ITE 522

ECOLOGY OF VEGETATION CHANGE IN UPLAND LANDSCAPES

by

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This is a <u>draft</u> summary and interpretation of the study done by ITE under the NERC/DOE contract DGR/483/23. It is intended for publication by ITE. Comments are welcomed, especially in relation to the interpretation and implications of the results. The final draft will be completed by 31 March 1981. Full details of the study are being published as two ITE Bangor Occasional Papers.

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"Comments are welcomed" - well I have four:-

1. Reads very well, sounds OK or I liked it - words to that effect but

2. Pages 45-46 - moorland marginals while I can accept that 11% of the area has been subject to fulctuating change in use in the last 200 years I am not happy with the inference that this will continue. If the fluctuation in use has been caused by osilllation in social and physical environmental factors then stabilization of the oscillation could lead to a long term trend and ultimately to a new equilibrium state. Indeed the last 200 years could be regarded as an equilibrium state resulting from past pressures becoming stabilized - which is in effect what you are sgying. Would a longer historical perspective help? What was the extnet of the moor at the tillage maximum (circa 1300 AD) - my impression is that it was very much less than now but possibly there are archaelogical features or documentary evidence spatially distributed such that the next land class at risk, presuming stablézation of environmental factors, could be indentified?

3. Pages 46-47 Shrub heath and Bracken are mentioned but my impression is that moorland fringe/marginals often have greater extents of Nardus grassland. As it is this marginal land on which usages come and go then Nardus communities may be assumed to be at a greater level of risk. They are rich in species (159 in class 16, see page 11) and therefore of conservation interest - but possibly it is this disturbance factor which causes the richness? Some dicussion of this might find a place under the title Vegetation Change on the Moor?

4. Finally I must say I missed any discussion of the factors controlling rates of change. There is great local variation in climate, aspect affects temperature and length of growing season, topagraphy affects rainfall etc. but I didn't see this mentioned. No did I see any comparison between moorland areas - my impression - very subjective - is that south-western moors - Bodmin, Dartmoor, Exmoor, are low, level plateaux or domes while Wales and the Pennine/Cheviot lot are higher and more dissected - they would show more fine grain pattern and perhaps be less at risk.

Well at least I showed willing.

Max Hooper
18 February 1981

C O N T E N T S

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INTRODUCTION

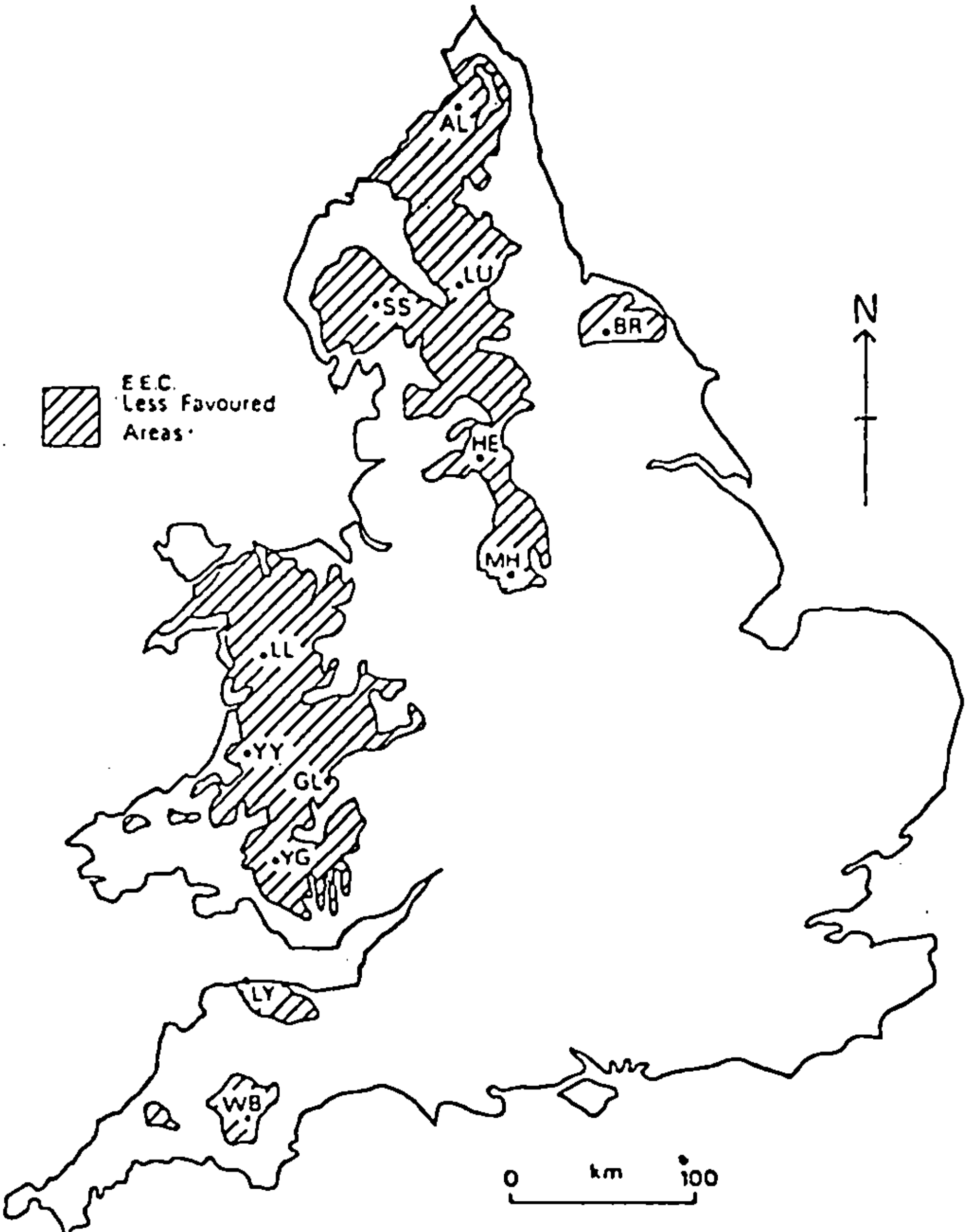
The traditional upland landscapes of England and Wales are based on the geological formations moulded by glaciation, water and climate to produce the varied landform of hills and valleys. Superimposed on the geology, the soil development has produced a varied pattern of vegetation which in turn has been modified by man. The intensity of his influence is seen in the associated development of walls, hedges and buildings. Thus the landscape pattern and form has been developed through a number of interacting factors, over varying time scales.

The pattern and composition of the landscape is, however, not static. Changes in land use, such as agricultural improvement of moorland, afforestation and reservoir construction, have a rapid and obvious effect on the landscape. Less obvious and more gradual change in the landscape occurs through the vegetation succession induced by changes in land use such as reduction in fertiliser use, alteration in stocking density or burning frequency. Other gradual changes in vegetation occur through natural successions and cycles associated with the ageing of plants, with soil development or with exceptional events such as a fire. Change is the norm rather than the exception, but many of the changes in vegetation are detectable only over decades and the current vegetation may still be responding to adjustments in management which took place around the Second World War or earlier.

The important question is: How will the vegetation change in the future? The answer depends on the type of vegetation, the physical environment in which it occurs, the type of management to which it has been subjected, and the future management. An analysis of 12 areas spread over the uplands of England and Wales shows the composition of the main types of upland vegetation and how its distribution is related to both the physical environment and man's management. From the known history of the areas we can deduce something of how the vegetation has been changing over the past two hundred years. From these strands of evidence, and from the general understanding of the dynamics of plant communities, it is possible to predict

MAP 1

STUDY AREAS IN RELATION TO THE E.E.C. LESS FAVOURED AREAS



Based on a map from 'The Future of Upland Britain' vol 1 how the general pattern of vegetation in the areas will change given various trends in future management. As the 12 areas are a reasonable sample of the uplands, predicted trends can be expected to occur generally. Obviously, in any particular site local factors will determine the course of change.

THE STUDY AREAS

The 12 study areas were selected from major upland regions in England and Wales (Map 1) and all were within the boundaries of the European Economic Community (EEC) 'Less Favoured Areas' with 'mountain and hill farming'. The study areas reflect the range of conditions characteristic of main uplands, as shown by a national land classification (ITE 1978). The type of farming, farm size and stocking characteristics of the 12 areas are very similar to the average features of the 339 parishes which are within the Less Favoured Areas (ULS 1981). A number of the study areas are within National Parks, other parts are used for water catchment, military training, grouse shooting or forestry development. Thus the range of 'problems' associated with upland land use are well represented in the 12 areas and, although the areas were not selected as representative or typical of the regions in which they occur, they show many of the physical and land use features of their regions, especially when compared with other regions (Table 1). For example, the study area in Exmoor, Lynton and Lynmouth shows moderately good agricultural land and significant agricultural improvement of moorland, in contrast with Llanfachreth and Alwinton which show the development of forestry characteristic of Wales and the Cheviots.

The interaction of physiography, geology, climate and soil in general determines the land use which can be maintained in an area, although the extent to which land use potential is realised depends on additional social and economic factors. The physical environment thus provides the foundation for contrasts between the land use of upland areas. It is easy to recognise major differences in the type of land in various upland areas, such as the steep high mountains of Snowdonia compared with the undulating hills of the Cambrian Mountains, or cold wet climates with peaty soils of the northern Pennines compared with warmer, relatively dry climates and reasonably drained soils of Exmoor. However a much finer scale is necessary when considering the the effects of land type on the vegetation within a study area, or to

Table 1 General characteristics of the study areas and their regions, expressed as % of the area or region. Data for the regions given in parenthesis. Agricultural data for study areas are as % of the total area, but for the regions are as % of the total agricultural land. Further details in Ball *et al.* (1981 a, b).

Study area and region	Land above 244 m	Land above 427 m	Land with slope more than 5°	Agricultural Land Grade 3	Agricultural Land Grade 4	Agricultural Land Grade 5	Other use	Agricultural Land Use: Tillage	Agricultural Land Use: Improved grass
Alwinton, Cheviot	91 (81)	65 (21)	83 (76)	0 (1)	0 (7)	85 (84)	15 (8)	0.4 (32)	5 (21)
Lunedale, North Pennines	100 (87)	74 (40)	58 (34)	0 (3)	5 (20)	95 (70)	0 (6)	0 (11)	8 (31)
[illegible]	93 (76)	54 (7[illegible])	[illegible]1 (7[illegible])	[illegible]	2[illegible] (19)	75 (71)	5 (9)	1 (10)	25 (39)
Bransdale, North York Moors	69 (57)	3 (0)	57 (43)	0 (4)	15 (17)	75 (72)	10 (6)	2 (46)	20 (25)
Heptonstall, South Pennines	92 (75)	9 (9)	62 (41)	0 (6)	20 (36)	70 (43)	10 (15)	0 (3)	20 (59)
Monyash, Peak District	98 (78)	1 (11)	42 (68)	15 (6)	70 (42)	15 (40)	0 (12)	4 (8)	89 (58)
Llanfachreth, Snowdonia	65 (77)	28 (28)	89 (84)	0 (1)	20 (17)	65 (64)	15 (19)	1 (5)	16 (25)
Ysbyty Ystwyth, Cambrian Mountains	90 (79)	51 (24)	69 (82)	0 (0)	0 (23)	90 (58)	10 (19)	1 (9)	12 (45)
Glascwm, Radnor Clun Forests	85 (80)	23 (13)	75 (83)	0 (6)	50 (56)	45 (29)	5 (0)	5 (14)	55 (55)
Ystradgynlais, Brecon Mountains	84 (77)	32 (23)	61 (62)	0 (3)	10 (29)	85 (49)	5 (19)	1 (11)	16 (55)
Lynton, Exmoor - Brendon Hills	75 (65)	0 (10)	74 (52)	0 (6)	50 (47)	50 (38)	0 (8)	3 (16)	54 (60)
Widecombe, Dartmoor	84 (87)	6 (35)	76 (28)	5 (8)	30 (13)	55 (74)	10 (5)	3 (14)	39 (26)

identify small areas of land within one site which are similar to extensive areas elsewhere. A further complication is that two areas may be similar in some respects, such as altitude and slope, but different in others such as climate and soil. 'Land' is a complex of features.

To distinguish the main variations in land in the 12 study areas the features defined on the Ordnance Survey and climatic maps were measured for each 0.5 and 0.5 grid square. The data from all the squares was then analysed by a multivariate method, Indicator Species Analysis (Hill, Bunce & Shaw 1975). The method determines the major and minor patterns of variation and groups squares with similar combination of features together in the same land class.

Within the study areas three main land groups were distinguished with subsidiary types (Table 2):

Hill land is a group containing land mainly in the altitude range 428-610 m, within which three land types are distinguished by their combinations of slope and relief: steep hill, hill and high plateau.

Upland land is a group dominated by land between 245 and 335 m, also of three land types, again distinguished by slope and relief: steep upland, upland and upland plateau.

Upland Margin is a group of a single land type (given the same name) which is dominated by altitudes between 122 and 244 m, moderate relief and rather steep slopes.

There are marked differences in land character both between and within the study areas. The detailed distribution of land types, summarised in Table 3, shows a relative ranking of the study areas with increasing degrees of 'hilliness':

Widecombe, Lynton and Monyash - have little hill land. Most of the land in these areas is upland, upland plateau and upland margin with the least extreme altitude and relief and greatest potential for agriculture and forestry.

Llanfachreth - while having a moderate amount of hill land, particularly steep hill, has a high proportion of upland margin.

Table 2 Summary Description of Land Types

Descriptive terms are relative to the range of characteristics in the study areas. Further details in Ball *et al.* (1981a).

