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Ecological consequences of land use change

Final report to Department of Environment

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EXECUTIVE SUMMARY

The project was initiated by DOE to determine changes in the underlying ecological patterns associated with the general changes in land use and cover reported by Government Agencies. Although the balance of land use in Britain has remained relatively constant, there has been a loss of ecological and genetic diversity that has implications for the appreciation of the countryside and the maintenance of variety in British vegetation and fauna.

1. In landscapes dominated by arable farming, ie East Anglia, southern and central England and eastern Scotland, over the last 40 years there has been a shift from mixed farmland, with a wide degree of ecological variability, to a uniform landscape dominated by cereals. The ecological composition of agricultural land has been widely modified by use of herbicides, pesticides and fertilisers. There has been a concurrent decline in hedgerows, although the loss is a smaller proportion than in other lowland areas. There has also been a widespread loss of semi-natural habitats such as wetlands and chalk grassland. Linear features occupy less than 5% of the land surface, but are of major ecological significance because they act as a reservoir for species which are no longer able to survive in open fields. They also act as corridors linking fragmented habitats. These linear features currently have no protection. In recent years, new small woodlands have been planted and many small marginal habitats associated with human use, eg motorway verges, have been created. Urban development has significantly affected these landscapes but mainly at the expense of already intensively farmed grasslands, so there has been little effect on native vegetation.

2. In landscapes dominated by grasslands, in western Britain, the use of slurry, fertilisers, silage and zero grazing has caused a major shift in species composition away from relatively species-rich grasslands, in favour of those species which respond to high nutrient levels, and at the expense of slow-growing species which are often of interest to nature conservation. There has been an associated loss of hedgerows, proportionately greater than in other areas, because of the greater length originally present. The ecological significance of such losses is emphasised because of their high species diversity. Other linear features are also important as refuges in the otherwise intensively farmed landscape. There has been a major loss of ancient woodlands, mainly replaced by conifer plantations with a consequent loss of ecological diversity. Other relicts of semi-natural vegetation, such as lowland heaths, have also been lost. Urban development has been locally important.

3. In the mixed land cover types found in the marginal uplands of Wales, northern England and Scotland, the main change of ecological significance has been the conversion of upland pastures and heathlands to productive grassland. The major losses occurred in the 1940s and 1960s, but the process is still continuing. Greater grazing pressure on moorlands has led to loss of heather cover in some areas. There has also been intensification of managed grasslands in parallel to that in the lowlands. Linear features are more varied in the marginal areas, with more walls and fences, and have changed less than in other parts of the country. In this region the main changes have been linked to modifications of socio-economic patterns, such as the amalgamation of farms, because of pressure on farm incomes and the release of land for afforestation.

4. Afforestation has been the main land use change in landscapes dominated by moorland and bogs in the mountain areas of Wales, northern England and Scotland, and there has been an associated loss of species caused by the dense canopy cover. Indirect changes, such as drainage and acidification have also caused ecological decline. In many regions grazing pressure has increased, causing loss of heather. Elsewhere, in isolated areas, declining grazing pressure has lead to colonisation by aggressive species. In general there are fewer changes in the uplands than the lowlands, but they have a radical effect over a limited area.

5. Faunal populations are largely linked to the availability of suitable vegetation for cover or food, which in turn are associated with the local ecological characteristics. Within relatively uniform environments, management determines the actual composition of species, and known relationships can be used to predict the consequences of change. Some species, eg badgers, have been able to maintain adequate populations, but others, eg bats and maybugs, may be declining through loss of food supplies or the use of chemicals. A range of different species was examined, from badgers and wildcats to moths and birds, to assess methods of linking such data to existing data sets on change.

6. The environmental characteristics of a region determine the type of agriculture practised. However, within a given environment, management determines the ecological composition. The types of change which occur depend upon the initial starting point. The average ecological composition of a landscape can be used to assess appropriate policies for regions.

7.In the lowlands there is now a restricted range of plant species in open fields. It is difficult for colonisation of such sites to take place, for example from set-aside, because of the lack of seed sources from either vegetation or buried seed and because of problems of dispersal. Corridors such as roads and hedgerows have been shown to be important as pathways for the movement of species between fragmented habitats. They can also supply propagules for colonisation.

8. In many lowland areas the patterns in the landscape have become simplified, because of loss of the linear features and habitats, with progressive isolation of residual patches of native vegetation. This reduction in complexity not only has ecological implications for animal species that require mosaics of habitat, but also changes the appearance of the countryside. The principal patterns in the British landscape are described and associated with the changes that have taken place within them.

9. The project has shown the value of coordinating data from a variety of different sources into a common framework to prove the links, such as those between freshwater invertebrates and land use. Existing previously isolated information has been used, eg for wildcats and growth strategies, and has been combined with other data of plants using the land class framework.

10. A comparison of available scenarios indicated that the lowlands were particularly susceptible to change in crop patterns, land cover and landscape features because of the greater financial pressures and wider options for alternative uses. The predicted changes largely depended upon the assumptions made at the outset. The current consensus was that upland Britain would remain under the sheep regime rather than be abandoned. However, it was suggested that expansion of sheep into the lowlands could threaten farming in the uplands. But it was likely that,there would be fewer farmers on the land. Marginality may be ecological, or financial and will differ from region to region.

11. Satellite imagery can be coordinated with ground truth information to provide a combined system that incorporates the synoptic coverage of satellite imagery with the detail of ground survey. Monitoring procedures have been developed that could provide coverage at a local or national scale. National coverage from satellite imagery can also be used to provide information on the geographic distribution of major land cover categories, enhanced by field sampling of ecological parameters. In certain situations, eg moorlands, the images can be used directly to estimate ecological parameters such as bird populations.

12. It was found that diagnostic expert systems were not generally appropriate for the provision of advice to policy advisors. The potential for a decision-support system based on information tied to the national grid was been demonstrated by development of a preliminary system with associated databases. Improved graphic and interpretative facilities would increase the value of the system tousers. Policy advisers can already obtain from the system ready and rapid access to relevant ecological information on stock and change.

1. BACKGROUND AND INTRODUCTION

1.1 HISTORY

The present contract arose from concern about the ecological effects of the rate and direction of changes in land use, land cover and the overall landscape. Many previous estimates of changes in land use have been made, but most have concentrated on individual land uses, and have not often examined the ecological consequences or the underlying ecological processes. The main objective of this project was to identify the ecological consequences resulting from the changes in land use and cover detected by the ITE surveys in 1978 and 1988. The project considered the qualitative aspects of land use, rather than direct estimates of land use change. In addition, the project has integrated data from a variety of sources, including that provided from a series of subcontracts, in order to obtain a balanced national picture of change and a broader impression of the implications of change.

Over recent years, with the increased awareness of change in the countryside, confusion has developed about the objectives adopted by conservationists, and it is necessary to clarify which are covered in the present document. Firstly, many organisations exist to conserve artefacts, eg steam engines or cars, that are quite outside the present remit, which concerns conservation of the countryside alone. Within this topic there are four principal types of conservation:

(i) Wildlife, which involves the maintenance of populations of species and/or habitats.

(ii) The ecological resource, which involves the maintenance of a resource being exploited by man, eg soil or forest, in a sustainable fashion.

(iii) Amenity, which involves the appreciation of the countryside, principally in visual terms.

(iv) Rural populations, the maintenance of viable communities of people in the countryside.

The present document is concerned primarily with (i) and (ii), although (iii) to some extent and (iv) are indirectly involved. Thus, electric pylons do not affect wildlife, but do affect amenity; whereas removal of scrub destroys wildlife but may create rural employment.

Information is available on the extent of various land use and land cover types throughout Britain, and reviews, eg Coppock & Gebbet (1978), have appeared regularly in various publications on land use. The MAFF/DAFS statistics provide information on the main types of agricultural land use in Britain. They are supported by the Forestry Commission annual statistics, giving the area of new planting, to add to the various national surveys on forest cover. For derelict land, the figures produced by the Department of the Environment are collected from various local authorities, and there is also a project with the ordnance survey to estimate the annual area of urban expansion, but the current figure for urban land most generally used is that of Best (1976).

The above statistics provide information on land use change as well as about the current situation, but they do not refer to change in the overall landscape or in the underlying ecology, for which only fragmentary data are available. The first major initiative which attempted to obtain information about change in the wider landscape was the *Monitoring Landscape Change* (MLC) project sponsored by the Department of the Environment (DOE), and undertaken by Huntings (Huntings Surveys & Consultants Ltd. 1986). The results have been incorporated into various elements of the present project. The National Countryside Monitoring Scheme, sponsored by the Nature Conservancy Council, has been completed for three or four counties, eg Cumbria, Budd (1989), but no national figures are available. These projects have produced regional figures, but maps of land distribution patterns cannot be produced from them, so the visual interpretation of the principal land uses and patterns of change is not possible. Similarly, no figures are available for Scotland. Other studies have been carried out at a local level, eg Devon (Branden *et al* 1989), and are valuable in describing local patterns.

The only national survey of land cover, and of the associated composition of vegetation was undertaken by ITE in 1978. In 1984, the survey of land cover was repeated, as well as further detailed information on trees and linear features. As a sampling framework, these surveys followed a system of land classification (Bunce 1978; Bunce *etal* 1983; Bunce 1990) which has been used in a number of other studies by ITE and other organisations. It is this national system, with its detailed field information, which provides the focal point for the present project and it is discussed in section 2.2 below. The main aim is to bring together information of known and potential changes in land cover, and to identify the likely effects of these changes on the species composition and diversity of flora and associated fauna.

1.2 PROJECT DEFINITION AND SUBDIVISIONS

The above sources of information form the background for the programme of work set out in the contract document. These main sections of the contract document were:

(i) the core project, forming the main component of ecological research;

(ii) the remote sensing project, to define the application of remote sensing to detect ecological change, and its utility for providing greater explanatory power to ecological observations;

(iii) the expert systems project, to assess the potential role of computers in disseminating information;

(iv) the link project, designed to coordinate studies from groups with relevant experience.

However, the present document does not follow the above structure; rather it has been arranged to give a continuous story. The structure presented follows more logically the stages required to achieve an advisory system. Thus, the link project and subcontracts will be described in the relevant sections below, rather than being presented separately.

2. NATIONAL COUNTRYSIDE SURVEYS

2.1 ITE LAND CLASSIFICATION

The ITE land classification system is designed to provide an overall system for classifying the environment of Britain and to coordinate information relevant to ecological patterns.

The initial requirement for the land classification in 1975 was to provide information on the distribution and total area of the main vegetation types and land uses in Britain. The system had to reconcile requirements for information on detailed ecological processes with the limited resources available for field survey. The system had to be flexible, capable of handling a wide range of ecological parameters, and able to produce information at national and regional levels (Bunce & Heal 1984) . The classification is based on the principle that significant ecological factors are associated with environmental variables, such as altitude, which are available from existing cartographic sources. The statistical procedure (ISA originally, but now TWINSPAN; Hill 1979) formalised the relationship, which is based on the way an expert ecologist can predict species distributions from maps.

