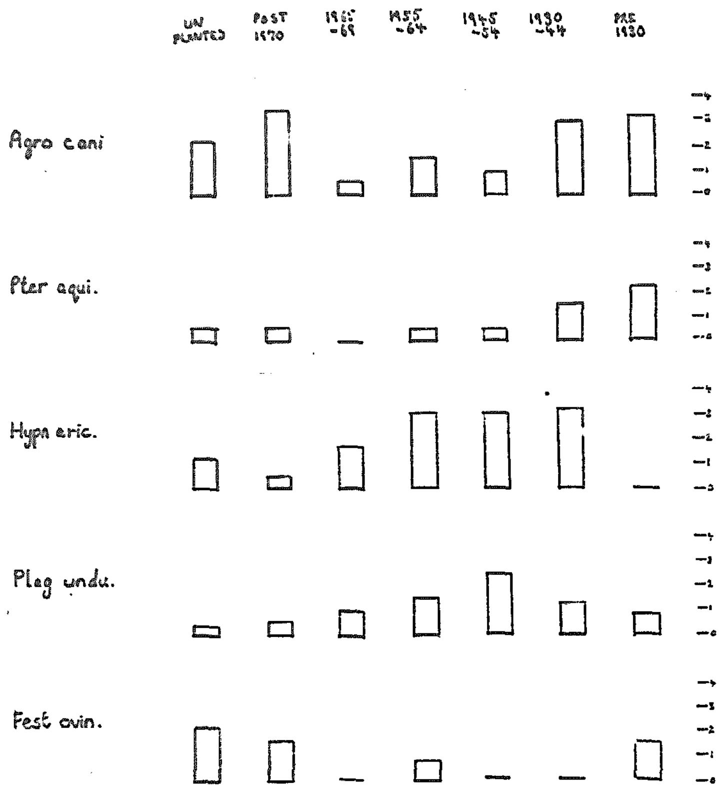


Fig. 15 Streamsides and rides: species numbers in special habitats plotted against mean numbers in regular plots in same 1 km square.

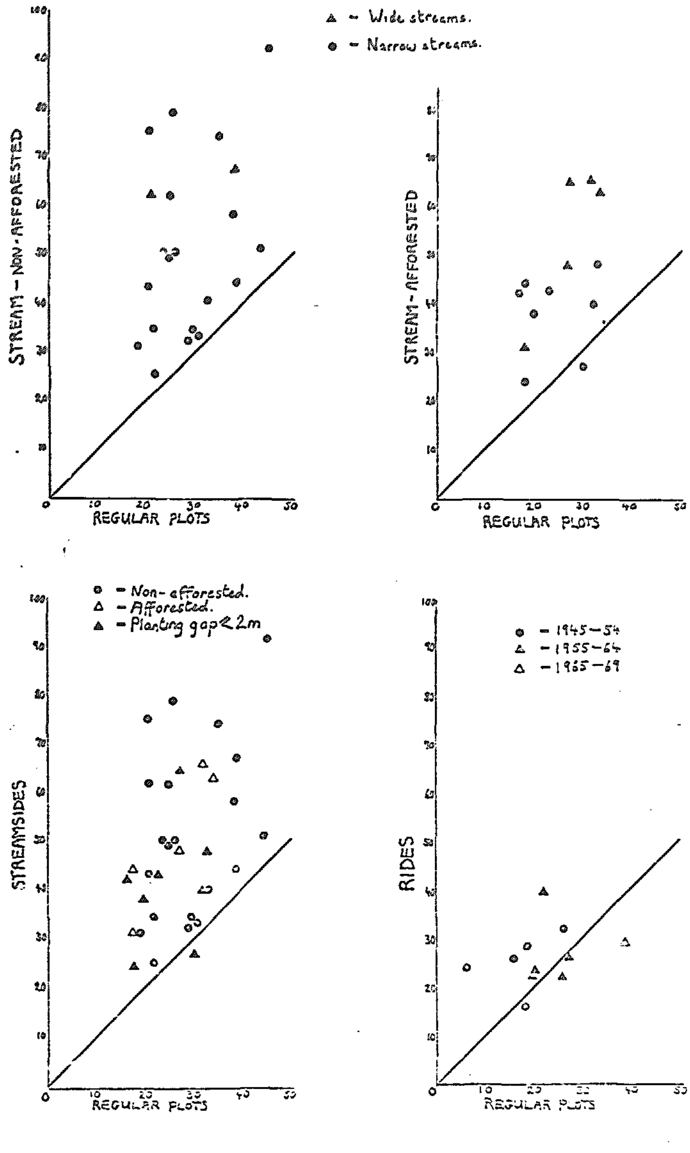
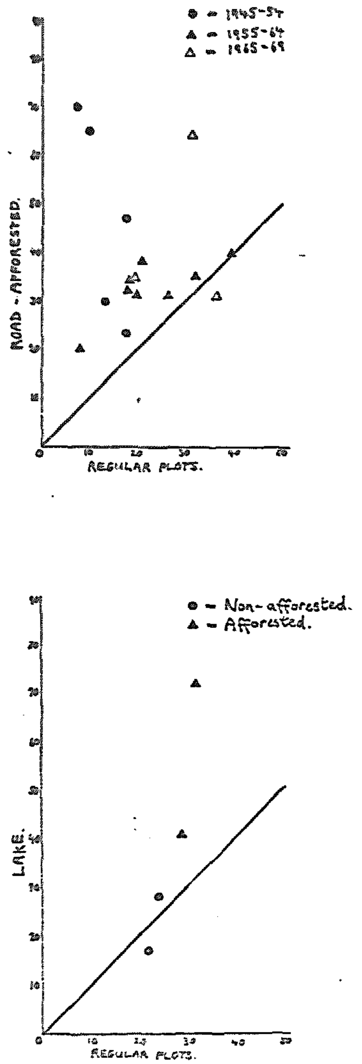