Land group	Land type	General description
Hill	Steep Hill	High altitude, strong relief, steep slopes; very low density of habitation, low frequency of road access and intensity of agricultural use.
	Hill	High altitude, moderate relief and slopes; low density of habitation, frequency of road access and intensity of agricultural use.
	High Plateau	High altitude, low relief and gentle slopes; low density of habitation, frequency of road access and intensity of agricultural use.
Upland	Steep Upland	Moderate altitude, strong relief and steep slopes; low density of habitation, moderate frequency of road access and intensity of agricultural use.
	Upland	Moderate altitude, relief and slopes; high density of habitation, frequency of road access and intensity of agricultural use.
	Upland Plateau	Moderate altitude, low relief and gentle slopes; moderate density of habitation and frequency of road access; high intensity of agricultural use.
Upland Margin	Upland Margin	Low altitude, moderate relief and rather steep slopes; high density of habitation, frequency of road access and intensity of agricultural use.

Table 3 Land Group Representation in the Study Areas

Three land types are included in Hill and Upland Groups. Results are given as % of the study area. Further details in Ball *et al.* (1981a, b).

Study area	Land group		
	Hill	Upland	Upland Margin
12 study areas combined	48	36	16
Alwinton	67	28	5
Lunedale	80	11	9
Shap	54	39	7
Bransdale	30	42	28
Heptonstall	27	57	16
Monyash	0	86	14
Llanfachreth	31	25	44
Ysbyty Ystwyth	57	27	16
Glascwm	23	50	27
Ystradgynlais	54	27	19
Lynton	12	56	32
Widecombe	12	64	24

Heptonstall, Bransdale and Glascwm are predominantly upland, but have moderate amounts of both hill and upland margin.

Shap, Ysbyty Ystwyth and Ystradgynlais - have about 50% hill land, but Shap has a low proportion of upland margin similar to Alwinton and Lunedale.

Alwinton and Lunedale - have a high proportion of hill land, and only small amounts of upland margin.

It is the variation in the environment which largely determines the distribution of vegetation and the extent to which agriculture, forestry and other land uses have developed. Undoubtedly other factors are important in particular situations. For example, in Shap and Monyash the upland plateau land is based on Carboniferous Limestone, with a thin glacial drift. This gives high levels of agricultural use and settlement that contrast sharply with upland plateau elsewhere which is on less agriculturally favourable rocks. Past and present land ownership has also influenced local patterns of vegetation and land use, but the physical characteristics of the land set the limits for the variety of vegetation and land use.

THE CURRENT UPLAND VEGETATION

In the upland areas four main types of vegetation can be identified from detailed composition of species and they make distinct contributions to the landscape. More subtle differences, visually and in species composition, occur within the four types as a result of different environmental conditions and management practices.

Improved pastures

These pastures are characterised by the presence of introduced species of high agricultural value, eg *Lolium perenne* (rye grass), *Dactylis glomerata* (cocks foot) and *Trifolium repens* (clover), together with a range of herbs. Agriculturally undesirable species may be present, such as *Pteridium aquilinum* (bracken), *Juncus* species (rushes) and *Cirsium* species (thistles), depending on soil conditions, management and drainage.

Four classes of improved pasture show a sequence from the most productive herb-rich *Lolium* grassland to the poorest *Lolium/Holcus/Pteridium* grassland which has an increased 'weed' content of lower nutritive value than the main introduced species. The sequence represents responses to the interaction of the inherent site fertility, management intensity and the time since the pasture was reseeded.

Herb-rich *Lolium* grassland (class 4*). This class includes recently resown swards and is *Lolium perenne*-dominated with a range of agricultural weeds present. *Trifolium repens* and *Dactylis glomerata* are also prominent.

Lolium grassland (class 2). *Lolium perenne* is again dominant, but *Agrostis tenuis* (common bent) and *Holcus lanatus* (Yorkshire fog grass) are present as major co-dominant species. The class includes some land utilised for hay meadows.

Lolium/Trifolium grassland (class 3). *Lolium perenne* and *Trifolium repens* are co-dominant species. There is a tendency towards drainage impedence which is reflected in the presence of thistle and rush species.

Lolium/Holcus/Pteridium grassland (class 1). This class is to be found on shallower soils than the other improved pastures. Rocks and boulders are typically present on the surface. *Lolium perenne* and *Holcus lanatus* are co-dominant with *Pteridium aquilinum* present as an invading species. Trees and scrub are present on many sites.

Rough pastures

Rough pastures are subjected to less intensive management than the improved pastures. They are characterised by the prominence of species such as *Agrostis tenuis* and *A. canina* (bent grasses), *Festuca ovina* (fescue), *Juncus* spp. and other coarser species. There are fewer introduced species than in the improved pastures. Lower soil fertility (assessed from soil acidity) is also characteristic and poor drainage is frequent. The

* Class numbers refer to the original statistical analysis and are retained here to allow reference to Ball *et al.* (1981a, b) and to the original analysis.

grasslands in this group show a general ecological sequence, influenced by soil conditions, with an associated decrease in grazing value. These rough pastures contain a wider variety of plants than the other vegetation types.

Agrostis/Holcus grassland (class 7). The dominant grasses are *Agrostis* spp. and *Holcus lanatus*. This grassland contains a variety of herbs and is confined to well drained soils mainly on moderate slopes (range 6-11°). Species diversity is high (188 species recorded). Trees are typically present, as are also some surface rocks and boulders.

Agrostis/Juncus grassland (class 5). Herb-rich flushes are a feature of this grassland, while bracken and brambles are fairly frequent, as also are scattered trees. Species diversity (189 species recorded) is again high.

Festuca/Agrostis grassland (class 8). *Festuca ovina* and *Agrostis tenuis* are the co-dominant grass species but *Lolium perenne* is moderately constant. Soils are fairly shallow and slopes mainly moderate. There is a tendency to poor drainage and some species of wetter habitats are often present, eg *Juncus effusus*. There are generally rather fewer trees and surface rocks and boulders present than in other types of rough pasture.

Festuca/Juncus grassland (class 6). The main feature which distinguishes this class from the *Agrostis/Juncus* grassland (class 5) is the frequent presence of more coarse grass species, including *Deschampsia cespitosa* (tufted hair-grass), *Agrostis canina/stolonifera* (brown bent/creeping bent) and *Nardus stricta* (mat grass). Slopes also tend to be slightly steeper and soil pH somewhat lower than for class 5.

Grassy heaths

Grassy heaths, consisting of three classes, are characterised by the dominance of coarse grasses such as *Nardus stricta*, *Deschampsia flexuosa* (wavy hair-grass) and *Molinia caerulea* (purple moor grass). A secondary shrubby element, consisting of mainly ericaceous species, links the group with the shrubby heaths. Rushes and bracken may also be present. In the grassy heaths as a whole, *Galium saxatile* (heath bedstraw) shows a very high constancy, and bilberry, *Vaccinium myrtillus*, is probably the most prominent of the shrubby species. The three classes of grassy heaths are arranged in order of increasing heath element.

Festuca/Nardus/Vaccinium heath (class 15). This class occurs typically on moderate to steep slopes, which are drier than those of class 16 which it most closely resembles. As well as *Festuca ovina* (sheep's fescue) and *Nardus stricta, Deschampsia flexuosa* is also a prominent grass, while *Vaccinium myrtillus* is a common associated species. Gullies and scree patches are landform features frequently present.

Festuca/Nardus/Molinia heath (class 16). Wet upland grassy heath with relatively high species diversity (159 species recorded). Species characteristic of wet situations such as *Carex nigra* (common sedge), *Eriophorum vaginatum* (cotton grass), *Juncus bulbosus* (bulbous rush), *Trichophorum cespitosum* (deer-grass), and *Narthecium ossifragum* (bog asphodel) are present. Surface water, as pools and streams, is frequently present.

Festuca/Vaccinium heath (class 14). This heath is found mainly on gentle to moderate slopes with shallow soils and good drainage. Soil pH is relatively low, mainly below 4.7. This is the typical dry grassy heath characterised by species such as *Galium saxatile, Festuca ovina, Deschampsia flexuosa, Juncus squarrosus* (heath rush) and *Potentilla erecta* (common tormentil).

Shrubby heaths

Shrubby heaths are characterised by the predominance of dwarf shrubs such as *Calluna vulgaris* (heath or ling), *Vaccinium myrtillus* (bilberry), *Erica cinerea* and *E. tetralix* (bell heather and cross-leaved heath) and *Empetrum nigrum* (crowberry), as well as *Ulex* spp. (gorse) and various grasses, sedges (*Carex* spp.) and rushes. The group is found on the poorer soils and at sites with the lowest intensity of management. The main trend among the heaths, shown in the order presented, is of decreasing intensity of agricultural use and reduction in the potential of the vegetation for easy modification through management.

Calluna heath (class 13). Dry *Calluna* heath, with bracken present in some cases, occurs mainly on rocky sites with pockets of well drained soils. *Ulex* is usually present and is sometimes conspicuous as large bushes. *Agrostis tenuis* is the grass species of highest constancy, but the other grasses of acidic soils are also prominent.

Calluna/Molinia/Vaccinium heath (class 9). This rather species-poor (55 species recordd) type of heath, of limited occurrence, is found mainly on relatively shallow soils. *Calluna vulgaris* is the dominant species but all the other common ericoids are also present. Five grass species also occur frequently.

Vaccinium/Calluna heath (class 10). Again a rather species-poor (65 species recorded) heath, which mainly differs from class 9 in that the shrubby heathland element is less diluted; only one grass species *(Deschampsia flexuosa)* occurs frequently. Heathland attributes such as burning, and eroding peat, are conspicuous.

Nardus/Sphagnum/Calluna heath (class 11). This mixed heath occurs on boggy moorland with coarse grasses *(Nardus* and *D. flexuosa)* present in most samples. Other species with moderately high constancy include *Trichophorum cespitosum* (deer-grass), *Empetrum nigrum*, *Carex echinata* (star sedge) and *Narthecium ossifragum* (bog-asphodel).

Eriophorum/Calluna heath (class 12). This class is a blanket bog community on deep peaty soils. *Calluna/vulgaris* is dominant with *Eriophorum vaginatum* and *Deschampsia flexuosa* co-dominant. *Eriophorum angustifolium* and *Sphagnum* spp. (bog moss) are usually present.

FACTORS AFFECTING THE VEGETATION

As mentioned in the descriptions of the main types of vegetation, both the physical environment and management affect the plant communities. The physical environment sets limits to the range of vegetation which can occur. The type and intensity of management varies considerably over the study areas.

Thus from the current distribution of plant communities in the study areas we can see the range of vegetation which can be produced by man's activities, with indications of the sequence of vegetation which would result from varying intensities of management in comparable types of land.

The vegetation of different upland areas

Diversity is often regarded as an asset to the landscape and the biological interest of an area and the range of plant communities contributes to both landscape and biological diversity. However, although there are marked differences in the diversity of vegetation between the study areas (Table 4), there is no simple relationship to environmental or management factors. In order of increasing variety, Monyash, which is dominated by a limited range of grasslands, is followed by Lunedale, Alwinton and Bransdale, where the extensive moorlands are fairly uniform and there are few grassland types. Ysbyty Ystwyth, while mainly moorland, has an increased range of grasslands giving it a diversity similar to that of Widecombe which has a wide range of grassland but few types of grassy and shrubby heaths. Glascwm and Lynton follow the pattern of Widecombe but with an increased variety of heaths. Shap and Heptonstall combine a wide variety of both grasslands and heaths, while the full range of vegetation occurs in Llanfachreth and Ystradgynlais. Size is certainly not a factor. Heptonstall, the smallest area studied, shows a diversity similar to that of Shap, which is five times larger. Diversity of land type is not simply related to range of vegetation, although Monyash, Lunedale and Alwinton show restricted ranges of both land and vegetation. The variation in management of both moorland and grassland, when linked with the physical characteristics, helps to explain the vegetation variety.

Eight of the study areas (Lunedale, Ysbyty Ystwyth, Bransdale, Shap, Alwinton, Ystradgynlais, Heptonstall and Llanfachreth) are distinctly moorland in character, with more than 50% of grassy and shrubby heaths. Lunedale and Ysbyty Ystwyth particularly contain very low proportions of improved pasture classes, with rough pastures also rather poorly represented. The very high occurrence of *Eriophorum/Calluna* blanket bog in Lunedale gives it, overall, the most moorland character, reflecting its major land use as a grouse moor. In Shap there is a contrast between a fairly strong representation of improved pastures associated with limestone outcrops and

Table 4 The distribution of vegetation classes in each study area, given as % of main sites recorded in each area. The dominant vegetation in each study areas is shown in bold type. Vegetation classes are arranged to show the successional response to environmental conditions and management (see text). Numbers used to identify vegetation classes refer to the original computer classification (see footnote).