A regular sampling grid of 15 km 15 km was placed over maps of Great Britain, and information on climatic, topographic, human geographic and geological variables was recorded for the central 1 km square from each 225 km^2 block. The classification produced 32 groups of 1 km squares, termed land classes (Bunce *et al.* 1981). The sample was then extended by a further 4912 squares, so that one in 45 squares in Great Britain were classified which was the database available to the project. Subsequently, the whole of Great Britain has been classified but it was not possible to re-evaluate all the tables in the present report. The land classes represent well-defined geographical distributions which can be interpreted in terms of environmental features and were used in the information system section.

The classification has been used as a sampling framework for two major national surveys, in 1978 and 1984, which aimed to identify the land use and vegetation types in sample squares randomly selected from each of the 32 land classes. In 1978, data on plant species, soil profiles and land use were recorded in 256 squares; in 1984, additional detail was included on linear features and land cover types in the same 256 squares and in a further 128 squares. These data have been analysed for the present project.

Correlation analyses have been carried out to test the relationship between the environmental classification and various features recorded during the field surveys, to explore the ability of the land classification to predict the distribution of these features. These analyses are discussed in *The ITE land classification and its application to survey: an internal appraisal* (ITE, 1990.). The land classes are treated separately in some sections but are generally grouped into broad cover classes for ease of information. Thus, 1, 2, 3, 4, 9, 11, 12 , 14, 25 and 26 are dominated by arable crops, 1, 5, 6, 7, 8, 10, 11, 13, 15, 16 and 27 by grassland, mixed marginal upland 17, 20, 21, 28 and 31 and open moorlands 18, 19, 22, 23, 24, 29, 30 and 32. The distribution of these four groupings in Britain and their descriptions are given in Figs 1-8.

2.2 THE MONITORING OF LANSCAPE CHANGE PROJECT

The MLC study, based on interpretation of aerial photographs, provided important comprehensive statistics for land cover change in England and Wales from the 1940s to the early 1980s. The ITE surveys of 1978 and 1984, which also included Scotland, are based on field survey. As part of the ECOLUC contract, a detailed examination of the two surveys was undertaken to define the comparability of the two data sets and, as far as possible, explains discrepancies. In some cases it has been possible to revise figures by aggregating subcategories into categories which allow more legitimate comparison of the summary statistics. The main results for both cover and change in cover are summarised in Table 1.

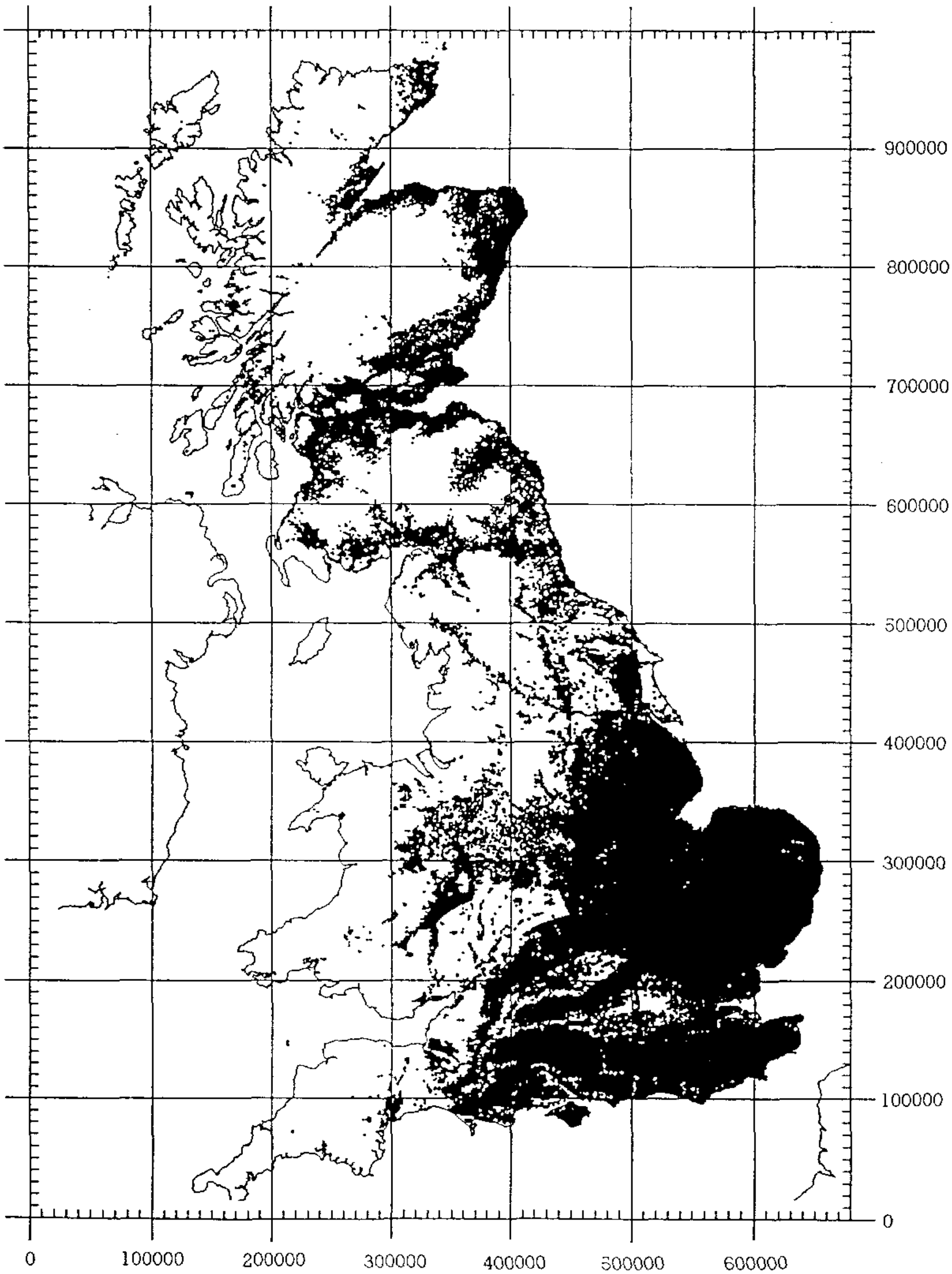


Figure 1 The distribution of land classes in Great Britain dominated by arable crops. The land classes were derived from multivariate classification of environmental data as described by Bunce *et al.* (1981). The data from 1978 were used to identify land classes 1, 2, 3, 4, 11, 12, 14, 25 and 26 which were, in general, dominated by arable crops. These classes are combined and their distribution shown throughout Great Britain from the all square classification.

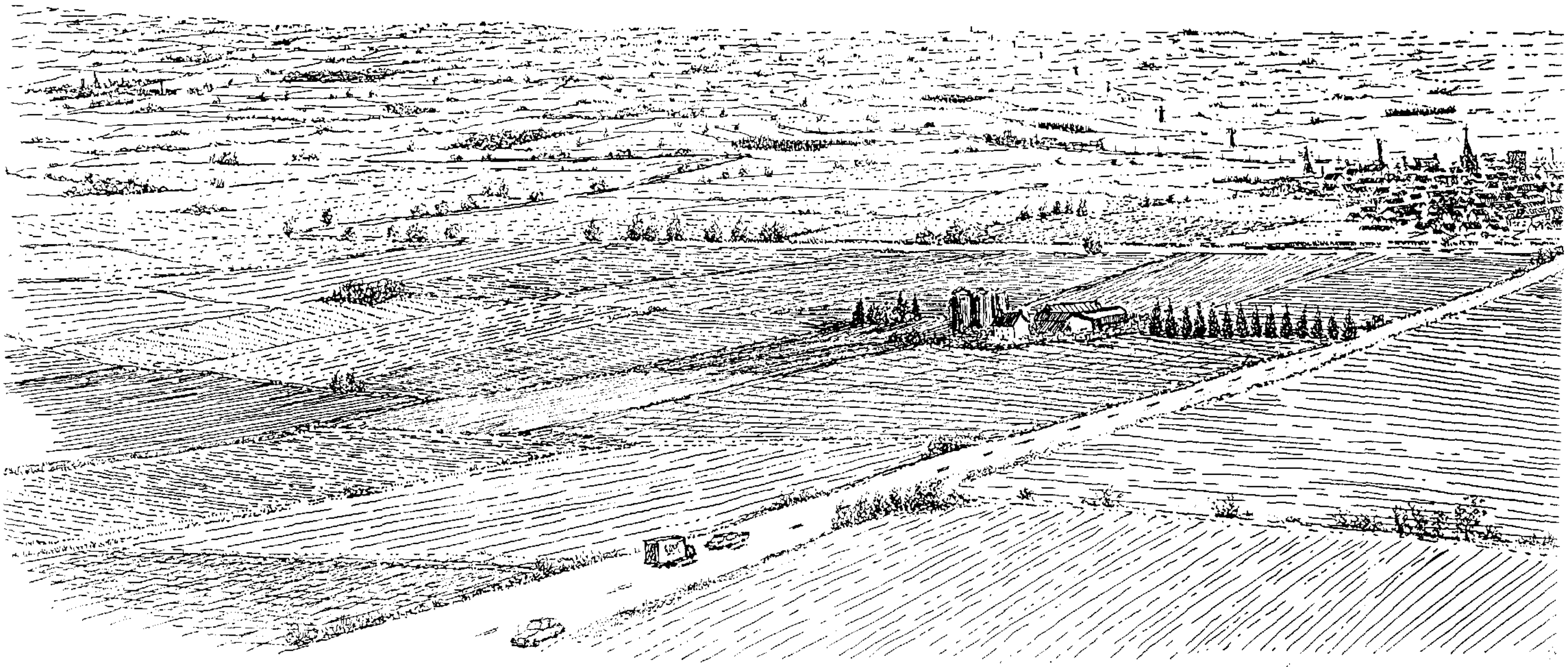


Figure 2 Pictorial representation of land classes dominated by arable crops. The principal features of the classes of Figure 1 were derived and combined to give a general representation of the typical appearance of arable landscapes in Britain.