Fig. 14 Roads and lakesides: species numbers in special habitats plotted against mean numbers in regular plots in same 1 km square.



Mean values and ranges of environmental variables for the nine groups of unafforested sites created by sub-division of the ordination diagram (Fig. 9).

Altitude

1	192	374	578	3
4	144	326	551	6
7	141	305	515	9

38–244	198–564	472–686
130–213	130–465	387–792
99–183	244–396	137–655

Site drainage

1.4	2.2	2.7
4.0	3.2	2.7
3.5	3.4	2.8

1,2,3	1,2,3,5	1,2,3,4,5
3,4,5	1,2,3,4,5	1,2,3,4,5
3,4	2,3,4,5.	1,2,3,4,5

Moisture*

2.0	2.0	2.3
3.1	2.6	2.3
2.7	2.9	2.4

1,2,3,4	1,2,3,4	2,3,4
2,3,4	1,2,3,4	2,3,4
2,3,4	2,3,4	2,3,4

% LoI*

16.0	29.0	34.5
68.9	63.6	49.3
76.8	66.5	49.2

4.2–45.2	3.2–94.3	8.3–89.8
18.1–96.6	3.2–97.5	6.1–96.9
11.0–95.0	3.0–98.4	7.9–92.6

Texture*

3.8	3.3	1.8
1.4	1.7	1.9
1.1	1.2	1.8

1,3,5	1,2,3,5	1,2,3
1,3	1,2,3,5	1,2,3,4,5
1,2	1,2,3	1,2,5

Stoniness*

2.0	2.1	1.8
1.0	1.3	1.7
1.0	1.1	1.7

1,2,3	1,2,3	1,2,3
1	1,2,3	1,2,3
1	1,2,3	1,2,3

* Of the lowest layer usually down to 30 cm. LoI on an O.D. wt basis.

Fig. 15 (continued)

1	1·5	2·3	3·0	3
4	2·8	3·2	3·8	6
7	1·6	3·3	2·9	9

LF thickness (cm)

0-5	0-6	0-7
1-5	0-9	0-9
0-5	0-9	0-7

4·1	4·4	3·8
4·4	3·6	3·7
3·4	3·8	3·8

4·6	4·7	4·1
4·3	3·8	4·0
3·8	3·9	4·1

4·7	4·6	3·8
4·4	3·8	3·7
3·7	3·9	3·9

weighted mean pH* whole profile

3·3-5·2	3·3-7·6	3·3-4·7
3·5-5·3	3·1-5·1	3·1-4·5
3·3-4·1	3·3-4·9	3·2-5·0

pH of LF*

4·1-5·6	3·5-5·8	3·4-4·9
3·6-5·2	3·2-5·2	3·1-4·9
3·5-4·1	3·5-4·6	3·6-5·3

pH of layer 1*

3·8-6·5	3·4-6·5	3·2-5·0
3·5-5·3	3·1-5·2	3·1-4·7
3·2-4·1	3·3-4·7	3·2-4·9

* Arithmetic mean

Fig. 15 (continued)

1	1·88	1·76	1·74	3
4	1·78	1·66	2·02	6
7	1·73	1·75	1·85	9

1·00	1·22	1·22
2·09	1·83	1·67
1·95	1·86	1·88

% N of LF*

% N of layer 1*

1·37-2·17	0·92-2·31	0·66-2·41
1·17-2·32	0·70-2·49	1·06-2·50
1·39-2·12	1·22-2·34	1·36-2·62

0·09-2·17	0·06-2·53	0·41-2·51
0·98-2·72	0·08-3·02	0·46-3·57
1·59-3·37	0·43-3·12	0·36-2·58

0·170	0·155	0·107
0·094	0·108	0·116
0·072	0·059	0·087

0·130	0·142	0·117
0·106	0·117	0·115
0·078	0·070	0·101

% P of LF*

% P of layer 1*

0·092-0·347	0·090-0·279	0·061-0·143
0·039-0·189	0·043-0·211	0·058-0·184
0·067-0·077	0·033-0·152	0·053-0·162

0·077-0·347	0·045-0·335	0·062-0·207
0·055-0·169	0·020-0·337	0·044-0·217
0·045-0·129	0·014-0·163	0·024-0·165

* O.D. wt basis

Table 7. Mean environmental characteristics of the age sub-groups within groups.