Study area	Improved Pastures 4	2	3	1	Rough Pastures 7	5	8	6	Grassy Heaths 15	16	14	Shrubby Heaths 13	9	10	11	12	Number of sites
Alwinton	1	5					**23**	5	14	5	16				14	**18**	80
Lunedale	1						9	3	16	3	1			1	8	**58**	79
Shap	9	8	1	2	3		6	5	4	**24**	5		2	2	**26**	3	115
Bransdale	6		5	1			11		1	15	18			**35**	6	2	88
Heptonstall	11	9	3	1	1	1	7	1		3	6		1	**23**	3	**27**	70
Monyash	**44**	**40**			11		4										72
Llanfachreth	3	1	1	4	13	4	10	3	1	**22**	7	8	1	1	15	4	72
Ysbyty Ystwyth	0	1	4	1	3		9			12	17		1	3	**23**	**25**	75
Glascwm	**24**	1	**18**	6	7	3	10	3	1	1	13			13			71
Ystradgynlais	11	1	3	1	3	10	3	1	1	**16**	**21**	3	1	7	11	1	70
Lynton	**51**	1	8	7	6	3		1	1	3	10	3	4		1		71
Widecombe	**24**	5	4	4	5	11	1	3			5	**31**	7				75
12 areas combined	15	6	4	2	4	2	8	2	3	9	10	4	1	7	10	12	[illegible]38

Code numbers: 4 - Herb-rich *Lolium*, 2 - *Lolium*, 3 - *Lolium/Trifolium* and 1 - *Lolium/Holcus/Pteridium* grasslands
7 - *Agrostis/Holcus*, 5 - *Agrostis/Juncus*, 8 - *Festuca/Agrostis* and 6 - *Festuca/Juncus* grasslands
15 - *Festuca/Nardus/Vaccinium*, 16 - *Festuca/Nardus/Molinia* and 14 - *Festuca/Vaccinium* heaths
13 - *Calluna*, 9 - *Calluna/Molinia/Vaccinium*, 10 - *Vaccinium/Calluna*, 11 - *Nardus/Sphagnum/Calluna* and 12 - *Eriophorum/Calluna* heaths

the strong moorland component found on the more extensive volcanic rocks on the western side of the study area. Bransdale is another area influenced by sporting interests, so that the management of its moorland sector for grouse leads to a relatively high representation of shrubby heaths, particularly *Vaccinium/Calluna* heath. Alwinton is largely controlled by the Ministry of Defence, which uses much of the area as a military range and training ground, a use mirrored in a low proportion of improved pastures, since the normal agricultural pressures do not operate freely in this parish and grassland improvement schemes have not been undertaken on the same scale as in other physically similar upland areas. Heptonstall is an important water catchment area, of which part again is also managed for grouse. The moderate representation of improved pastures in Heptonstall has in part resulted from the abandonment of farms in the vicinity of the reservoirs, and the relatively high presence of shrubby heaths results from the shooting interests. In Ystradgynlais opencast coal mining has had some influence on the vegetation in that these operations have inevitably disturbed areas which have subsequently been allowed to revegetate to a form of rough pasture or have been planted to coniferous forest. Moorland is still dominant in Llanfachreth, but with the grassland elements occupying almost 40% of the sample sites, this parish tends to be intermediate between those of undoubted moorland character and those in which the influence of agriculture is predominant.

In Monyash the moorland element is absent and this study area forms the opposite vegetation extreme to Lunedale in the range represented by the 12 study areas. The reasons for the lack of the moorland element in Monyash are its geology, of Carboniferous Limestone giving relatively fertile soils, and its geographic position, surrounded as it is by major conurbations which created substantial demands for agricultural produce, particularly dairy products. This has meant that there have been long standing economic incentives for the potential grassland improvements to be carried through to completion in Monyash. Widecombe, Glascwm and Lynton all have an above average representation of improved pastures, which is a reflection of their generally more favourable plant growth conditions, both in terms of soils and climate. Since these three areas are more remote than Monyash from major centres of population, they have retained a wider range of vegetation diversity and have not been subjected to the extreme pressures for improvement that have totally turned Monyash to farmland. The farmland element is weakest in

Widecombe out of those three areas, but in Glascwm grassland improvement schemes are currently making deep inroads into the remaining areas of unimproved moorland. In Lynton moves for landscape conservation may prevent further losses of unimproved moorland.

The vegetation of different land types

The variations between the study areas are condensed in the land types, which allow us to see the range of vegetation which has been developed under man's influence in comparable environments. Combining the information from the 12 areas shows (Table 5) that each type of land contains one or two dominant classes of vegetation with a number of subordinate or occasional communities. The interpretation is that the dominant vegetation is the 'norm' for that type of land. In the hill land types the dominant vegetation is determined mainly by environmental conditions, but in the upland and upland margin man's influence is more important in selecting the dominant vegetation. The subordinate vegetation in each land type reflects the minor variations in the physical conditions and management. The frequency of occurrence of each vegetation indicates the probability of it being developed through a change in management. In general terms, increased intensity of management would move vegetation classes towards the left side of Table 5, and decreased management to the right. For example, in steep hill land increased grazing would change the shrubby heaths into grassy heaths, with a limited probability of succession into two types of rough pasture. In contrast, in upland margin land there is a high probability that increased management would transform the rough pastures and heaths into improved grassland, predominantly into herb-rich *Lolium* swards.

As always, general trends are tempered by local conditions, but the main patterns are as follows.

Hill land supports negligible improved pastures, and its rough pastures are principally *Festuca/Agrostis* grassland (class 8) which, with *Festuca/Juncus* grassland (6), occurs mainly on steep hill land. Grassy heaths of the steep hill are mainly *Festuca/Nardus/Molinia* (16) and *Festuca/Vaccinium* (14) and their association suggests that they could develop from the grasslands (8 and 6) under appropriate management. The commonest shrubby heath class is *Nardus/Sphagnum/Calluna* (11). The vegetation range of steep hill land is less

Table 5 The distribution of vegetation classes in the land types. Results are for the 12 study areas combined and are given as % of sites in each land type. The dominant vegetation is shown in bold type. Vegetation classes are arranged to show the successional response to environmental conditions and management (see text). Numbers used to identify vegetation classes refer to the original computer classification (see footnote).

Land type	Improved Pastures				Rough Pastures				Grassy Heaths			Shrubby Heaths				
	4	2	3	1	7	5	8	6	15	16	14	13	9	10	11	12
Steep Hill							10	3	9	**17**	**17**	4	4	10	**17**	9
Hill							3		6	9	8	4	1	8	**30**	**31**
High Plateau			1	1	1		3	1	5	6	10	2		9	18	**43**
Steep Upland	10	2	6	1	6		14	3	5	**20**	**17**	3	1	8	1	3
Upland	32	8	2	2	7	9	5	4	1	3	5	7	3	5	2	5
Upland Plateau	**24**	**20**	4	3	3		4	3	1	3	8	3	3	10	6	5
Upland Margin	**25**	9	9	7	8	6	12	2	1	6	6	2	1	2	2	2

Code numbers: 4 - herb-rich *Lolium*, 2 - *Lolium*, 3 - *Lolium/Trifolium* and 1 - *Lolium/Holcus/Pteridium* grasslands
7 - *Agrostis/Holcus*, 5 - *Agrostis/Juncus*, 8 - *Festuca/Agrostis* and 6 - *Festuca/Juncus* grasslands
15 - *Festuca/Nardus/Vaccinium*, 16 - *Festuca/Nardus/Molinia* and 14 - *Festuca/Vaccinium* heaths
13 - *Calluna*, 9 - *Calluna/Molinia/Vaccinium*, 10 - *Vaccinium/Calluna*, 11 - *Nardus/Spaghnum/Calluna* and 12 - *Eriophorum/Calluna* heaths

concentrated than in the case with hill and high plateau, giving a greater vegetational diversity to this land type. In the hill and high pleateau, shrubby heaths of *Nardus/Sphagnum/Calluna* (11) and *Calluna* (12) are prominent. Both these are typical peat bog vegetations in which the likelihood of gradual vegetation change by simple management modifications is slight.

Upland types of land carry a greater range of vegetation than hill land. All the vegetation classes occur on upland, and only *Agrostis/Juncus* grassland (5) was not recorded on steep upland and upland plateau. Improved pastures are mainly the better *Lolium* classes (2, 4) and rough pastures tend to be dominated by *Festuca/Agrostis* grassland (8). The latter, as in the hill land, is associated with grassy heaths (14, 16) on the steeper sectors. Upland margin also contains a wide spectrum of the vegetation classes, but because of its greater potential for agriculture this land type has become dominated by improved pastures and rough pastures.

PAST CHANGES IN UPLAND LAND USE AND VEGETATION

So far, we have concentrated on the current vegetation in relation to variations in the physical environment and intensity of use. However to understand the current pattern of vegetation, and the extent to which it has changed, and is changing, it is necessary to appreciate the fluctuations in land use, particularly in agriculture, that have affected the vegetation. The broad pattern of open moorland in the hills, with pastures on the lower slopes is the result of early clearance of woodland, followed by centuries of grazing and burning, which induced slow changes in the vegetation. Documentation before about 1800 is very erratic and difficult to interpret, but there is reasonable evidence for the distribution and timing of the more rapid changes which occurred in the uplands through industrial developments, afforestation and fluctuations in agriculture.

In the mid-19th century, a 'Golden Age' of agriculture in Britain, improved communications and greater accessibility to large markets, which might have been expected to lead to further upland land reclamation and agricultural development, often acted in the opposite direction. It had become easier to transport produce to distant towns but it was also easier to import foodstuffs, so that the primacy of farmers in their local markets was removed. Previously, farmers could depend on the prices received for their products rising and falling according to the quality of the local harvest. This self-balancing mechanism ended when it became easy to import products whose price was unaffected by local seasonal conditions. Prices not only fell, but remained low even when home output was depressed. Low yields no longer brought a compensatory rise in prices. In these changing circumstances the farmers' response was to economise by reducing arable acreage and investment in pastoral management. Often poor husbandry practices made adjustment difficult. Garnett (1912) complained of how some of the higher ground in the Lake District had been 'ploughed so hard and so long' that it was difficult to re-establish a sward, and there was insufficient capital for agricultural essentials. When much of this marginal arable land was abandoned in the late 19th century, it reverted directly to rough pasture or moor, rather than being maintained as improved pastures.

With the exception of the brief period between 1915 and 1921, agricultural prices remained depressed throughout the first 35 years of the 20th century, and the impact on the upland countryside was accentuated by the collapse of many rural industries and occupations. The plight of the upland farmer was the subject of a number of *ad hoc* inquiries before and after 1945, the most relevant of which was a study of 120 000 ha (290 000 acres) of central Wales, including the parish of Ysbyty Ystwyt (Welsh Agricultural Land Sub-Commission 1955). The Commission emphasised that with the disappearance of subsidiary incomes there was a tendency for smaller farms to become deserted or amalgamated, and their homesteads to be left ruinous.

An indication of general trends in upland farming this century may be obtained from the Annual Returns made by farmers to the Ministry of Agriculture and its predecessor. As might be expected, the average area under tillage declined until the First World War, then rose and remained at a level comparable to that of the early 1900s (Figure 1a). The average animal population has fluctuated far less, and numbers in the mid-1960s were comparable with those of the first decade of the century (Figures 1b, c). The number of sheep per hectare has risen since the 1930s (Figure 1d). The overall impression is, therefore, one of broad stability in stocking rates over this period, except