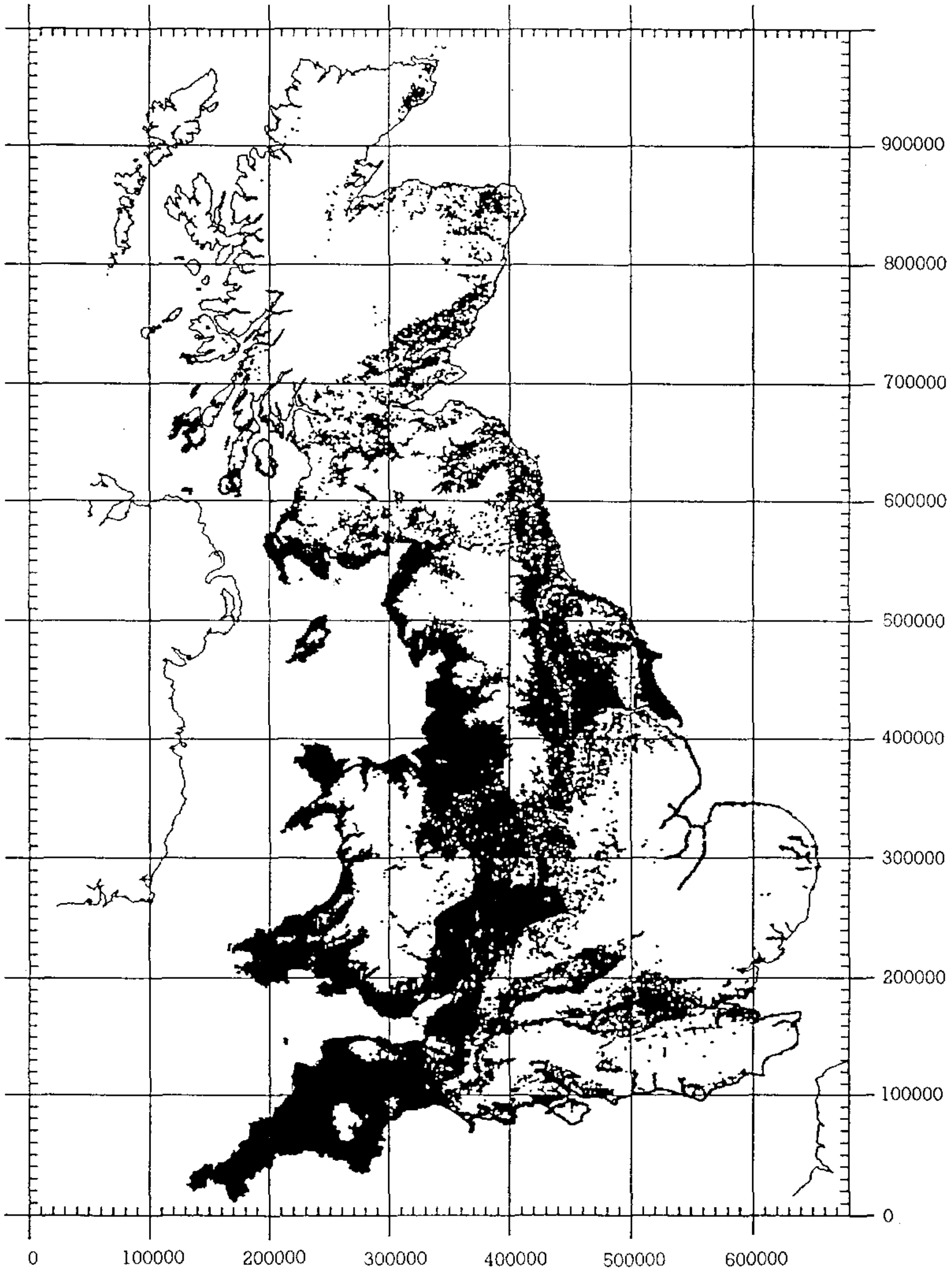


Figure 3 The distribution of land classes dominated by lowland grasslands in Great Britain. The land classes were derived from multivariate analysis of environmental data as described by Bunce *et al.*, 1981 and defined according to the field survey carried out in 1978. All squaresare derived from the full classification carried out in 1991. The classes involved are 1, 5, 6, 7, 8, 10, 11, 13, 15, 16 and 27.

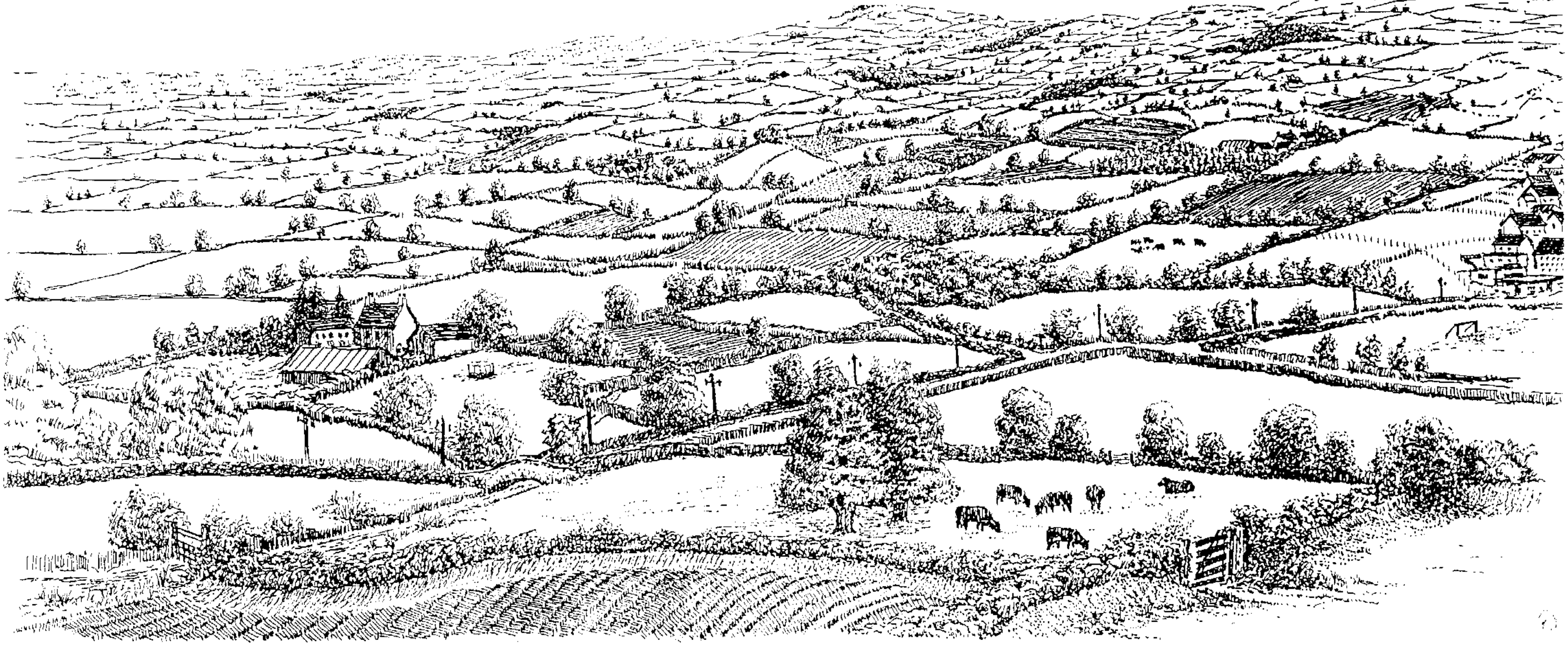


Figure 4 Pictorial representation of land classes dominated by lowland grassland. The principal features of the classes of Figure 3 were derived and combined to give a general representation of the typical appearance of lowland grassland landscapes in Britain.

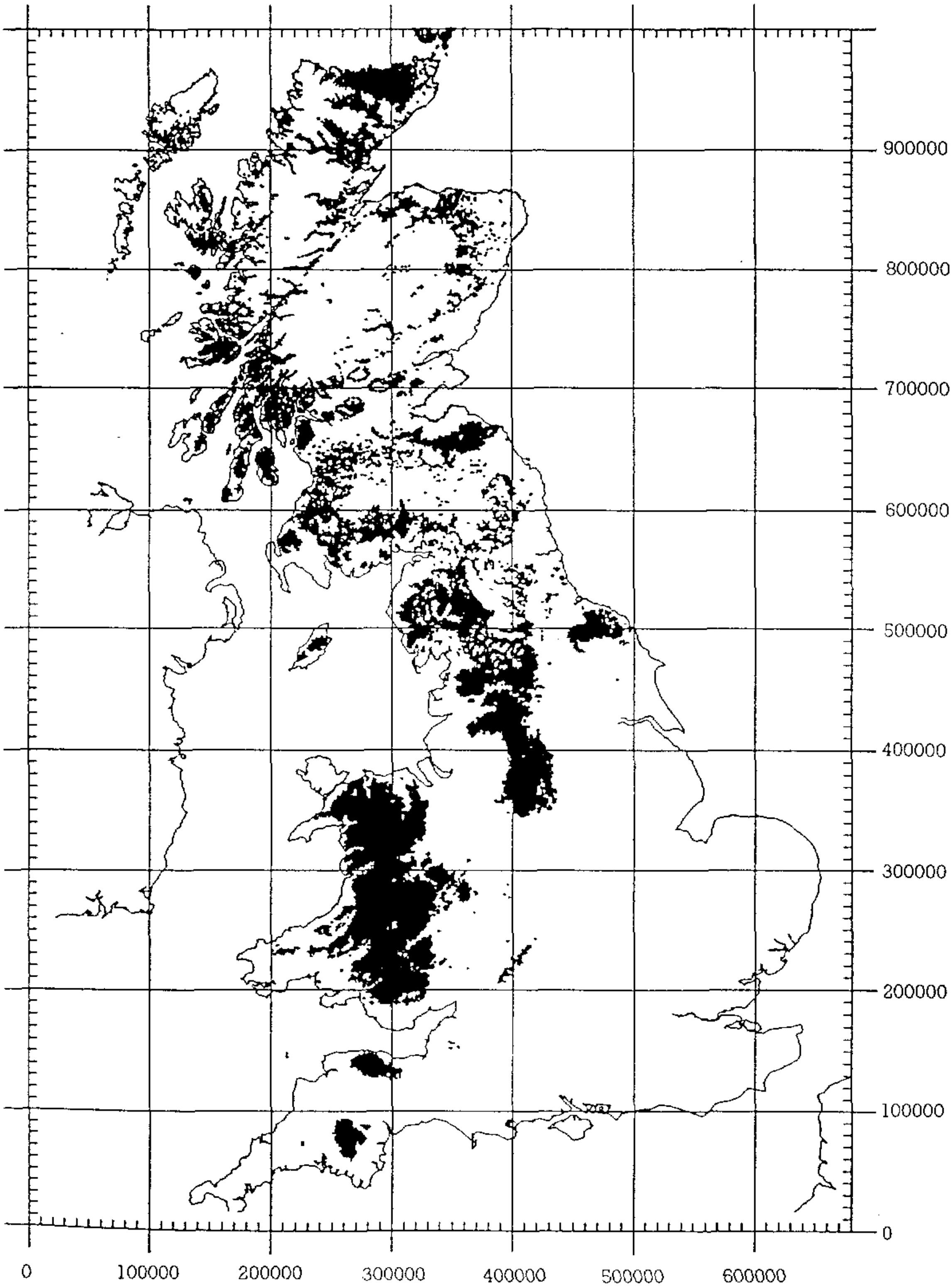


Figure 5 The distribution of land classes domianted by mixed marginal upland in Great Britain. The land classes were derived from multivariate analysis of environmental data as described by Bunce *et al.* (1981) defined according to thefield survey carried out in 1978. All squaresare shown derived from the full classification completed in 1991. The classes involved are 17, 20, 21, 28 and 31.