Groups three, six and nine are not included here because they contain too few data.

Environmental Group	Age of stand (yrs)	Altitude (m)	Site drainage *a*	Moisture on sampling *b*	% LOI of lowest layer *c*	Texture *b*	Stoniness *b*	LF thickness (cm)	pH LF *d*	pH Layer 1 *d*	% N LF *c*	% N Layer 1 *c*	% P LF *c*	% P Layer 1 *c*
1	U	192	1.4	2.0	16.0	3.8	2.0	1.5	4.6	4.7	1.88	1.00	0.170	0.130
	0-10	290	2.0	3.0	5.0	3.0	2.0	1.0	5.5	5.3	0.93	0.72	0.130	0.112
	10-20	236	2.0	1.3	16.3	5.0	2.3	2.3	5.0	4.0	1.54	0.93	0.251	0.103
	20-30	208	2.5	2.0	10.9	4.5	1.8	3.5	3.9	4.1	1.49	1.48	0.102	0.097
	30-45	64	1.0	1.3	14.7	5.0	2.0	2.3	3.9	4.2	1.72	0.62	0.128	0.128
	45-60	96	1.5	1.4	9.2	4.0	2.0	4.6	4.6	4.4	1.39	1.00	0.109	0.094
2	U	374	2.2	2.0	29.0	3.3	2.1	2.3	4.7	4.6	1.76	1.22	0.155	0.142
	0-10	381	2.0	2.0	32.9	3.0	2.5	4.0	5.5	3.5	1.59	0.93	0.159	0.117
	10-20	343	1.5	1.3	35.9	3.7	2.3	6.3	5.0	3.4	1.82	1.16	0.166	0.115
	20-30	253	2.8	2.0	15.6	2.0	2.0	4.0	3.9	3.5	1.59	1.84	0.104	0.096

Table 7 (continued)

4	U	174	4.0	3.1	68.9	1.4	1.0	2.8	4.3	4.4	1.78	2.09	0.094	0.106
	0-10	140	3.3	2.7	63.8	1.3	1.3	4.7	4.6	4.1	1.60	1.55	0.104	0.062
	10-20	163	1.8	2.4	16.3	3.0	1.6	3.2	3.9	3.8	1.78	1.58	0.110	0.062
	20-30	160	1.5	1.7	49.5	2.3	1.6	4.4	3.6	3.6	1.66	1.38	0.101	0.120
	30-45	38	2.0	3.0	30.5	5.0	2.0	0	-	4.3	-	0.81	-	0.085
	45-60	63	1.7	1.8	22.3	4.0	1.3	2.0	3.9	4.0	1.80	0.72	0.100	0.095
5	U	326	3.2	2.6	63.6	1.7	1.3	3.2	3.8	3.8	1.66	1.83	0.108	0.117
	0-10	340	3.5	2.7	86.8	1.3	1.1	6.2	3.9	3.5	1.71	2.16	0.139	0.123
	10-20	297	3.2	2.4	51.9	1.6	1.5	4.7	4.3	3.8	1.76	1.82	0.171	0.110
	20-30	297	3.6	2.6	72.7	1.6	1.2	4.5	3.6	3.5	1.33	2.17	0.112	0.143
7	U	141	3.5	2.7	76.8	1.1	1.0	1.6	3.8	3.7	1.73	1.95	0.072	0.078
	0-10	168	4.0	2.0	92.8	1.0	1.0	5.0	4.2	3.2	2.00	2.20	0.099	0.067
	20-30	133	3.0	2.3	68.2	2.0	1.3	4.5	3.8	3.9	1.71	2.25	0.114	0.104
8	U	305	3.4	2.9	66.5	1.2	1.1	3.3	3.9	3.9	1.75	1.86	0.059	0.070
	0-10	290	2.7	2.7	94.2	1.0	1.0	3.7	3.8	3.7	1.69	2.32	0.075	0.065
	10-20	264	2.3	2.2	56.4	1.8	1.2	3.7	4.2	3.4	1.80	1.78	0.116	0.062
	20-30	301	4.0	2.5	96.2	1.0	1.0	5.0	3.5	3.0	1.14	2.28	0.103	0.128

a Ranges from 1 well-drained to 5 very poorly drained

b Grades as on soil recording form (Appendix 2)

c Oven-dry weight basis

d Arithmetic mean

U unplanted