Figure 1a   Trends in the area of tillage for 7 study areas, 1900-1965

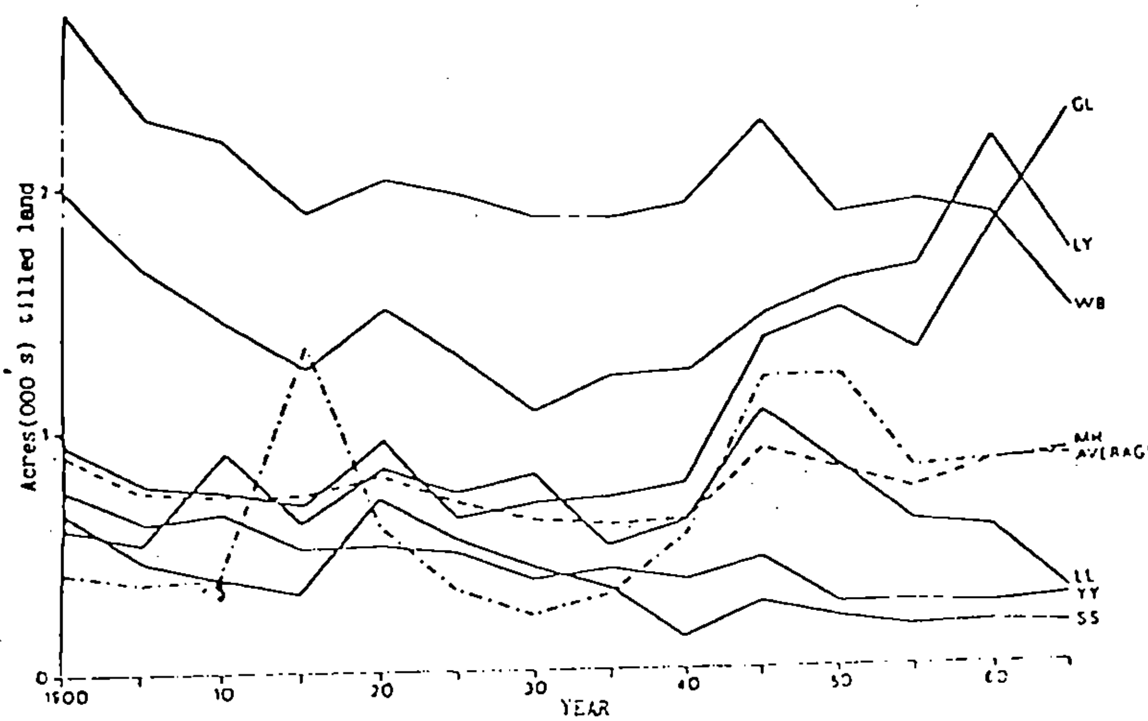


Figure 1b   Trends in the numbers of cattle for 9 study areas, 1900-1965

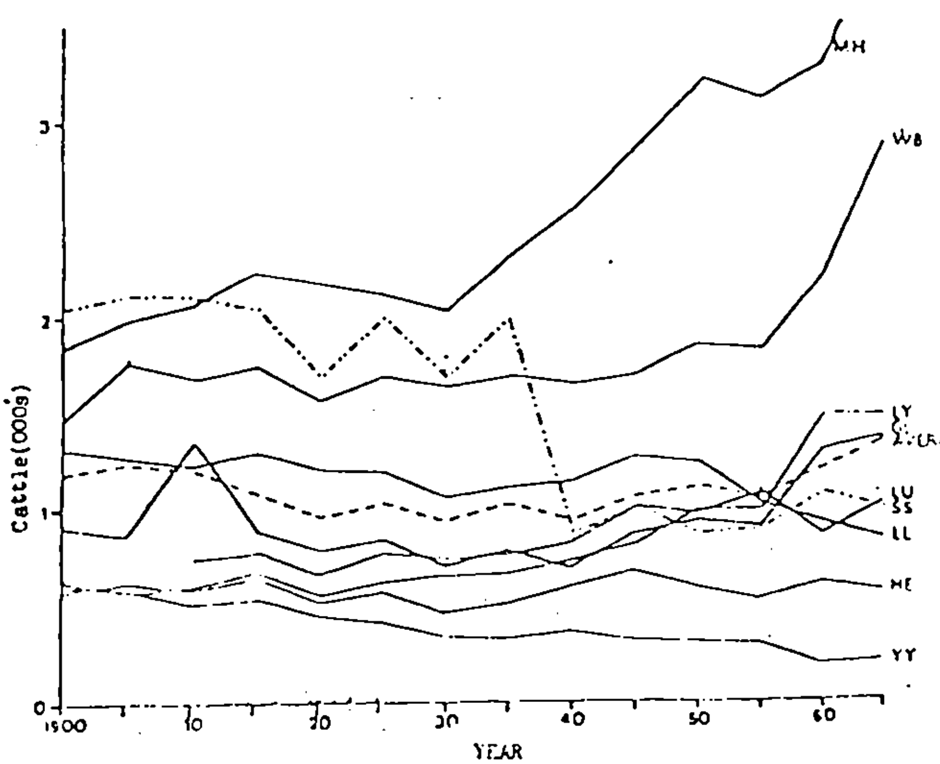


Figure 1c Trends in the numbers of sheep for 9 study areas, 1900-1965

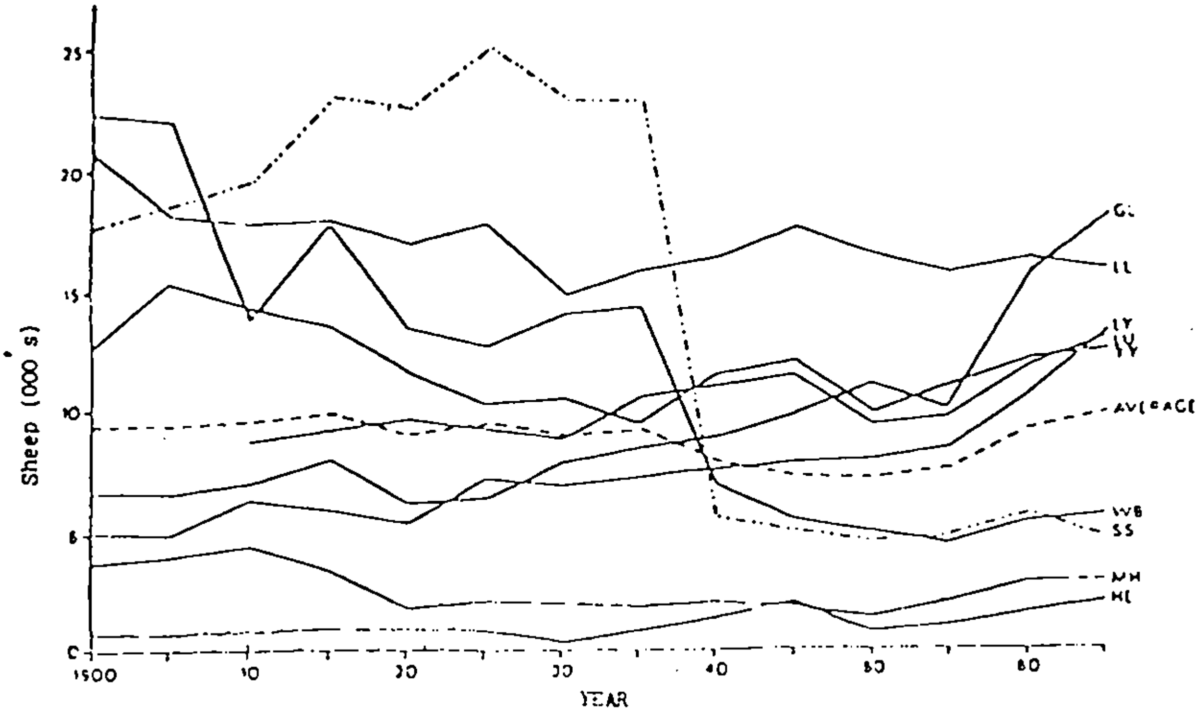
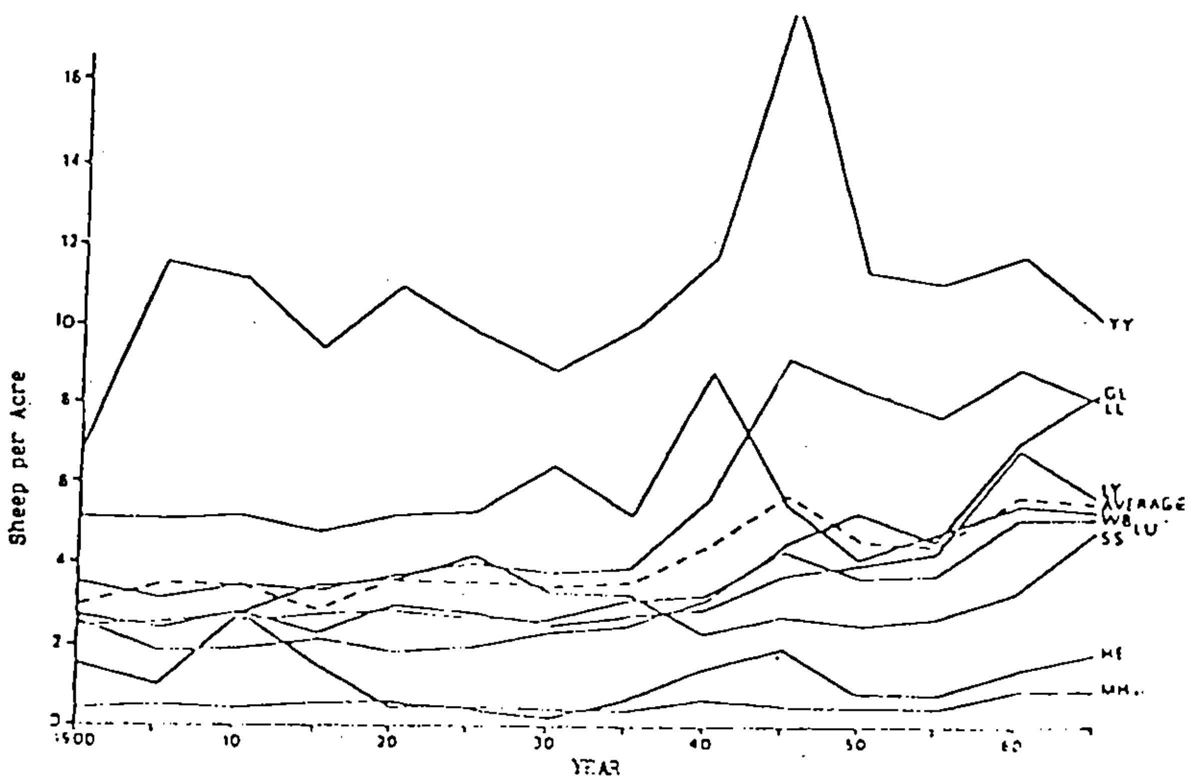


Figure 1d Trends in the numbers of sheep per acre of permanent grass for 9 study areas, 1900-1965



for particular situations such as the continuous increase in cattle numbers over the period from 1930 to 1965 in Monyash and from 1955 to 1965 in Widecombe.

There were considerable variations within the general trends, both within and between the study areas. Perhaps the most striking change to affect an area was the dramatic decline in the agricultural area and output of Shap in the period 1935-1940, at the time when Haweswater was enlarged and became a reservoir. The increase in tillage in Glascwm since 1940, and in sheep numbers since 1955, are also marked.

Changes in the size of the labour force and the number of farm holdings also indicate wider trends in land use and management and suggest a wide and complex variety of experience in the uplands. The average number of farm workers in Shap fell from 88 for the years 1925-1940 to 13 for the years 1950-1965, and in Ysbyty Ystwyth from 52 to 18. In contrast, the opportunities for employment rose in Heptonstall, Monyash and Glascwm. In most of the study areas, there was a decline in the number of holdings, but there was no significant change in Widecombe and Glascwm. The relative importance of very small holdings in Heptonstall, Llanfachreth, Ysbyty Ystwyth and Ystradgynlais persists into recent years.

The results from the Annual Returns indicate a trend since the 1950s of a rise in numbers of livestock in many parishes. This trend is corroborated by the Upland Landscapes Study (ULS) (1981), which also showed from their survey of farmers' attitudes that many farmers planned to increase stocks. Many farmers, especially in Alwinton, Llanfachreth, Ysbyty Ystwyth, Lynton and Widecombe, also planned to improve their rough grazing through moorland reclamation, enclosure and bracken clearance. Such proposals may be treated with scepticism but the ULS results showed that those farmers who planned improvements were the ones with a past record of improvement. A trend towards farm amalgamation was also observed, in line with the general pattern of farming, and it is possible that areas which still contain a relatively high proportion of small holdings may be subject to the greatest change in farm size. There is a trend for decreasing livestock densities as farm size increases in hill farms. Although this relationship is affected in part by land quality, it suggests that some areas may expect to reduce stock densities through amalgamation in contrast with the general trend of increasing numbers.

An overall impression in the agricultural use of the uplands is one of long term average stability, onto which is superimposed fluctuations over one or two decades, with marked local variations often resulting from factors external to the agricultural industry. If anything there is a current trend towards increasing livestock numbers and associated agricultural improvement. The historical record can, however, indicate where in the study areas earlier changes in agricultural fortunes have affected the vegetation. The implication is that similar fluctuations in future will affect similar areas.

From Ordnance Survey maps and recent air photographs three zones of decreasing intensity of agricultural use can be identified: i. farmland which has always been under intensive cultivation, ii. moorland fringe which in the past 200 years or so has interchanged between moorland and farmland or forest, iii. moorland core which has always been under extensive management. The moorland fringe is of particular interest because it is the zone in which fluctuations in management have the greatest effect. For example, in Bransdale (Map 2) a major area of moorland core surrounds the 'permanent' farmland in the valley bottom. The moorland core and farmland are separated by the fringe, which consists of some large blocks of moorland which have been reclaimed for forestry, plus many smaller pieces of farmland which have reverted to moorland at various times in the past.

In all the study areas the fluctuations in land use occur either as small blocks adjacent to the farmland where reclamation for or reversion from agriculture has taken place, or as larger blocks of moorland afforestation which may be sited well into the moorland. The patterns of reclamation and reversion are very distinct (Table 6). Apart from Monyash which has an insignificant area of moorland, changes in land use have had a marked effect on the moorland in eight of the study areas. Reclamation for forestry is dominant in five areas in Wales and northern England, especially Llanfachreth, in contrast to agricultural reclamation which is dominant in southern England (Lynton and Widecombe) plus Glascwm. Three of the northern areas (Heptonstall, Shap and Lunedale) have maintained a relatively stable moorland, less than 8% of which has been affected by relcamation or reversion.

Reversion of pastures which were intensively managed is relatively uniform throughout the uplands and affects between 2 and 13% of the moorland, again omitting Monyash (Table 6). The counteraction of reclamation and reversion