Figure 6 Pictorial representation of the land classesdominated by mixed marginal upland in Great Britain. The principal features of the land class of Figure 6 were derived and combined to give a general representation of marginal uplands in Great Britain

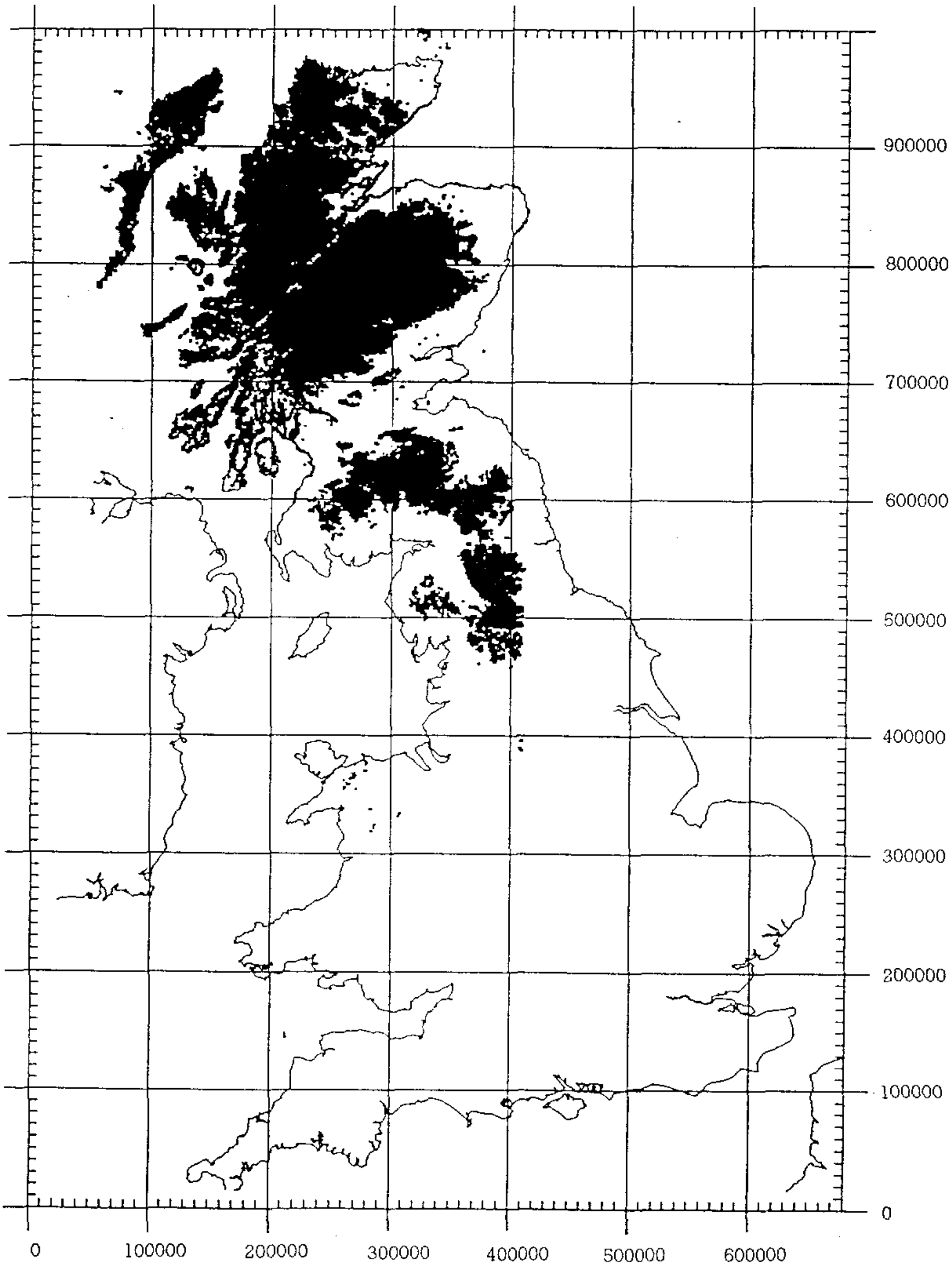


Figure 7 The distribution of the land classesdominated by open moorlands in Great Britain. The land classes were derived from multivariate analysis of environmental data as described by Bunce *et al.* (1981) and definedaccording to the field survey of 1978. All squares are shown derived from the full classification carried out in 1991. The classesinvolved are 18, 19, 22, 23, 24, 29, 30 and 32.

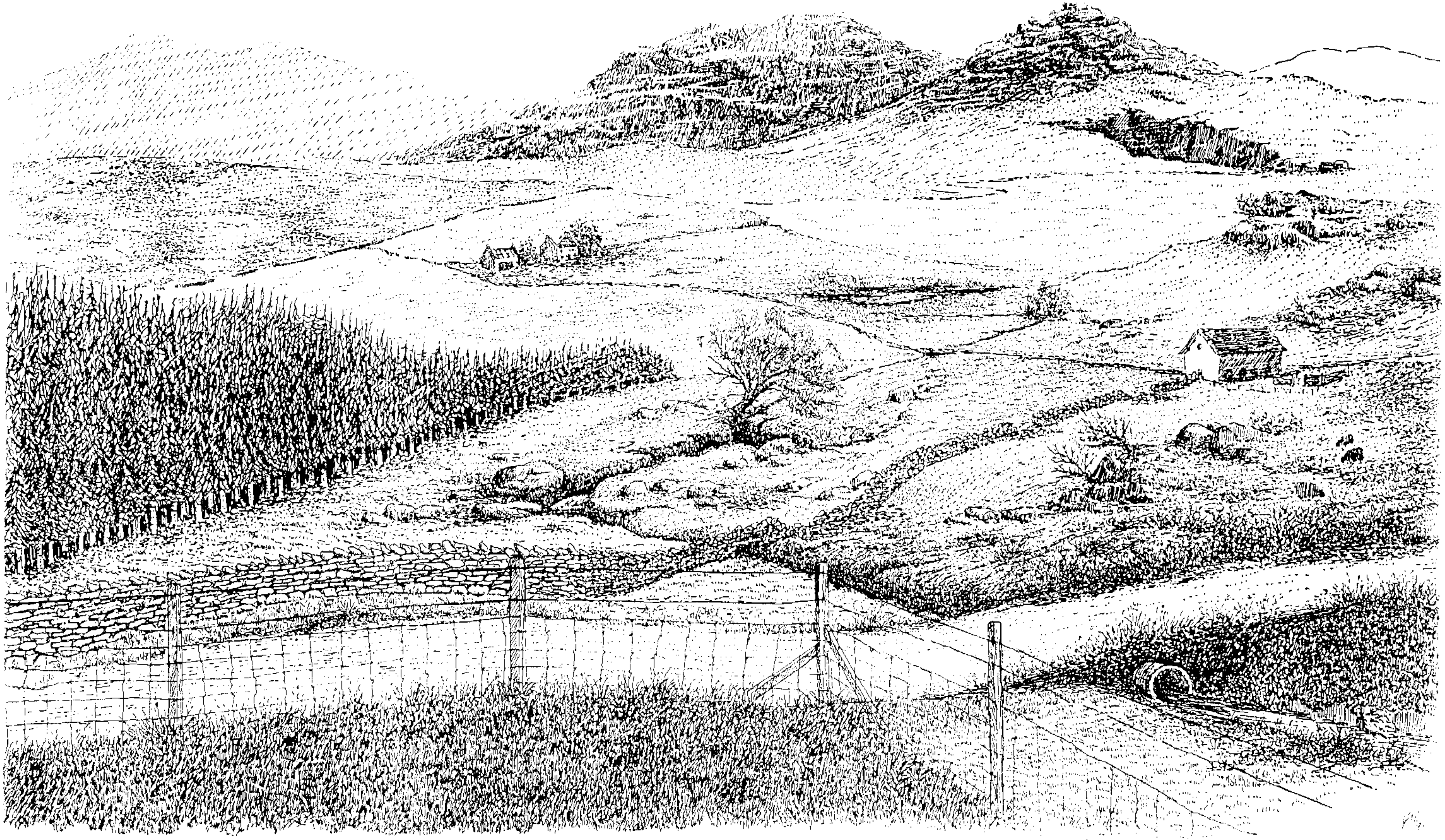


Figure 8 Pictorial representation of the land classes dominated by open moorland. The principal features of the land classes of Figure 7 were derived and combined to give a general representation of the typical appearance of open moorland landscapes in Britain.

Table 1. Area features: summarised results for England and Wales, comparing categories between ITE and MLC data using the same statistical methodlology.

% EW = Percentage area of England and Wales   CV = Coefficient of variation (standard error/cover)
SE = Standard error

	LAND COVER							CHANGE IN LAND COVER			
	%EW	CV	%EW	CV	%EW	CV	%EW	%EW	SE	%EW	SE
Woodland	9.82	12.86	10.01	12.82	9.1[a]	6.80	7.9[1]	0.18	0.17	0.0	0.
Semi-natural vegetation	12.34	14.17	11.92	14.38	13.9[bd]	10.20	11.3[2]	-0.14	0.23	-1.4[f]	0.17
Farmed land	62.90	4.26	62.76	3.79	65.9[ce]	1.40	63.9[3]	-0.14	NA	0.2[g]	0.19
Water/wetland	2.64	21.63	2.64	21.63	1.10	16.70	-	0.00	0.00	0.0	0.02
Urban	12.36	14.29	12.59	14.08	10.00	4.90	11.6[4]	0.23	0.12	1.1	0.11

a= +1.2% derived from ITE ecological scrub estimate

b = - 0.6%) 1.2% of ITE scrub assumed to be equally divided
c = - 0.6%)

d = + 5.3%) transfer of MLC Rough Grassland and MLC Neglected Grassland to coincide with ITE categories
e = - 5.3%)

f and g figures for change have been revised in line with adjustments in cover.

Other sources [1]FC Census 1980 [2] MAFF Census 1984 rough grazing [3]MAFF Census 1984 less woodland [4]Best 1976

The principal objectives of the MLC project can be summarised as follows:

(i) to obtain reliable information on the current and past distribution and extent of landscape features of major policy importance;

(ii) to determine the magnitude of any change in distribution and extent of these features between specific points in time, thus defining rates of changes and possible bases for the prediction of trends; and

(iii) to develop a method by which future changes in the extent of features can be monitored.

In the course of the study, three potential causes of discrepancy between MLC and ITE survey data have been reviewed:

The project was organised as two separate, but closely linked, elements: the analysis of area features such as woodland, semi-natural vegetation, farmed land and developed land, and the analysis of linear features such as hedgerows, walls and fences. The final classification of features was based on seven main categories each of which was subdivided into major landscape features with, where appropriate, further subdivision into more closely defined categories. For example, in the main category of semi-natural vegetation, a major feature is upland grass moor, which has been further subdivided into smooth grassland, coarse grassland and blanket bog.

This final classification was determined both by the requirements of the DOE/CCEW and by the reliability with which the features could be identified by aerial photographs. No account was taken of the species of vegetation, the management history, or the current land use of different landscape types, unless these factors had clear expression on the aerial photographs. There were exceptions, particularly bracken, a species which could be reliably separated from other semi-natural vegetation types. Market gardens could be separated from other cultivated land on the basis of field size and shape, and grassland in urban open spaces could be distinguished from other grassland by its location.

The basis of the project was aerial photograph interpretation, and the categories used were approximations to their ecological composition in the field. Ecological classification of vegetation similarly depends on the criteria adopted, such as dominance, cover or species composition. Differences between MLC and ITE data are therefore inevitable and are a feature of the approach rather than a conflict. The problem is in reconciling these differences, so that differences between national estimates for, say, upland heath, can be understood and minimised.

The Bristol University project (Harrison *et al.* 1989) 'A Statistical and Graphical Examination of Monitoring Landscape Change Data', was initiated by the DOE to assist in the planning of a repeat national survey. The objectives were to assess the potential for improving the accuracy of the MLC methods, to compare the MLC classification and results with related data sources, and to identify the potential for increasing the accuracy of the existing MLC data archive.

Three of their five major conclusions are relevant to the present report.

(i) *MLC objectives and general method.* A review of related data sources and literature concluded that the major objectives of the MLC project were valid, in that a general survey is necessary to detect the nature of the change. It was also concluded that aerial sampling as in the case of aerial photography was valid.

(ii) *Sampling method.* The stratification system used by MLC (based on the FC census methodology) was considered inefficient because of the variable intensity of sampling which "left many strata with very few observations." "We recommend that a repeat survey should be based on a very large number of smaller sites, dispersed more evenly throughout England and Wales. Specifically, we suggest 2000 sites, of size 1 km^2." It was suggested that these should be at random on a regular grid.

(iii) *Measurement methods.* A series of detailed guidelines were recommended to reduce the level of error introduced as the aerial photography is converted to computer-readable form.

Although the ITE sample is based on land classes, the squares are on a grid. The recommendations above were considered, and were incorporated in the strategy adopted in the ITE Countryside Survey 1990, in which 535 samples were sampled from a grid of 1212. Whilst random sampling would probably achieve similar accuracy to stratified sampling, the latter allows the exploration of the allocation of land in ecologically meaningful classes.

A further source of difference has been identified and results from the use of the initial FC census methodology which is specially designed to estimate woodland areas in the following way:
"From the pilot data, sampling strata for the main survey were derived by comparing those soil groups that produced a similar mean number of trees and a similar variance."

Such a procedure places more samples in areas with more trees, as these are likely to contain the most variation. It follows that undersampling, for other parameters, is likely to be in areas of few trees and involve counties with high proportions of urban land. Because of the highly skewed distribution of urban land, the most likely affect would be therefore in an underestimate of urban land.

In principle, therefore, the system of stratification by soil types is similar to the ITE classification of environmental factors, with the counties being comparable in some respects to regional variables, such as climate, except that the smaller counties would distort the overall pattern. In conclusion, the whole geographical spread by MLC with the relatively large number of samples is likely to be a relatively small source of difference in comparison with the use of aerial photographs rather than ground surveys.

2.3 ESTIMATES OF COVER

The estimates of major cover categories at different times, and of changes in cover, are given in Table 1. Comparisons are made at this high level of aggregation because the effects of discrepancies between definition of the more detailed cover types cannot be adequately quantified at this stage. Some adjustments have been made to increase the comparability of the data, and the main features from Table 1 are as follows.

Woodland. The MLC estimate of 7.9% woodland cover of England and Wales in 1980 excludes the category of 'scrub', which is absorbed in other categories. The revised estimate in Table 1 includes 1.2% added from the ITE estimate of scrub. The revised MLC and ITE figures are higher than those from the FC census of 1980, probably because of differences in the definition of woodland. It is also likely that removal of 1.2% of scrub contained in the ITE figure would legitimately bring the ITE estimate of cover closer to that of FC and MLC. Therefore, in the table the figure for scrub has been added to the 7.9% to enable a reasonable comparison to be made.

The net change in woodland cover combines decreases in broadleaved woodland (MLC 0.5% between 1969 and 1982) and increases in coniferous (0.5%). ITE data (Barr *et al.* 1986) show similar trends but with lower accuracy than MLC, possibly influenced by the selective emphasis on woodland area in the MLC sampling.

Semi-natural vegetation. To the original MLC estimate of 9.2% has been added the MLC estimates of 2.2% Rough Grassland and 3.1% of Neglected Grassland, and 0.6% removed to Woodland as scrub. The resulting estimate is more comparable with the ITE estimate in definition, and is close to the MAFF figure for rough grazings.

Both MLC and ITE estimate a decrease in the area of semi-natural vegetation. The original MLC estimate of -0.9% is increased to -1.4% by the inclusion of their estimates of change in Rough and Neglected Grassland.

Farmed land. The transfer in MLC data of Rough Grassland and Neglected Grassland into Semi-natural Vegetation and removal of Scrub to Woodland (on the assumption of 0.6% cover) makes the categories defined within Farmed Land more directly comparable between MLC and ITE, and of similar magnitude.

MLC results show an increase in cultivated land from 28% of England and Wales in 1947 to 35% in 1980, with a corresponding decrease from 38% to 31% in improved grassland. MAFF census data from 1981 to 1985 for crops and grass show the same trend to be continuing, but with the rough grazings remaining constant.

Water/Wetland. The difference between MLC and ITE figures for cover (1.1% and 2.6% respectively).

Urban. The three estimates for Urban land given in Table 1 differ markedly from each other, and discrepancies are discussed in section 2.2. Both MLC and ITE data indicate a small rate of increase.

Estimates of the statistical errors attached to land cover data for ITE are higher than those of MLC when calculated in the same way. This is largely a result of the relatively small sample size of the ITE survey. However, in any comparison or interpretation of errors it is essential to recognise that the statistical errors do not reflect errors that arise from classification and measurement. MLC estimated that errors in photographic interpretation varied between 42% and 100% for different classes of area features. Such differences are relatively large in comparison with the estimates of statistical errors.
However, the difficulties in ground survey concern the practical problems of consistent interpretation and distinction between categories within vegetation continua and mosaics.

There are, therefore, no major differences in the estimates for area and change in dominant cover types in England and Wales. The discrepancies which exist between national estimates from the two surveys, and between those from other independent sources, are primarily associated with differences in the criteria by which categories are defined.

The discrepancies are likely to be greatest in grassland and rough grazing cover types which form a gradation of plant composition, as this is difficult to interpret by aerial photography and can be classified in different ways from field survey.

The various examinations of the ITE land classifications show that the 256 one km squares represent an adequate sample for estimating Great Britain coverage of large or common features, while additional squares may be needed for estimating smaller and rarer features. The necessary number of samples for a required accuracy can be calculated from the available data. Smaller errors will be obtained for national land use estimates if the land classes are sampled in proportion to their size and variability.

2.4 DESIGNATED AREAS

Government agencies and local authorities have designated land for conservation, to restrict development and/or to introduce management plans to secure ecological stability. They have designated areas within which development control, of varying degrees, is now exercised. Taken together, these areas constitute an increasingly significant area in Great Britain, acting as a constraint to development, and they need to be taken into account in modelling studies designed to predict changing land use at the national scale. To that end, a database of institutionally designated areas has been established during a contract for the Energy Technology Support Unit, the basis and extent of which is described here, and is available on a 1 km square basis.

Firstly, all relevant government agencies in Great Britain and Northern Ireland were approached to supply maps of the areas which they had designated.

As the boundaries of the designated areas were to be manually digitised it was important, in order to maintain accuracy, that the scale of the maps was large enough, ie at least 1:250,000. Fortunately the agencies were, in general, able to provide what was required.

The Nature Conservancy Council's (NCC) Sites of Special Scientific Interest (SSSI) and National Nature Reserve (NNR) constitute the largest group of sites (approximately 5000) designated by a single agency.

The Countryside Commissions for Scotland, and England and Wales, provided maps of National Scenic Areas and Regional Parks (Scotland) and Areas of Outstanding Natural Beauty (including Heritage Coasts) and National Parks (England and Wales) at 1:250,000.

The Department of the Environment for Northern Ireland provided maps of all designated areas in the province.

Transfer of map data into geographically referenced electronic form by digitising areal boundaries is a well-established technique. The database was linked directly with the ITE Land Classification Scheme, by conversion of the stream of vector coordinates to a raster format, and subsequently into percentage cover of each 1 km square wholly or partly included within the area. Each 1 km square was registered to the OS national grid.

Some samples will indicate the measure of development control in different designation types.

Example 1. Designation: Sites of Special Scientific Interest

Agency:	Nature Conservancy Council (NCC)
Control:	(i) Potentially damaging operations must be notified to NCC.
	(ii) Where planning permission is being sought the planning authority must consult NCC.
Main Legislation:	The Wildlife and Countryside Act 1981, s28 (as amended by the Wildlife and Countryside (Amendment) Act 1985 and the Wildlife and Countryside (Services of Notices/Act 1985).