MAP 2 Moorland Core, Moorland Fringe and Farmland in Bransdale

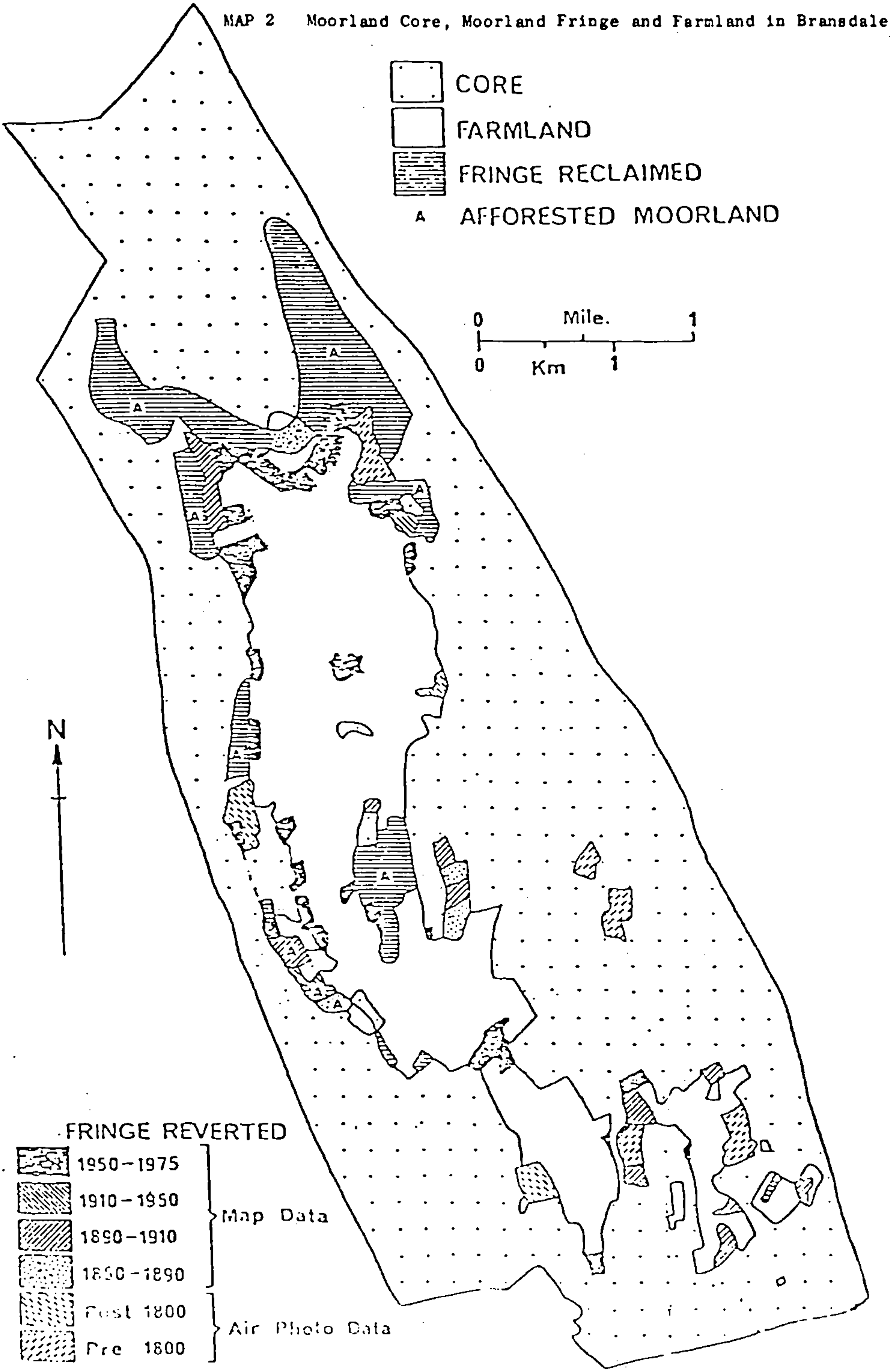


Table 6 The extent of moorland in the study areas, in hectares. The moorland core and fringe are determined from Ordnance Survey maps and air photographs. The fringe, the area of changing land use since 1800, is composed of both reclaimed moorland and reverted farmland.

Study area	Total area	Original moor	Final moor	Moorland core	Moorland fringe	Reclaimed moorland		Reverted to moor
						Forestry	Agriculture	
Alwinton	15 525	14 222	12 787	12 365	2 279	1 752	105	422
Lunedale	9 275	7 765	7 845	7 660	290	-	105	185
Shap	11 325	7 695	8 131	7 591	644	78	26	540
Bransdale	3 200	2 087	2 080	1 896	375	186	5	184
Heptonstall	2 300	1 319	1 391	1 300	110	-	19	91
Monyash	3 600	226	169	107	181	-	119	62
Llanfachreth	7 200	5 016	3 428	3 226	1 992	1 759	31	202
Ysbyty Ystwyth	5 350	4 160	4 058	3 825	568	320	15	233
Glascwm	3 675	1 682	1 362	1 300	444	76	306	62
Ystradgynlais	4 775	3 617	3 444	3 221	619	375	21	223
Lynton	3 150	1 182	929	885	341	-	297	44
Widecombe	5 050	2 453	2 451	2 140	624	6	307	311
12 areas combined	74 425	51 424	48 075	45 516	8 467	4 552	1 356	2 559
% of original moor		100	93.5	88.5		8.9	2.6	5.0

has resulted in a major net loss of moorland in Llanfachreth, Lynton and Glascwm, but net gains of moorland of about 6% in Heptonstall and Shap.

Over the combined areas about 16% of the moorland has been directly affected by land use changes. The main influence has been a 9% loss to forest. Agricultural reclamation has affected 2.6% of the total moor but this loss is offset by reversion from intensive agriculture to moorland on about 5% of the moor. The net result of these fluctuations has been a loss of about 6.5% (3 350 ha) of the original moorland (51 400 ha) over a period of about 200 years. The timing of the changes is also significant. As observed by ULS (1981) the rate of loss of moorland has increased markedly in the last decade, mainly through afforestation, whereas reclamation and reversion through agriculture is a long standing feature of the landscape. Reclamation of moorland for agriculture, as shown by the Annual Returns (Figure 1a) has long term fluctuations, although the ULS results indicate a recent rise in the area of crops and grass, particularly in Lynton, Widecombe and Glascwm, and to a lesser extent in Alwinton and Lunedale. Reversion of farmland to moorland appears to be more consistent than reclamation with only minor fluctuations over the last 200 years, 40% of reversions occurring before 1885 and 60% since then. Recent reversion has been slow, concentrated in Bransdale and Llanfachreth.

The only apparent discrepancy between the present results and those from ULS (1981) is in the total estimated loss of moorland or semi-natural vegetation. The estimated area of moorland c. 1800 was 51 400 ha, which has been reduced to the present level of 48 100 ha, a loss of 6.5%. The comparable figures from ULS (1981) are 52 900 ha of semi-natural vegetation in c. 1872, which is now reduced to 46 400 ha, a loss of 12.3%. Bearing in mind the shorter term fluctuations in use, the different sources of information, the inaccuracies in the original mapping and errors in measurement, the two results provide valuable independent estimates of the loss rate, averaging out at between 17 and 65 ha yr^{-1} or 0.03 to 0.12% yr^{-1}. Both studies show the same wide variation between areas, ranging from losses of 32% to gains of 6% in the present study, compared to losses of 36% and gains of 5% in the ULS (1981) study, the results from study areas being closely correlated.

As already mentioned, the moorland fringe, with fluctuating land use, tends to form a distinct zone in the uplands. It is concentrated in a particular quality of land, 60% occurs on the steep upland and upland margin land types.

Thus on the assumption that the general pattern of land use will be maintained, future changes are likely to be concentrated in these land types and the visual effect will be greatest in areas which have a high proportion of such land, ie Llanfachreth with 69%, and Glascwm and Lynton with 52%. Alternatively changes may be concentrated where there are large areas of these land types, ie Llanfachreth with 5 000 ha and Alwinton with 3 900 ha.

Reversion of pasture to moorland

Examining the succession of vegetation following reversion of pasture has shown the expected sequence through rough pastures and grassy heaths to shrubby heaths from an assumed starting point of improved pasture. What was unexpected was the very long period of time necessary for reversion to reach the shrubby heath stage on many sites. Although some sites had reverted to shrubby heaths within 40 years, others only developed the proportions of different types of heaths similar to the adjacent moorland after more than 130 years.

The sequence of change, interpreted from sampling sites which had reverted at known times, is shown in Figure 2 and is summarised as follows:

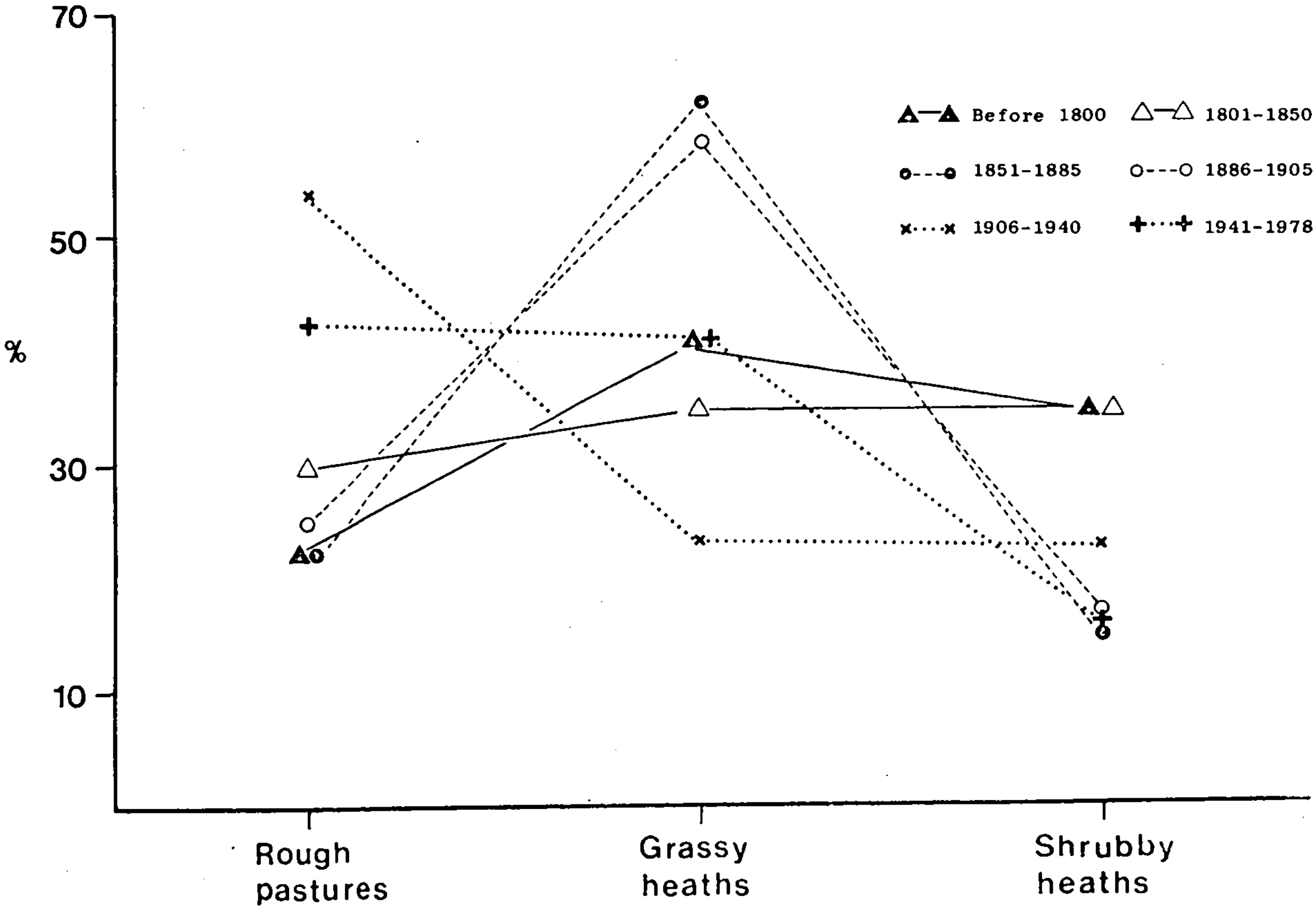
i. In the first period of up to 40 years after reversion (reversions between 1941-1978) the vegetation on about 40% of the improved pastures has changed to rough pastures, a further 40% has moved through rough pastures and developed into grassy heaths, while the remainder has developed shrubby heaths either directly or through a series of intermediate stages.

ii. The situation remains fairly stable over another 35 or so years (1906-1940), representing a stabilised sub-climax.

iii. In the period 75 to 130 years after reversion (1851-1905) half of the earlier rough pastures show a gradual development to grassy heaths, these heaths representing about 60% of the vegetation on sites of this age of reversion.

iv. Between 130 and 180+ years (before 1850) dwarf shrub development on the grassy heaths increases and the proportion of shrubby heath vegetation classes now reaches 35%.

Figure 2 The change in frequency of Rough Pastures, Grassy Heaths and Shrubby Heaths on land which reverted from intensive agriculture during different time periods



This interpretation of a time sequence obviously represents an hypothesis, but mechanisms which can account for the postulated slow sequence of events can also be postulated. The fairly rapid initial change to rough pastures and grassy heaths results from factors such as the drainage deterioration possible on some sites, and the leaching of fertilisers and growth of native species invading or already present in small quantities in the original sward in all situations. On the most naturally acid and readily leached soils shrubby heath development can occur relatively rapidly as grazing pressures are reduced. However, in general, because of the residual effects of former intensive management, grazing on the reverted areas remains at a higher level than on surrounding moorland. Sheep and cattle preferentially graze these sites and sustain a more rapid circulation of nutrients on these pastures through cropping the vegetation and the return of nutrients to the soil surface in their dung and urine. Some sites gradually revert to grassy heaths depending on local conditions and grazing pressures. The succession beyond these to shrubby heaths is very slow on most sites, not only because of the grazing pressures, but because the development of the very acid soil conditions required for dominance by ericaceous shrubs is a very slow process.

Even after 180 years or so the sites on which improved pastures were abandoned have not reached the vegetation pattern shown by the moorland core. This has 13% rough pastures, 34% grassy heaths and 53% shrubby heaths compared with the oldest reversions which have 23, 42 and 35% of sites respectively in these groups. It has to be considered, however, that the reverted areas may never reach the composition shown by the moorland core because of slight inherent environmental differences in local conditions which, in the first place, would have caused farmers to select areas for improvement.

The key point arising from the examination of reverted pastures is the long period required before these sites redevelop the visual characteristics of the adjacent moorland. In contrast, moorland improvement is virtually an instantaneous process. Apart from the obvious interpretation that what man can change quickly takes a long time to restore by natural processes, there is a second implication. The current vegetation is still responding to changes in management that occurred decades or even centuries ago and that alterations in management since the Second World War will still be influencing the vegetation well into the 21st century.

POTENTIAL CHANGES IN VEGETATION

The discussion of vegetation types and their distribution has repeatedly indicated their potential for change and their response to management. There are various strands of evidence on the response of particular plant communities which can now be combined to provide a general scheme showing the inter-relationships of the upland communities. This scheme can then be used to predict the likely response of plant communities to alterations in management.