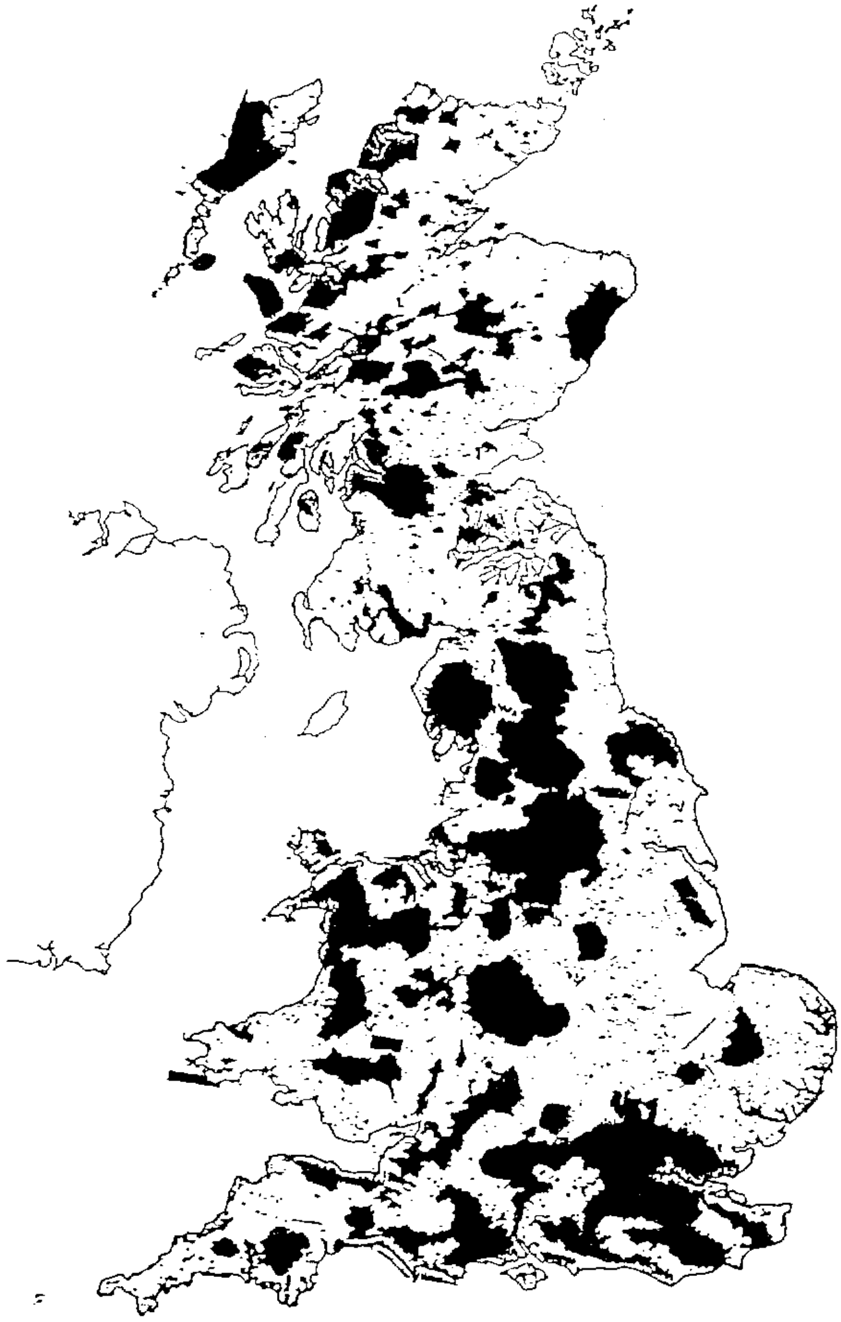


Figure 9 The distribution in Great Britain of designated areas. The boundaries of SSSIs, NNRs, National Parks, Areas of Outstanding Natural Beauty, National Scenic Areas andGreenbelts were obtained from the relevant agencies. These were digitised and their presence or absence recorded on a 1 km square basis. The presence of any one of these areas is indicated on the map.

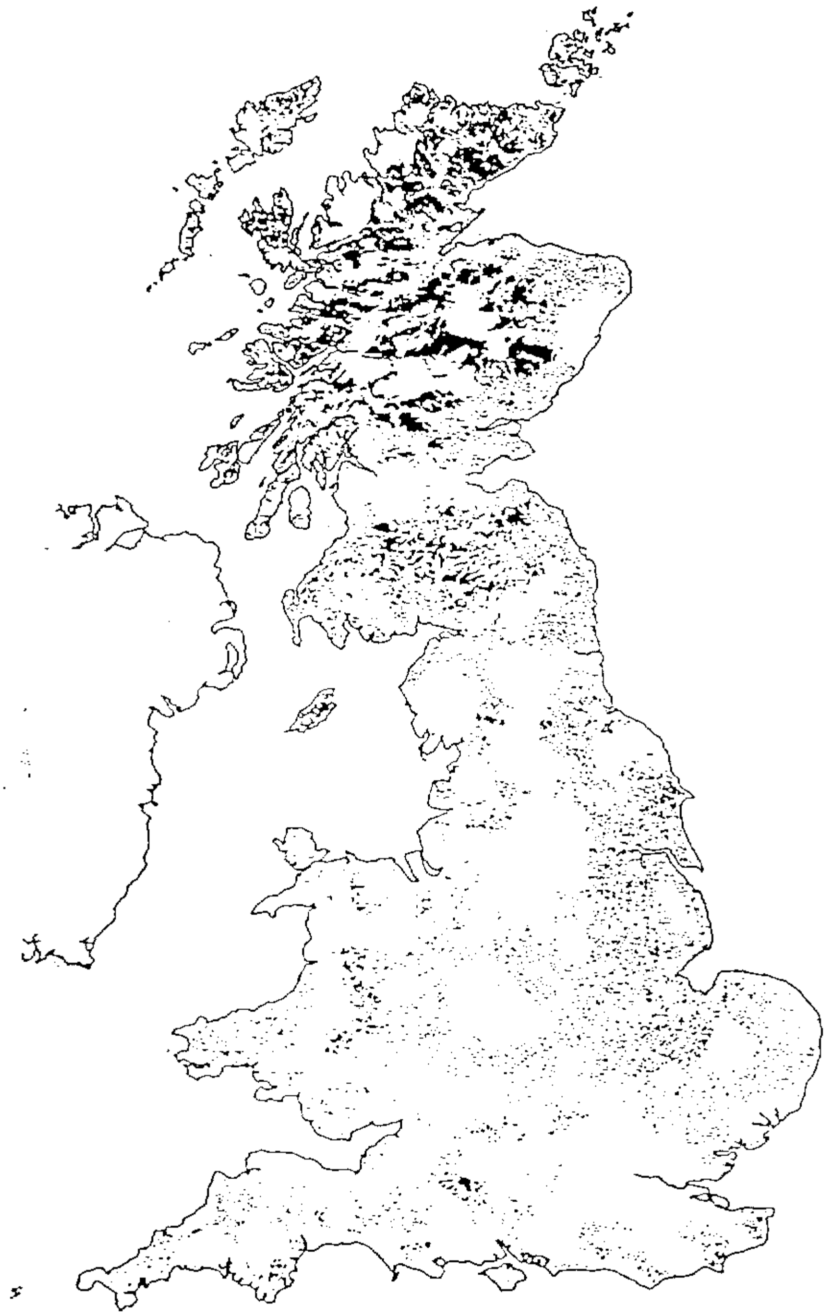


Figure 10 Land without defined constraints. The designated areas were first removed from each kilometre square, followed by woods, lakes and roads in the residual squares. The map was designed to show areas where kilometre squares were outside the series of constraints set at the outset.

Example 2. Designation: National Scenic Area

Agency: Countryside Commission for Scotland (CCS)

Controls: Any large development application must be notified to CCS, eg scheme for five or more houses, buildings more than 12 metres high, vehicle tracks.

Main Legislation: Town and County Planning (Scotland) Act 1972.

Example 3. Designation: Environmentally Sensitive Area

Agency: Ministry of Agriculture, Fisheries and Food, Department of Agriculture and Fisheries in Scotland

Control: Management prescriptions for land use.

Main Legislation: Agriculture Act 1986, S18, following art. 19 of EEC Regulation 799/85.

2.5 DISCUSSION

The database can be used to prepare maps based on the presence/absence of a designation in each 1 km in Great Britain, ie each square is essentially a pixel as shown in Figs 9 and 10. Alternatively, maps showing boundary outlines may be produced.

The attribution of designated status to each 1 km square in Great Britain (as a percentage for each square) can be overlain with all other feature data held at ITE Merlewood at the level of 1 km square units, including the ITE Land Classification.

3. LAND USE CHANGE

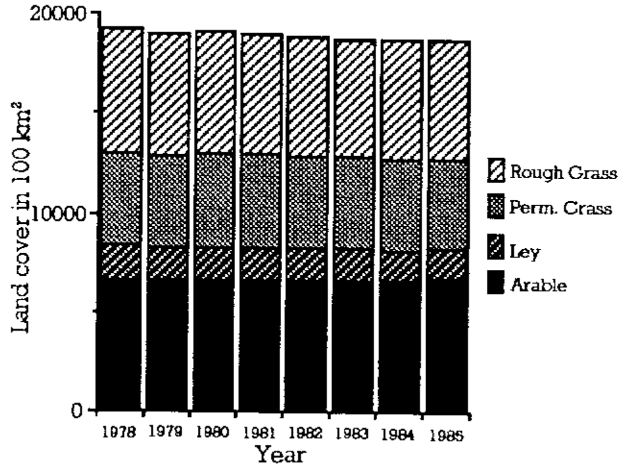
3.1 REVIEW OF AVAILABLE DATA

3.1.1 Introduction

Spedding (1988) summarised the agricultural statistics produced by MAFF and DAFS for England, Wales and Scotland, for 1900 and 1983. During this period, 7% of agricultural land changed to non-agricultural uses; the area of crops increased by 18%, grassland fell by 30%, and rough grazing rose by 13%.
These total figures mask considerable temporal and regional variability; for example the area of crops, especially cereal crops, rose only in the eastern counties of England, whilst they decreased in Scotland and Wales. More important in terms of ecological impact has been the increased intensity of management. For instance, between 1969 and 1983, wheat yields have doubled, partly because the use of nitrogen fertilisers doubled over that period. A summary of the MAFF and DAFS statistics for the period covered by the ITE surveys (1978-84 is given in Figure 11, which shows a relatively constant situation in terms of the overall balance of arable and grassland). Within the crops, the most radical change is the arrival of oil seed rape; otherwise, wheat has increased whilst the area of barley has fallen.

The official Forestry Commission figure for forest cover in 1977 was 8.6% and in 1984 was 9.4% of the land area of Great Britain. The area of new afforestation was, on average, 22.2 thousand hectares per annum between 1978 and 1985. In the uplands, afforestation represents the major land use change in recent yars, in terms of the area affected.

Apart from these agency statistics, the project which most consistently covered England and Wales was the MLC project (Hunting Surveys and Consultants Ltd 1986) for the period 1947-80. This study showed a decline in semi-natural vegetation, and a change in the relative importance of cultivated land and improved grassland, as reflected by the MAFF statistics. The MLC project also estimated the total length of linear features. These figures indicate a loss of hedgerows and banks, an increase in fences, and a relatively constant length of woodland fringe. These data were the first to demonstrate the significant national decline in habitats, which had been discussed previously by various authors, eg Shoard (1980).



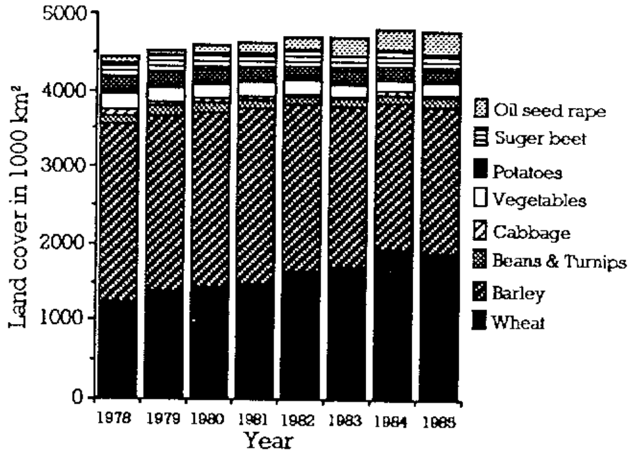


Figure 11 Land cover change in Great Britain. Data were derived from the MAFF/DAFS statistics for Great Britain over the period of time and summerised according to the main categories concerned.

3.1.2 Presentation of MLC results by regional groups

Within ECOLUC an analysis was carried out in order to utilise the historical data from MLC. The MLC strips contained a mixture of land classes, and the data could not be disaggregated from strip to square level of resolution. It was therefore decided to extract figures for individual 1 km squares, rather than complete strips. This greatly restricted the number of squares for which data were available. The original MLC study covered 707 sample strips for aerial features, of which 140 were also used for linear features. For the present study, Huntings Technical Services extracted data on linear features for 94 one km squares and on areal features for 59 one km squares. In each case a 1 km square was selected from within the MLC sample strips. Data were provided for 29 areal categories from aerial photography on three dates, and for the following linear features on the same three dates: fences, hedges, walls, ditches, banks, woodland edge and urban fringe. Absence of a feature in one time period could be because it had not yet been created, or it had been recently removed, or because there was no aerial photograph taken.

Each square from this subsample of MLC sites was then classified, according to the ITE land classification, and using data based on the 76 indicator attributes identified by the initial ISA analysis as reported by Ball & Barr (1986).

The recorded changes in land cover for these land types from MLC are described below, and shown in Figures 12-14, whereas Figures 15-17 show linear features. The land classes are grouped according to the categories given in Section 2. The upland group of classes contained insufficient samples.

Lowland land classes dominated by arable crops (Figure 12)

The overall trend is for an increased concentration of land into the predominant land use, ie arable farming. The major change took place between the 1940s and 1960s, when there was a transition from improved grass to cropped land. In the 1940s, the proportion of arable land was only slightly greater than grassland, but by the 1980s it was double the area of grassland. The area taken up by built-up land, transport routes and urban open space steadily increased. The broadleaved forest declined with a concurrent increase in conifers. The remaining categories occupy only small areas, emphasising the overall dominance of arable farming.

Lowland land classes dominated by lowland grassland (Figure 13)

In this group, arable farming has also increased at the expense of grassland. The area of coniferous forest has also increased, from a small base, with a concurrent loss in broadleaved woodland. The woodland cover has changed more in this group than in areas dominated by cereals. This suggests that more of the woodland in the cereal areas has been maintained in its original condition, perhaps because of use as game cover. The increase in built-up land and urban open space is comparable to that for the predominantly arable areas. Otherwise, the picture is of fragmented semi-natural habitats occupying a small part of the landscape.

Land classes in the marginal uplands (Figure 14)

Land cover categories have changed less in the marginal uplands than in the lowland groups. The improved grass category increased markedly in the 1940s but then stabilised. There was a small increase in the area of cropped land in the 1980s, which may be due to EC policies. Upland grass has continued to decline steadily into the 1980s. Conifer forest has increased at the expense of broadleaved forest and upland heath.

There is therefore a general increase in arable land at the expense of grassland, and an increase in conifer forest at the expense of broadleaved woodland. The loss of lowland heathland is also identified; this extends the coverage of the ITE sample, which was too small to make valid comparisons of this type.

The changes in linear features are shown in Figures 15-17.

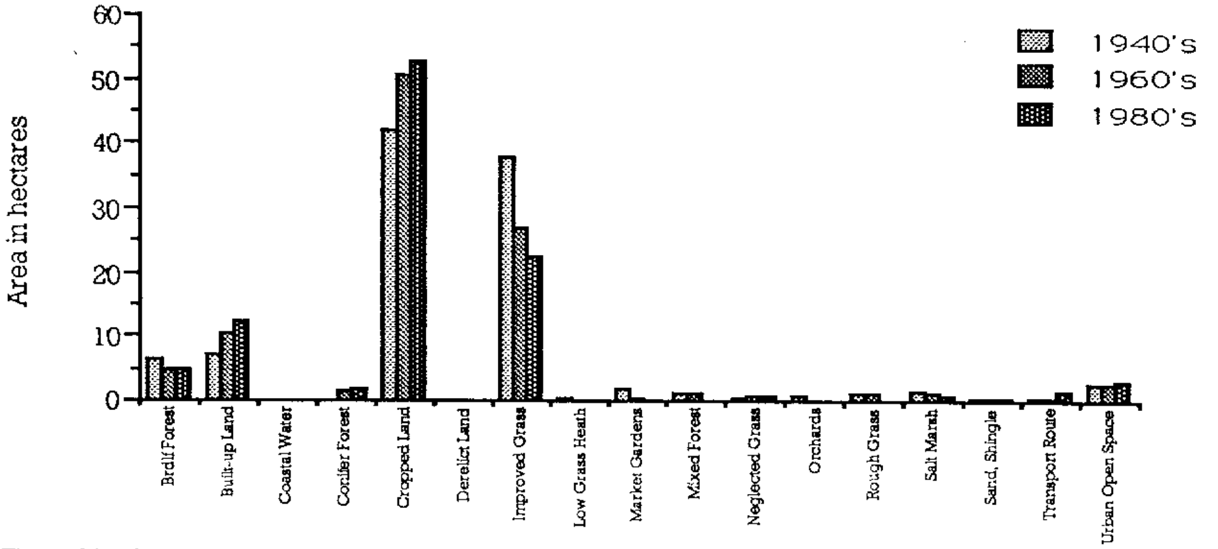


Figure 12 Change in land cover from MLC for land classes dominated by crops. Twenty-one 1km squares were extracted from MLC strips and the areas from the three periods measures. These were then combined into the appropriate classes.

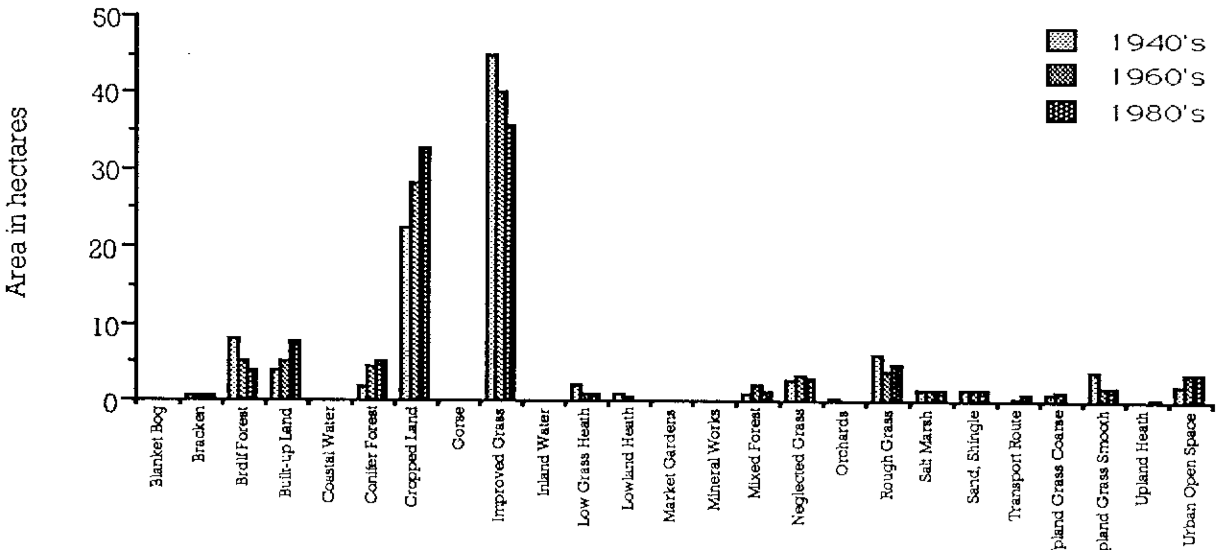


Figure 13 Change in land cover from MLC for land classes dominated by lowland grassland. Twenty-five 1 km squares were extracted from the MLC strips and the areas for the three periods measured. These were then combined into the appropriate classes with the land cover being expressed as the mean area per kilometre square.

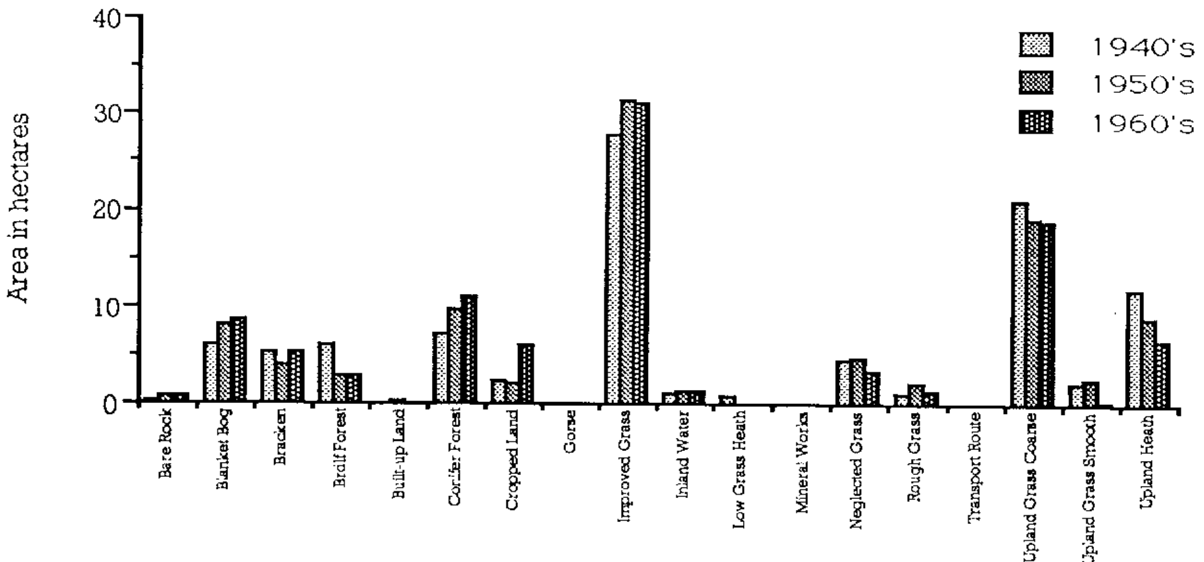


Figure 14 Change in land cover form MLC for land classes dominated by marginal upland vegetation. Data were extracted for 11 one km squares from the MLC strips and digitised with the areas being measured. Land cover is expressed as the mean area from the 1 km squares.

Lowland land classes dominated by arable farming (Figure 15)

In this group there has been a consistent decline in hedgerows, correlated with the increasing proportion of arable land. In other features most of the changes occurred between the 1940s and 1960s, with the extent of urban fringe and fences increasing whilst walls declined.

Lowland land classes dominated by grassland (Figure 16)

In these land classes the length of hedgerows, which in the 1940s was almost a third higher than in the land classes dominated by arable land, has declined to a level which is now similar to that in arable areas. This is correlated with the conversion of grassland to arable land and could be because not all grassland areas have as much hedgerow as may be expected. Other features show no patterns of change.