Some of the evidence of vegetation change comes from general experience in the ecology of plant communities and species. Other evidence comes from historical evidence as already described and from specific management experiments. The latter provide the most direct evidence but the number of controlled experiments on upland vegetation is very small. Experiments relevant to the present topic, but outside the study areas, were visited during the research, and the type of vegetation was related to the classification used here. The experiments were at the Hill Farming Research Organisation's Experimental Farm at Lephinmore in Argyll, the Ministry of Agriculture, Fisheries and Food Experimental Farm at Redesdale in Northumberland and the Nature Conservancy Council National Nature Reserves at Snowdonia in Gwynedd and Moor House in Cumbria. These experiments, some of them extending for more than 20 years, have examined the response of different types of upland vegetation to variations in management, mainly in sheep grazing intensity, but with some study of effects of burning and fertilisation.

The general trends in vegetation change are summarised in Figure 3, using the vegetation classes described earlier. The probable change from one class to another is arrowed with indications of particular factors, eg moisture, which influence the succession. In the case of grassy heaths some regional distinctions are recognised. In general the sequence of change is reversible and the flow diagram shows the direction with reduced intensity of grazing, the time scale being indicated on the right hand side. The changes would be reversed with intensification of grazing and, in the case of rough and improved pastures, of surface management. The time scale of change through intensification is shown on the left. In most cases the development of scrub and woodland can occur as indicated given low grazing and adjacent seed sources. One set of factors is not shown, ie the general environmental constraint or land type, but the limitations to successional changes have already been shown in

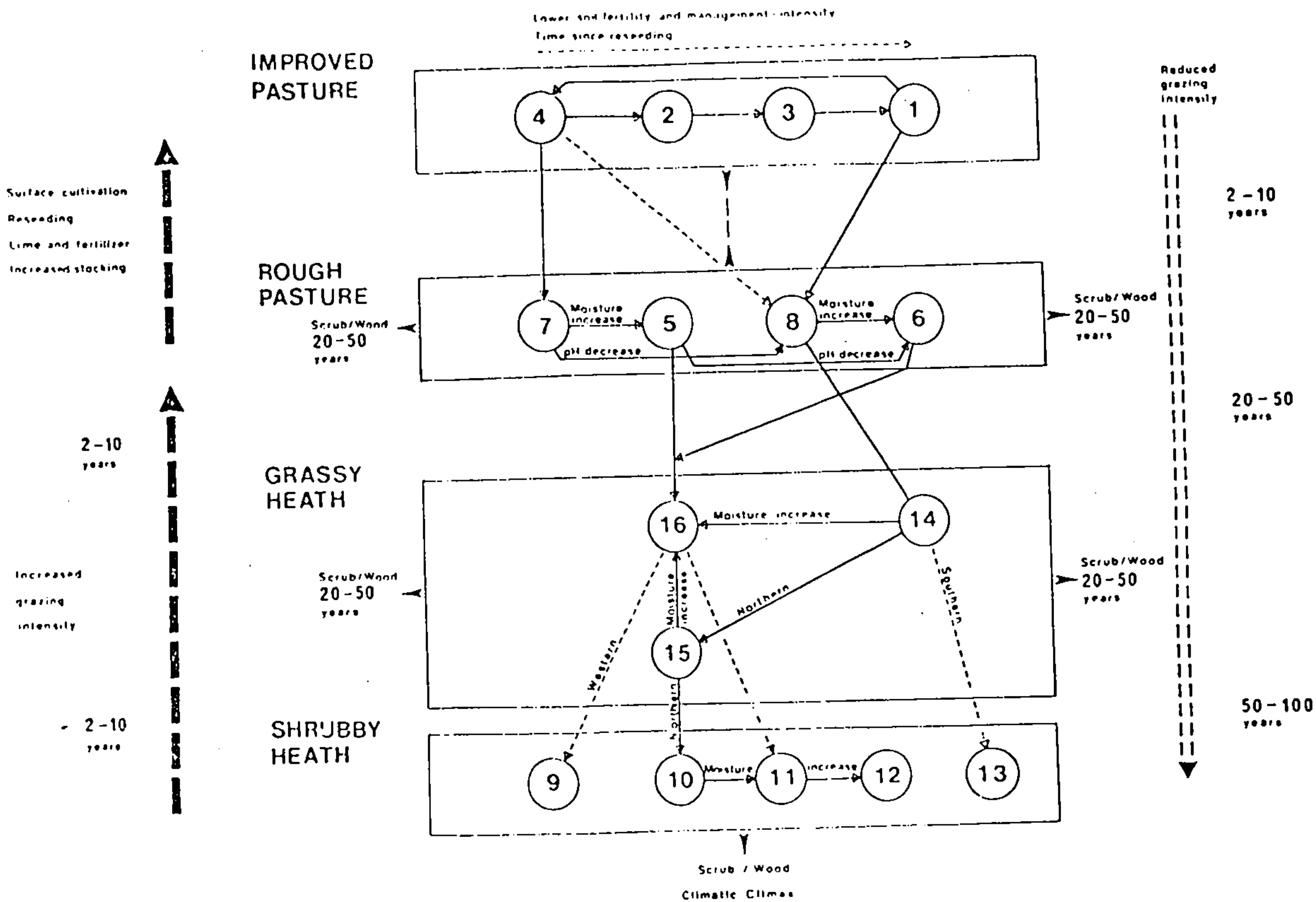


Figure 3 The rate and direction of upland vegetation change through natural succession and management - a working hypothesis

Code numbers: 4 - Herb-rich *Lolium*, 2 - *Lolium*, 3 - *Lolium/Trifolium* and 1 - *Lolium/Holcus/Pteridium* grasslands
7 - *Agrostis/Holcus*, 5 - *Agrostis/Juncus*, 8 - *Festuca/Agrostis* and 6 - *Festuca/Juncus* grasslands
15 - *Festuca/Nardus/Vaccinium*, 16 - *Festuca/Nardus/Molinia* and 14 - *Festuca/Vaccinium* heaths
13 - *Calluna*, 9 - *Calluna/Molinia/Vaccinium*, 10 - *Vaccinium/Calluna*, 11 - *Nardus/Sphagnum/Calluna* and 12 - *Eriophorum/Calluna* heaths

Table 5. The main succession and management summarised in Figure 3 is as follows:

1. Improved pastures. These grasslands have been produced by cultivation, with reseeding and fertilising. Stocking densities are high, usually of about 7-10 sheep per hectare. Some variation in the vegetation of the initial pasture will depend on local conditions, but in most instances the recently sown swards will be herb-rich *Lolium* (class 4), especially under the more favourable soil and climatic conditions. The sward composition changes with time if there is no repetition of the cultivation, approximately in the sequence shown, as weed species begin to colonise. On wetter sites if drainage is impeded, rushes and thistles will tend to increase, moving towards *Lolium/Trifolium* grassland (3), while bracken may encroach on drier soils. The succession through the improved pastures may take up to 20 years if there is no further cultivation. Normally the cycle is repeated with redevelopment of the initial swards and control of weeds through repeated cultivation, seeding and lime, fertiliser and herbicide application.

Improved pastures↔Rough pastures. Without repeated cultivation the improved pastures, after moving through a succession within the group, will gradually revert to rough pastures, although local soil characteristics and moderate grazing may delay the change almost indefinitely. Generally a move from *Lolium/Holcus/Pteridium* grassland (1) to rough pasture communities can take about 10 years and the type of rough pasture which develops will depend on the local environment. The succession sequence between individual improved and rough pastures is not clear, but the associations shown in Table 5 suggest that on more fertile, drier sites herb-rich *Lolium* grassland (4) may revert directly, or via *Lolium* grassland (2), to *Agrostis/Holcus* rough pastures (7) or possibly to *Festuca/Agrostis* grassland (8). The latter may also be the main line from the *Lolium/Holcus/Pteridium* grassland (1) at the end of the improved pasture succession. The rate of reversion from improved to rough pasture is typically one of the more rapid vegetation changes.

ii. Rough pastures. Grazing at about 4-7 sheep per hectare maintains the rough pastures. The grazing intensity depends on sward composition, which partly reflects soil fertility. The *Agrostis/Holcus* grasslands (7) tend to be more fertile and the *Festuca/Juncus* grasslands (6) on poorer sites. Successional changes between types of rough pasture are complex but tend to be associated with gradual increases in soil moisture and acidity. Thus *Agrostis/Holcus* (7) and *Festuca/Agrostis* (8) pastures occur mainly on relatively dry soils, associated with low rainfall and/or good drainage. *Fesctua/Agrostis* is the main rough pasture at the higher altitudes and tends to develop from *Agrostis/Holcus* pastures, with time, if soils become more acid. If soil moisture increases through deterioration of drainage, rough pasture classes 7 and 8 will tend to develop to *Agrostis/Juncus* (5) and *Festuca/Juncus* (6) grasslands respectively. *Festuca/Juncus* pastures may also develop from *Agrostis/Juncus* grassland if soils become more acid and organic matter accumulates. These successional changes would probably take decades to occur and could be promptly reversed by improvement of drainage and/or liming. Scattered trees and bushes are present on some of these pastures and scrub and woodland would often develop if grazing pressures were sufficiently low.

Rough pastures↔Grassy heaths. The reversion from improved to rough pastures, and the succession within rough pastures, is associated with a decrease in soil pH, as lime is progressively leached and not replaced. Grassy heaths have a still lower average pH and, with their peaty soils, are often wetter than the rough pastures. At the wetter sites *Agrostis/Juncus* (5) and *Festuca/Juncus* (6) grasslands tend to change to *Festuca/Nardus/Molinia* heath (16), the change being initiated by reduction in grazing pressure. Where grazing pressure is reduced on the drier rough pastures the succession probably moves through *Festuca/Agrostis* grassland (8) to *Festuca/Vaccinium* heath (14). With the exclusion of grazing on rough pastures, succession to grassy heath vegetation can take less than 10 years. However grazing intensity tends to be reduced rather than removed, and the succession normally takes much longer. An increase in grazing intensity on grassy heaths can result in development of rough pastures by suppression of the dwarf shrubs and coarser grasses, the change taking 10 years or more.

iii. Grassy heaths. The grassy heaths are maintained by a grazing pressure of about 2-4 sheep her hectare, and successional changes between them and the shrubby heaths are also often prevented by burning. The inter-relationships between the three types of grassy heaths are not distinct. Soil drainage tends to be poorer on the *Festuca/Nardus/ Molinia* heaths (16) so that this class develops very slowly from the other grassy heaths (14, 15) only when the surface soil becomes wetter. Given exposure of the soil surface, tree seed may germinate from local sources at moderate altitudes and in the absence of grazing.

Grassy heaths↔Shrubby heaths. The interchange between grassy and shrubby heaths is determined mainly by the effect of grazing and burning on the survival of dwarf shrubs. The change in vegetation is again associated with a shift to lower pH, partly cause and partly effect. Reduced grazing pressure allows the expansion or incursion of dwarf shrubs on grassy heaths, but the process is usually very slow and may show regional differences. *Festuca/Vaccinium* heath (14) appears to develop towards dry *Calluna* heath (13) in southern areas, but through *Festuca/Nardus/Vaccinium* (15) to *Vaccinium/Calluna* heath (10) in more northern areas.

iv. Shrubby heaths. Burning is the principal means of maintaining vigorous shrubby heaths, allied to a grazing pressure of less than about 2 sheep per hectare. Shrubby heaths tend to be stable for long periods under consistent low levels of management. Classes 10, 11 and 12 tend to develop in response to differing environments, but there is some trend through these with increasing development of more peaty soils and permanent waterlogging. As with grassy heaths, scrub woodland may be established below about 400 m, or in drier sites, where grazing and burning is restricted. Local tree seed sources, particularly of birch, rowan, hawthorn or conifers, encourage woodland development. Above about 400 m tree growth weakens and dwarf shrubs may remain as the climax vegetation, with *Calluna* declining above about 700 m.

FUTURE CHANGES IN VEGETATION

What will be the future pattern of vegetation? There is no simple answer. Much will depend on the extent to which farming and forestry are encouraged to expand, or contract, in response to national policies and other socio-economic forces. The extent to which these industries will respond varies between areas, depending on local environmental, social and economic conditions and on local constraints of competing land uses such as grouse shooting and amenity interests. Thus there are a number of possible answers to the question depending on the unpredictable expansion or contraction of land uses. Therefore we have examined a number of scenarios to indicate the distribution and type of vegetation change which would result from different trends in land use. Basically we have examined the vegetation pattern that would result from extreme, but feasible, developments in land use, particularly the extension or contraction of agriculture. This shows the maximum range of vegetation change and allows interpolation to estimate the effect of varying levels of development. The scenarios are based on the known distributions of vegetation in response to management changes.

The main options for land use change which are examined are:

i. Continuation of the historical pattern of change

ii. Major expansion or decline in agriculture. The likely change is assessed by two independent methods:

   a) change in the 1 000 vegetation sample points
   b) the agricultural potential of land types

iii. Major expansion of forestry but with retention of the better agricultural land for agriculture.

i. Continuation of the historical pattern of change

It is important to distinguish between the trenas in agriculture and forestry, and agriculture is examined first. The intensity of agriculture in the uplands has fluctuated considerably over the last 200 years. Marked changes in one parish are often independent of changes in other parishes (Figure 1). Overall there has been a small but detectable loss of moorland vegetation which is partly offset by reversion of land from agriculture to moorland. Given tho recent upward trend in stock numbers (Figure 1 and ULS 1981) and attitudes of farmers towards positive changes in management (ULS 1981), it is probable that in the near future the loss of moorland through agricultural reclamation will continue. The Upland Landscapes Study (1981) estimated the recent loss rate of moorland as 0.66% per year, but as at least three-quarters of this is by forestry (Table 6), the average loss rate as a result of agriculture is about 0.16% per year.

Agricultural reclamation has been greatest in Glascwm, Lynton, Widecombe and to a lesser extent in Monyash. As there has been little afforestation in these four areas the rate of reclamation is about 1% per year. These four areas are showing increased numbers of sheep or cattle and their farmers have a positive attitude to agricultural development. In addition, Glascwm and Lynton, and to a lesser extent Widecombe, contain a high proportion of the land types in which land use change has been concentrated in the past. The assessment of agricultural potential by ULS (1981) shows a significant reserve of improvable land in Glascwm, Lynton, Widecombe and Bransdale, with further options in Alwinton and Shap, which are less attractive because of climate.

The pattern of probable change through continuation of existing trends is clear:

i. Glascwm, Lynton and Monyash will lose moorland most rapidly (c. 1% per year) and with their small area of moorland, the loss will be visually obvious; Widecombe will probably also lose moorland quite rapidly but, as with Glascwm and Lynton, much of the moorland is Common Land and will probably not be affected directly.

ii. Lunedale may show a rate of reclamation of about 0.3% per year, but such activity will be restricted by the limited land quality and by moorland use for grouse.

iii. Very low rates of moorland reclamation (less than 0.1% per year) are likely to occur in Shap, Llanfachreth, Ystradynlais and Alwinton. This reflects a combination of poor quality land, limited increases in stock and less positive attitudes of the farmers, although there are some major constraints of ownership or competing land uses.

iv. Negligible rates of reclamation (less than 0.01% per year) are expected in Bransdale, Ysbyty Ystwyth and Heptonstall. Despite the relatively good quality of land in Bransdale and lack of common land constraint, reclamation is mainly restricted by management of the moorland for grouse. Improvement in the other two areas is unlikely for a variety of reasons, including Common Land registration and use of the areas for water catchment.

v. The area of pasture which has been allowed to revert to moorland has been very small in recent years; a total of 300 ha over 38 years, mainly in Llanfachreth and Bransdale where the addition to moorland is only at about 0.1% per year. There is some indication that recent reversion is associated with afforestation, but the pattern is not clear.

Given the continuing trends a total of about 1 800 ha of moorland would be improved for agriculture, representing about 4% of the current moor. The improvement is likely to occur at the edge of the moorland, on land types where change has occurred previously, ie in upland margin and steep upland. Thus the vegetation most likely to be affected would be *Festuca/Agrostis* and *Agrostis/Holcus* grasslands, and possibly *Festuca/Vaccinium* and *Festuca/Nardus/Molinia* grassy heaths. Shrubby heaths are uncommon on these land types, but some *Vaccinium/Calluna* heath may be lost. The predicted types of vegetation corresponds with the recent losses observed by ULS (1981), who showed that losses were predominantly (60%) from 'smooth grassland' dominated by *Festuca* and *Agrostis*, with 20% from 'coarse grassland' of *Nardus* and *Molinia*.

The projected continuing trend of increased area of improved grassland and increased stocking in some of the study areas will result in increased grazing intensity on the moorland. The trend in grazing intensity is likely to be partly offset by the trend from hill to upland farming noted by ULS (1981). There is no direct evidence of the rate at which vegetation change has been occurring on the moorland as a result of recent increases in grazing pressures. Some tendency to reduction in heather and bracken cover was suggested by ULS (1981), although in Widecombe both species appear to increase. Evidence from a study of heather moorland on Exmoor (Miller, Miles and Heal 1979) indicated that heather moor was being lost by increased grazing, uncontrolled burning and recreation pressures on the edge of the moor. Such changes are most marked where the areas of moor are small or fragmented, giving a large edge of effect. In addition controlled burning of heather as grouse moor is not common in the south-west, leading to degeneration of the heather.

From the scattered evidence, the projected trend towards agricultural expansion will result in slight changes in vegetation in the moorland core. Heather cover is most likely to be affected, but this will be detectable mainly in the areas where expansion is greatest (Glascwm and Lynton) and the moorland area is small.

A final qualification is that the scenario of projection of current rates of change assumes continuation over the next 20 years, with varying rates in different areas. Past experience indicates that long term trends are less likely than short term fluctuations. Therefore it is probable that the degree of change will be less than that predicted, and the focus may shift.

While maintenance of recent trends in agriculture would result in some loss of moorland, especially rough pastures, additional changes would result from continuation of recent trends in afforestation. In the last 30 years about 4 000 ha of coniferous forest has been developed, representing a loss of about 0.3% of the moorland annually. The highest rates and largest areas have been in Alwinton and Llanfachreth and to a lesser extent in Ystradgynlais and Bransdale. The continued expansion of forestry at the current rate would remove about 2 900 ha or 6% of the present moorland core by the turn of the century. Given the estimated areas of potentially plantable land and allowing that Common Land and grouse moors will remain unplanted, then the majority of the forest expansion is expected to occur in the northern areas, particularly Alwinton, but also Lunedale and Shap. These three areas combined have about 2 900 ha of moorland, of which about half is potentially plantable. Further afforestation will occur in Wales, mainly Llanfachreth, Ysbyty Ystwyth and Ystradgynlais, where moorland and plantable land are only a third of the size of the northern areas. Some restriction on forestry may occur through National Park status, but this will probably not be a major factor on the evidence that the distribution of recent afforestation is not correlated with National Park designation.

As with agricultural improvement, afforestation is most likely to occur on steep upland and upland margin land, thus affecting mainly rough grasslands and moorland dominated by *Nardus* and *Molinia*. The effect of afforestation on adjacent moorland is not well documented, but it is probable that in some areas it will result in reduced grazing pressures and increases in shrubby heaths. In contrast, forestry may cause concentration of grazing on remaining moorland, especially where there is a planned mixed land use, with a resulting reduction in shrubby heaths. Thus, there will probably be little change in the total area of different vegetation types, but their distribution may be affected.

The combined effect of continuation of recent rates of agricultural and forestry development, if maintained to the end of the century, will be a loss of about 4 700 ha of the present 48 000 ha of moorland, ie about 10%. Losses will be mainly to agriculture in southern England, to forestry in northern England, and to both in Wales. The main vegetation to be affected would probably be *Festuca/Agrostis* grasslands, *Festuca/Nardus/Molinia* and *Festuca/Vaccinium* grassy heaths, possibly 1 000 ha of each, with smaller amounts of *Agrostis/Holcus* grassland and *Vaccinium/Calluna* heath.

ii. Major expansion or decline in agriculture

Whilst the most probable scenario is a continuation of recent trends, it is possible that a major expansion or decline in agriculture could occur through external economic forces. The forces may act on selected areas or overall, but we have examined the effect in each area of an increase or decrease of 50% in the current management intensity, in particular stock densities. Such a degree of change over a period of 10-20 years is not unrealistic; it represents about the maximum rate of change which has occasionally occurred in some parishes in the past (Figure 1). To estimate response of vegetation we applied the general scheme of the potential vegetation change, summarised in Figure 3, to the 1 000 sites at which detailed recording of vegetation was made. The probable change at each site was assessed and results combined to show the expected degree of change in each study area.

A second, and independent, assessment of vegetation change in response to a major, possibly maximum, expansion of agriculture was made on the basis of the potential of each of the land types. Maximum expansion of agriculture, with increased pasture productivity, higher stocking rates and associated management changes, would utilise intensively the following percentage of each land type: upland margin 100%, upland and upland plateau 90%, steep upland 60%, hill 30%, high plateau and steep hill 20%. This would expand agricultural use through the moorland fringe and result in more intensive use of the moorland core. A development of this type would result in the proportions of improved pastures, rough pastures, grassy heaths and shrubby heaths being in the upland margin 70, 30, 0 and 0% respectively, in the upland land group 60, 20, 20 and 0%, and in the hill land group 10, 10, 50 and 30%. This degree of intensification is at about the maximum level currently achieved in some of the parishes.

The vegetation change that would result from intensification is very similar overall in the two predictions, although there are some variations within particular study areas (Table 7). In general, the area of improved pastures would increase by about 40% with major changes in Alwinton, Lunedale, Llanfachreth and Ysbyty Ystwyth and negligible change in Monyash and Lynton. The area of rough pastures and grassy heaths would show no major change, although the predictions based on vegetation response indicates a fairly general increase of about 35% in rough pastures. The shrubby heaths would show a major decline under intensification, being virtually eliminated in Widecombe, Lynton and Glascwm. Although the shrubby heaths would remain as a main vegetation type in Alwinton, Lunedale and Ysbyty Ystwyth, their area would be reduced by about 50%.

The change in the balance of vegetation with agricultural intensification is thus most obvious at the ends of the vegetation succession, the improved pastures and shrubby heaths. This is because although many existing rough pastures and grassy heaths will be altered, new rough pastures will be produced from grassy heaths, and new grassy heaths from shrubby heaths. Thus although the amount of rough pastures and grassy heaths may change only slightly, their distribution will change.

The effect of intensification would vary considerably between areas. Monyash, Lynton and to a lesser extent Glascwm would show relatively little change because they are already close or at their maximum agricultural potential. Alwinton, Lunedale, Shap, Heptonstall, Ysbyty Ystwyth and Ystradgynlais would

Table 7 The current and predicted percentage frequency of vegetation in the study areas, the predictions following agricultural intensification or decline.

C = current frequency at sample sites; I_1 = intensification, assessed from sample sites; I_2 = intensification, assessed from potential of land types; D = decline, assessed from sample sites.

Study area		Improved Pastures	Rough Pastures	Grassy Heaths	Shrubby Heaths
Alwinton	C	8	27	36	31
	I_1	33	36	13	18
	I_2	27	14	38	21
	D	6	0	28	66
Lunedale	C	1	12	22	65
	I_1	13	22	9	56
	I_2	21	13	42	24
	D	1	0	11	87
Shap	C	19	14	34	33
	I_1	33	34	30	3
	I_2	34	15	35	16
	D	17	5	11	67
Bransdale	C	11	11	34	44
	I_1	22	34	41	3
	I_2	49	19	23	9
	D	6	6	11	77
Heptonstall	C	25	11	10	54
	I_1	36	10	27	27
	I_2	48	19	25	8
	D	20	6	10	64
Monyash	C	86	14	0	0
	I_1	100	0	0	0
	I_2	63	20	17	0
	D	86	10	4	0
Llanfachreth	C	8	31	31	30
	I_1	39	31	26	4
	I_2	50	21	20	9
	D	4	17	18	61
Ysbyty Ystwyth	C	7	12	29	52
	I_1	19	24	27	25
	I_2	34	16	33	17
	D	1	8	9	81
Glascwm	C	47	23	16	14
	I_1	70	16	14	0
	I_2	51	20	22	7
	D	27	30	15	28
Ystradgynlais	C	20	17	38	25
	I_1	37	38	24	1
	I_2	35	16	33	16
	D	13	7	16	64
Lynton	C	68	10	14	8
	I_1	78	14	8	0
	I_2	57	22	17	4
	D	51	23	4	23
Widecombe	C	37	21	5	37
	I_1	58	5	37	0
	I_2	56	21	19	4
	D	24	19	15	43
All Areas	C	27	17	23	33
	I_1	44	23	22	11
	I_2	43	18	27	12
	D	20	10	13	57

show some improvement on the moorland edge but would retain much of their general character, including signficant areas of shrubby heaths. Probably the most marked change would be observed in Bransdale, Llanfachreth and Widecombe, where improvement in the moorland edge would be associated with large reductions in shrubby heaths on the moorland core.

The degree to which the change could be achieved would depend on a variety of local factors such as agreements over Common Land and competing interests such as grouse moors, water authorities, forestry and amenity interests. In the very unlikely event of concerted intensification of agriculture in all areas, overriding the local constraints,the loss of current moorland vegetation to improved pasture would be of the order of 11 500 ha. This represents about 24% of the existing moorland and is about six times the loss if agricultural improvement is maintained at its recent rate.

The projected change resulting from improvement could occur within a decade or so of a major incentive for agricultural development. The alternative of a major decline in agriculture, with a halving of stocking densities, would result in a much slower rate of vegetation change. Based on the vegetation of the detailed sampling sites and the vegetation succession under reduced management (Figure 3), there would be a general loss of improved pastures through reversion which would affect more than half of the pastures only in Llanfachreth and Ysbyty Ystwyth (Table 7). There would be virtually no loss of improved pastures in Alwinton, Lunedale, Shap and Monyash, although there would be some change in the type of vegetation on these pastures. In Alwinton and Lunedale major reductions in rough pastures would be likely as they revert to grassy heaths under reduced grazing intensity. The degree of change would be less in most of the areas and a reduction in grassy heaths is likely to occur consistently. Apart from the reversion of improved pastures on the edge of the moorland, the most marked change would be the conistent increase, usually about 100%, in the shrubby heaths.

A decline in agriculture of about 50% would, in a period of 10 to 20 years, add about 2 500 ha (5%) to the moorland or semi-natural vegetation. This rate of reversion has occurred in selected areas in the past, eg Shap at the end of the 19th century and in Llanfachreth since about 1940. With such a decrease in agriculture the vegetation change would continue for many decades and in some parts of the moor would allow regeneration of srub and woodland. Decline in agriculture of the scale projected are unlikely to occur, particularly in view of the expressed attitude of farmers. However, changes of this type are less inhibited by ownership and conflicting interests than are improvements and can be precipitated by local social and economic conditions or by pressures from other land uses. It is probable that reduced agricultural use would encourage forestry development and the final scenario examines the extent to which forestry expansion could affect the vegetation.

iii. Major expansion of forestry

The degree to which forestry could expand is determined by the forestry potential of the land, ownership, competing uses and other social and economic forces. Land quality is the ultimate constraint; other factors can be overcome by man. However, in this final projection we have estimated the vegetation change that would result from expansion of forestry onto all the plantable land, but with the proviso that intensive agriculture would be retained on the most productive parts of the uplands.

The projection is made using the distribution of land types and their associated vegetation. Upland margin would remain entirely in agriculture; of the upland and upland plateau, 50% would retain substantial agriculture; most (75%) of the steep upland would go to forestry. Of the hill land, only the part below 427 m (1 400 ft) would be of use for forest production, the remainder being retained for extensive grazing. With the reduced agricultural base, grazing intensities on the hill land would probably be reduced, resulting in a succession from grassy to shrubby heaths, with some scrub development immediately above the planted ground.

The resulting pattern of vegetation and land use (Table 8) indicates, rather surprisingly, that although the forest cover could expand from the present 10% to 40% of the total areas, there is room for expansion of land under agriculture from the current 21% to about 30%. The calculations indicate a decrease in agricultural use on Monyash, Glascwm and Lynton, but this is improbable because of the strength of existing agriculture. These areas will remain predominantly agricultural. Bransdale, Heptonstall, Llanfachreth and Widecombe would be equally concerned with agriculture and forestry. It appears that in Llanfachreth virtually all the potential land is already under forest and any further expansion would utilise land of a quality which is used for intensive agriculture in other areas. Alwinton, Shap and Ystradgynlais would have forestry as their most prominent use but with about 30% of open hill land remaining. Only Shap and Ysbyty Ystwyth would remain predominantly open hill areas.

The maximum area of land with forestry potential is about 37% of the total area, or 27 500 ha. This includes existing forest and some Common Land, thus a more realistic estimate of the land 'available' for forestry is of the order of 15 000 ha. However, given the maximum expansion of forestry, with protection of the best agricultural land and reduced grazing pressure on the unplanted hill land, the vegetation on the unplanted land would consist of about 17% improved pasture, 8% rough pasture, 6% grassy heath and 32% shrubby heath. Thus the area of semi-natural vegetation would be reduced to about 31 000 ha, a loss of about 35% or 17 000 ha.

INTERPRETATION

The aim of the study has been to provide a quantitative assessment of the relative importance of environmental and human factors which influence vegetation change and to indicate the possible course and cause of future change. The analysis has been objective and, whilst interpretation of the results and their implications must to a certain extent be subjective, there is no advocacy of particular land uses or value judgement of the consequences. The following points represent a preliminary assessment of the main implications of the study, the further application of the information and methods, and the requirement for additional information.

Loss of moorland

Fluctuation in upland land use should be regarded as normal. Change has been a characteristic over the last 200 years but the timing of moorland reclamation and agricultural reversion has not been consistent between parishes. Local social and economic factors have determined the rate and timing of land use change, but environmental factors are responsible for

Table 8 Estimates of maximum potential forestry land as a percentage of the study areas, assuming use of the best land for agriculture and no forestry above 427 m. Present percentage areas for agriculture and forestry, with conifer plantations in parenthesis, are from ULS (1981). Study areas where current agricultural use is dominant are likely to survive preferentially even in a high forestry strategy are marked *.

Study area	Unplantable	Forestry land		Agricultural land	
		Potential	Present	Potential	Present
Alwinton	30	58	18 (17)	12	5
Lunedale	75	12	1	13	8
Shap	35	42	3 (1)	23	26
Bransdale	2	53	9 (8)	45	22
Heptonstall	10	50	6 (1)	40	20
Monyash*	0	45	1	55	93
Llanfachreth	20	31	33 (30)	49	17
Ysbyty Ystwyth	50	25	8 (8)	25	13
Glascwm*	20	35	4 (2)	45	59
Ystradgynlais	30	42	11 (8)	28	16
Lynton*	0	45	9 (1)	55	58
Widecombe	6	39	8 (3)	55	42
12 areas combined	33	37	10 (8)	30	21

limiting fluctuations to a distinct zone - the moorland fringe. Thus in all the areas studied, the zone of land use change has directly affected about 11% of the total area. The majority of the resulting direct loss of 6-12% of the moorland or semi-natural vegetation has been in two land types. The inference is that future fluctuations in land use are most likely to occur in this type of land which can be distinguished in the 12 areas, and in other areas of upland.

Vegetation change within the moor

The degree of change within the moorland that has resulted from varying grazing pressures and management regimes is uncertain because of the lack of detailed descriptions of the past state. The Upland Landscapes Study (1981), through re-survey of the vegetation maps of the Second Land Utilisation Survey, detected some change in composition of semi-natural vegetation since 1967 but these are not quantified. The main changes on the moorland are probably in the cover of heather and bracken associated with variation in grazing and burning. Both plants are important visual components of the landscape and the sensitivity of dwarf shrubs to grazing and burning has been emphasised. Evidence suggests that the existing management regimes, particularly associated with grouse interests, will maintain the heather on many moors.

The dwarf shrubs in Lynton and Widecombe are probably most vulnerable, not only because of reclamation, but because they are not burned systematically. In addition, fragmentation and dissection of moorland increases the length of margin relative to the area. The increased edge effect with associated grazing, recreation and burning pressures is likely to reduce significantly heather cover. The increase in the length of margin is recognisable in Lynton, Widecombe, Glascwm, Llanfachreth and in part of Ysbyty Ystwyth. The conclusion is that the degree of change in moorland in sensitive areas needs to be monitored and the state of the shrubs assessed in relation to known burning and grazing regimes. Active, controlled management will have to be introduced, designed to conserve shrub heaths where they are most vulnerable and are of amenity value. However, in small areas of moor of high scenic value, the necessary burning regime may itself be visually unacceptable.

Although it is widely stated that bracken is spreading, the distribution and rate of spread is inadequately documented and the ULS (1981) results indicate that reduction in bracken cover is more general than is its spread. Again selective monitoring is required to define the 'problem'. Suitable management techniques for control are available, their application depends on the economic benefit gained from improved grazing and the extent to which bracken is regarded as detracting from the landscape value of an area.

The potential succession of vegetation in relation to management is reversible, but it is important to recognise that while vegetation change occurs rapidly with increased intensity of management, the reverse process is slow. As management intensity is varying over the years it is to be expected that the vegetation is in a state of flux. The moorland core, covering about 60% of the total area, contains a mosaic of vegetation resulting from environmental heterogeneity and variation in management. Although the vegetation at a particular place may be seen to change in one direction, a reverse change is likely to occur elsewhere. Thus the diversity of vegetation is likely to remain while the distribution of the components will change. The component which is most susceptible is the shrubby heaths, because they are at the end of the succession. Shrubby heaths are one of the most extensive types of vegetation, and are protected as grouse moors over much of the uplands.

Thus there are two general conclusions concerning vegetation within the moorland. First, that most of the uplands will retain the characteristic mosaic of vegetation. Second, that the moorlands on which significant landscape changes are occurring are the shrubby heaths of southern England.

Expansion of forestry

In recent years the rate of loss of moorland to intenstive agriculture and forestry has increased considerably, while the rate of reversion from agriculture has been slower than previously and does not affect reclamation. Afforestation, affecting mainly northern and Welsh parishes, is causing a greater loss of moorland than is agricultural improvement. The most reasonable prediction of future changes in land use is that forestry and agriculture will continue to expand, although there are indications that the rate of agricultural improvement will not be maintained because it is concentrated in southern England where pressures for moorland conservation are greatest. The expansion of the forest area is expected to continue with planting of about

30 000 ha per year in Great Britain. In the period 1975-79, about 16% of the total planting was in England and Wales (Forestry Commission 1980). Therefore the expected future planting in England and Wales will be about 4 800 ha per year. The majority of this will be in the uplands, and the 12 areas represent about 10% of the Less Favoured Areas and about 3% of the 2 million ha of uplands in England and Wales. As a result between 3 and 10% of the planting, or 144 to 480 ha yr^{-1} can be expected in the study areas. Thus the minimum planting rate that can be expected in the study area is equivalent to that of recent years. It is possible that higher rates may occur given the figure of 480 ha yr^{-1} and that the planting rate of 30 000 ha yr^{-1} is regarded by some people as conservative (CAS 1980, ITE 1978). Continuation at the recent, minimum, rate of planting would require just under 3 000 ha of land, possibly less given some replanting, which would increase the current area of coniferous forest by about 50% by the year 2000.

The projected expansion of the forest area is well within the forestry potential of the areas, even when the better land is retained for agriculture. The constraint to expansion is in the existing use of the moorland for grouse moor, water catchment and military training, the Common Land and National Park status, and the use as rough grazing. The need to reconcile conflicting interests is obvious, in particular relaxation of planting restrictions on catchment areas and in National Parks needs to be examined, with inclusion of more landscaping in the forestry. The extent to which afforestation affects agricultural use of adjacent land is not clear, both from a farming viewpoint and in relation to changes in grazing and burning of the moorland. More factual information is needed by selected sampling and monitoring. It is possible that the recent recommendation that part of the Forestry Commission (FC) holdings be sold could result in some change in land use pattern, because under private ownership there appears to be greater opportunity to integrate forestry and agriculture.

Expansion of agriculture

It is possible that the changes in land use in the next 20 years will be a continuation of recent trends as described. The additional scenarios of maximum agricultural development or decline represent extremes which are unlikely to occur simultaneously in all the areas, but could occur in individual areas as a result of special conditions. This is realistic in that changes of the order examined have occurred in some of the parishes in the past, and the degree of intensification of land types has been achieved in some areas. The results suggest that agricultural improvement is unlikely to proceed further in Monyash, Lynton and Glascwm, but there is the potential for expansion in other areas. The implication is that over much of the uplands, agricultural production is below capacity and could be expanded in response to adequate incentives. Given expansion, the main effects on vegetation would be an increase in improved pastures on the moorland edge and a decrease in shrubby heaths on the moor. Where the latter are regarded as an important landscape feature and are likely to be significantly reduced, eg Widecombe, some restriction of stocking densities may reconcile conflicts.

Reduction of agriculture

The reduction in agriculture could cause marked but slow changes in the moorland vegetation and reversion of pastures, with eventual increase in shrubby heaths and woodland. Such changes in vegetation are probably unimportant in terms of landscape compared with the abandonment of buildings and lack of repair of walls and fences. However, it is in areas of agricultural decline that forestry is most likely to develop. The ULS (1981) results indicate a number of factors which determine reduced agriculture, including farmers' attitudes, farm structure and tenure. These results could provide predictions of areas in which reduced farming is most likely to encourage forestry development. Such an assessment would focus discussion onto particular areas where unwelcome but inevitable landscape changes, such as abandonment of buildings, might be reconciled with unwelcome but more productive forestry development. As the national policy for forestry is clear, in terms of land requirement, it would be rational for forestry, agriculture and amenity interests to determine the extent to which their policies are in conflict and define the optimum solution. Although there is no statutory obligation for such a course of action, the problems may be more apparent than real, and co-operative action could be constructive.

General application of methods

The 12 areas are a representative sample of the parishes of the Less Favoured Areas and the trends and predictions are considered to be applicable to much of the uplands of England and Wales. Aspects of the approach used in the study are also applicable to other uplands. The summary of the response of vegetation to management can be used as a general guide to the rate and direction of vegetation change (Figure 3). The degree to which change can occur is determined by local environmental conditions. An indication of the potential range of vegetation which can occur under particular conditions is given for each land type (Table 5). The frequency of vegetation in a land type also indicates the probability of being able to modify one vegetation type to another. The vegetation and land types can be broadly identified from the descriptions given here, but more precise definition can be obtained by using the classification keys given in Ball *et al.* (1981a). Although not described here, Ball *et al.* (1981a) also give a more detailed description of the distribution of vegetation in relation to specific factors within land types, eg pH and rainfall.

Further research requirements

The outstanding need in relation to vegetation has already been identified - precise monitoring of vegetation change. Although loss of area of vegetation can be estimated from historical documents the change in vegetation can only be assessed against a detailed, quantitative base line. The maps of the 2nd Land Utilisation Survey are not generally available and are too dependent on subjective judgement to provide precise estimates of change. The present survey provides a series of sample points which can be used as a quantitative base for monitoring. The main requirement is to determine the change in shrubby heaths. Sample sites would be selected in areas where change is expected and in control sites. The effect of forestry would also be assessed by sampling heaths near to and distant from afforestation. In all cases it is critical to have detailed, on-site measurement of grazing intensity and burning frequency.

Changes in land use are predicted, as in earlier studies. The accuracy of such predictions is always debated but rarely tested. Reappraisal of the predictions should be made against actual changes in land use, in about five years' time.

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REFERENCES

Ball, D.F., Dale, J., Sheail, J.D.B., Dickson, K.E. & Williams, W.M. 1981a. Ecology of vegetation change in upland landscapes, Part I: General synthesis. *ITE Bangor Occasional Paper No 2.*

Ball, D.F., Dale, J., Sheail, J.D.B., Dickson, K.E., Williams, W.M. & Nelson, A. 1981b. Ecology of vegetation change in upland landscapes, Part II: Individual study areas. *ITE Bangor Occasional Paper No 3.*

CAS. 1980. *Strategy for the UK forest industry.* Rept 6, Centre for Agricultural Strategy, University of Reading.

Forestry Commission. 1980. *Forestry facts and figures 1978-79.* Edinburgh: Forestry Commission.

Garnett, F.M. 1912. *Westmorland agriculture*, 302 pp. Kendal: Wilson.

Hill, M.D., Bunce, R.G.H. & Shaw, M.W. 1975. Indicator species analysis; a divisive polythetic method of classification, and its application to a survey of the native pinewoods of Scotland. *J. of Ecol.*, 63, 597-613.

Institute of Terrestrial Ecology. 1978. *Upland land use in England and Wales.* Countryside Commission Publication 111. Cheltenham: Countryside Commission.

Miller, G.R., Miles, J. & Heal, O.W. 1979. *Moorland management study.* Report to Countryside Commission (unpublished).

Upland Landscapes Study. 1981. Draft report to Countryside Commission (unpublished).

Welsh Agricultural Land Sub-Commission. 1955. *Mid-Wales investigation report.* Cmd 9631. HMSO 1955.