Land classes in the marginal uplands (Figure 17)

The greater length of wall, rather than hedge, characterises these land classes, and although fencing is considered to be associated with grazing land, the length of fence is less than that in lowland arable and grassland areas.
Woodland edge length per km square is similar to that in lowland arable land and grassland areas, reflecting the larger size of the conifer plantations which predominate in the marginal upland areas. The changes in length of the other features show no pattern. The MLC data can therefore be linked to ecological patterns as well as to the original countries.

3.1.3 A review of other approaches The heather report was also used in the ITE report for DOE on *Heather in England and Wales* (Bunce 1989). Detailed analysis of the cover figures for heather showed that the major change had occurred during the late 1940s and the early 1960s. This result is at variance with the widely accepted perception of a substantial decline in recent years. The quantitative information probably masks qualitative changes — it could well be that the actual decline in the area covered by heather is being masked by the use of heather-dominated vegetation as a criterion, whereas observers have considered the decline of cover, say from 75% to 25%, as being critical. The heather report also demonstrated the usefulness of remote sensing in establishing census information for specific land cover categories across England and Wales.

3.1.4 Grassland decline

Neither remote sensing, as in the current National Remote Sensing Centre (NRSC) project, nor aerial photography, as used by the MLC, is able to detect adequately the extent and composition of lowland grasslands. This is because species-rich meadows often have a very similar spectral image to other lowland grasslands. Multi-temporal imagery provides one solution, but it is a costly one. Fuller (1987) has combined data from a variety of sources to produce figures for the changing areas of grassland, in England and Wales, since the 1930s. This shows a decline from 7.8 million hectares to around 5 million hectares at the present time. The decline of unimproved grasslands began in the 1930s, accelerated through the war years, and has continued steadily ever since. Drainage and ploughing are responsible for this loss, and more recently the use of inorganic fertilisers. Species-rich unimproved pasture now represents only 4% of grassland, just 3% of its area 50 years ago. These data demonstrate the importance of the species composition as opposed to broad cover estimates of change. Hopkins *et al.* (1988, 1989) also showed the increase in dominance of rye grass and nitrogen fertilisers.

3.1.5 Other studies

A wide range of other studies has been carried out, but these have largely been at a fragmentary level, dealing either with county or local figures, or with individual habitats. The present project concerns national trends and, whilst the individual projects can be useful in examining local

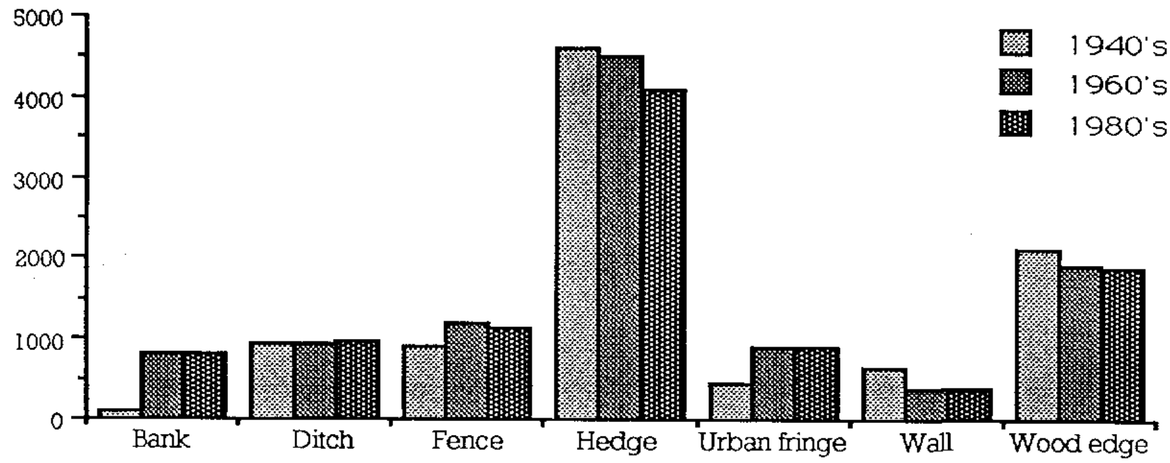


Figure 15 Change in linear features from MLC for land classes dominated by crops. Linear features were extracted from 1 km squares extractefrom the MLC strips. Twenty-two strips were used from the 1940s, 32 from the 1960s and 32 from the 1980s. Linear features are expressed as the mean length in metres from the 1 km squares.

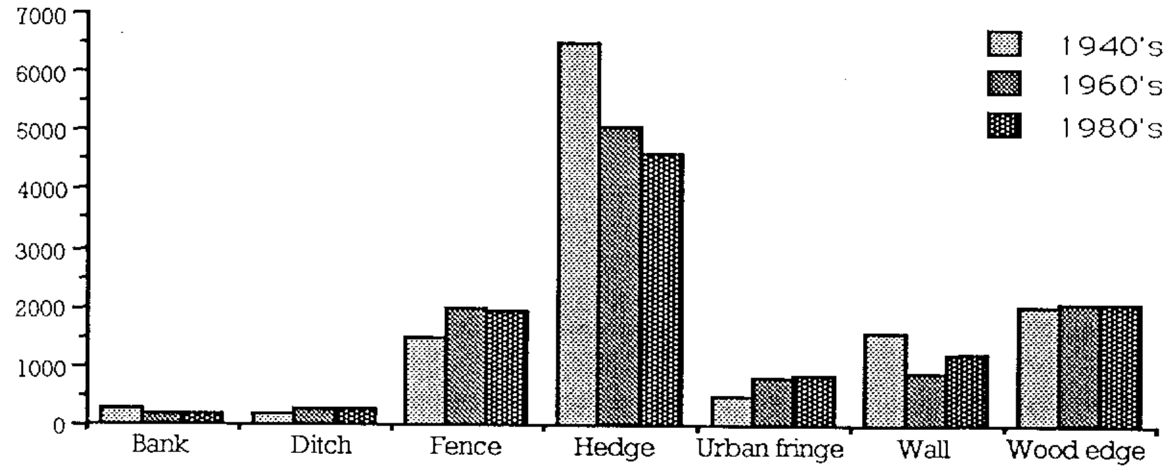


Figure 16 Change in linear features derived from MLC for land classes dominated by lowland grassland. Linear features were measured in a subsample of 1 km squares from the MLC strips with 36 from the 1940s, 42 from the 1960s and 45 from the 1980s. Linear features are expressed as the mean length in metres from the 1 km squares.

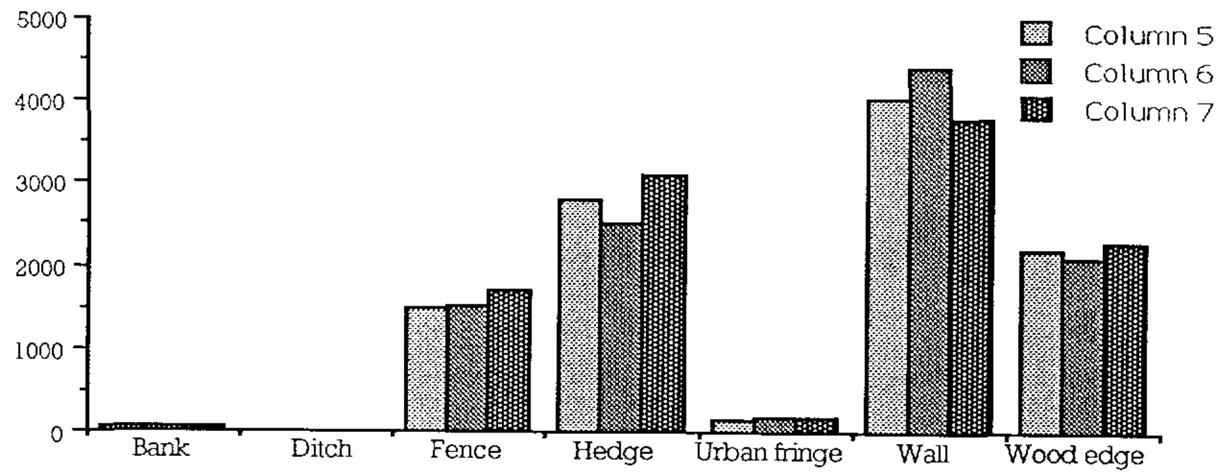


Figure 17 Change in linear features derived from MLC for land classes dominatd by marginal upland vegetation. Sample squares were extracted from the MLC strips and the mean length in metres extracted. Thirteen squares were recorded from the 1940s, 14 from the 1960s and 14 from the 1980s. Linear features are expressed as the mean length in metres per 1 km square from the sample.

variation, it is difficult to extrapolate from them to produce a national picture. Also, the location and siting of many of the sample areas often do not cover the full range of variation. The data from ITE's Biological Records Centre (BRC) provide extensive information on the presence of species and the major geographical changes in distribution, by repeated sampling over time, but they give no indication of the quantities of those species present across Britain. The BRC data are particularly appropriate for rare species that are at the edge of their range, with a limited distribution.

3.1.6 The ITE approach

In contrast, the ITE survey data for 1978 and 1984 provide consistent coverage over Great Britain (Barr *et al.* 1986). The main change has been a shift away from barley and grass production to wheat, and a large expansion in oil seed rape. This confirms the conclusions of both MLC and MAFF. Other changes in land use were fragmentary, but may be locally significant, although being under 1% of the national cover. The overall trend is one of a consistent increase in agricultural intensity, as opposed to less intensive forms of management. This trend is illustrated in Table 2, which gives the estimated area of ley and permanent grass in Great Britain, broken down by management intensity, between 1978 and 1984. Figure 18 shows how different types of rough grazing were improved between the two surveys. The assessment of such changes in quality of grassland and rough grazing requires a detailed ecological survey, as emphasised in Section 4.1 below.

Figures derived from the ITE survey for grassland support the generally accepted trends (Hopkins *et al* 1988), ie a shift away from reseeding towards increased use of inorganic fertilisers for increproduction, avoiding the added costs associated with ploughing and reseeding. A large proportion of grasslands have changed in their species composition, with reduced species numbers correlating with high nitrogen application.

In comparison with the total area, the losses of semi-natural vegetation from practices such as grassland improvement were small. The core of unimproved upland vegetation remained relatively constant overall, but the expansion of forestry in the uplands, eg within the Flow country, as shown by the forestry statistics and the impact on species composition by Hill (1986) is having a significant effect. More subtle qualitative changes, as emphasised in the heather study, require intensive local monitoring.

Table 2 Provisional national estimates of land cover change between 1978 and 1984, measured from the areas of fields.

Intensity category	1978-1984 change in area in thousand ha	1978-1984 % change in area
L1	228	70
L2	-825	-42
L3	-274	-37
P1	-19	-4
P2	1733	122
P3	784	-31
R1	114	-11
R2	-5	<1
R3	-17	-1

These estimates were made by identifying areas which have changed in sample squares between 1978-1984.

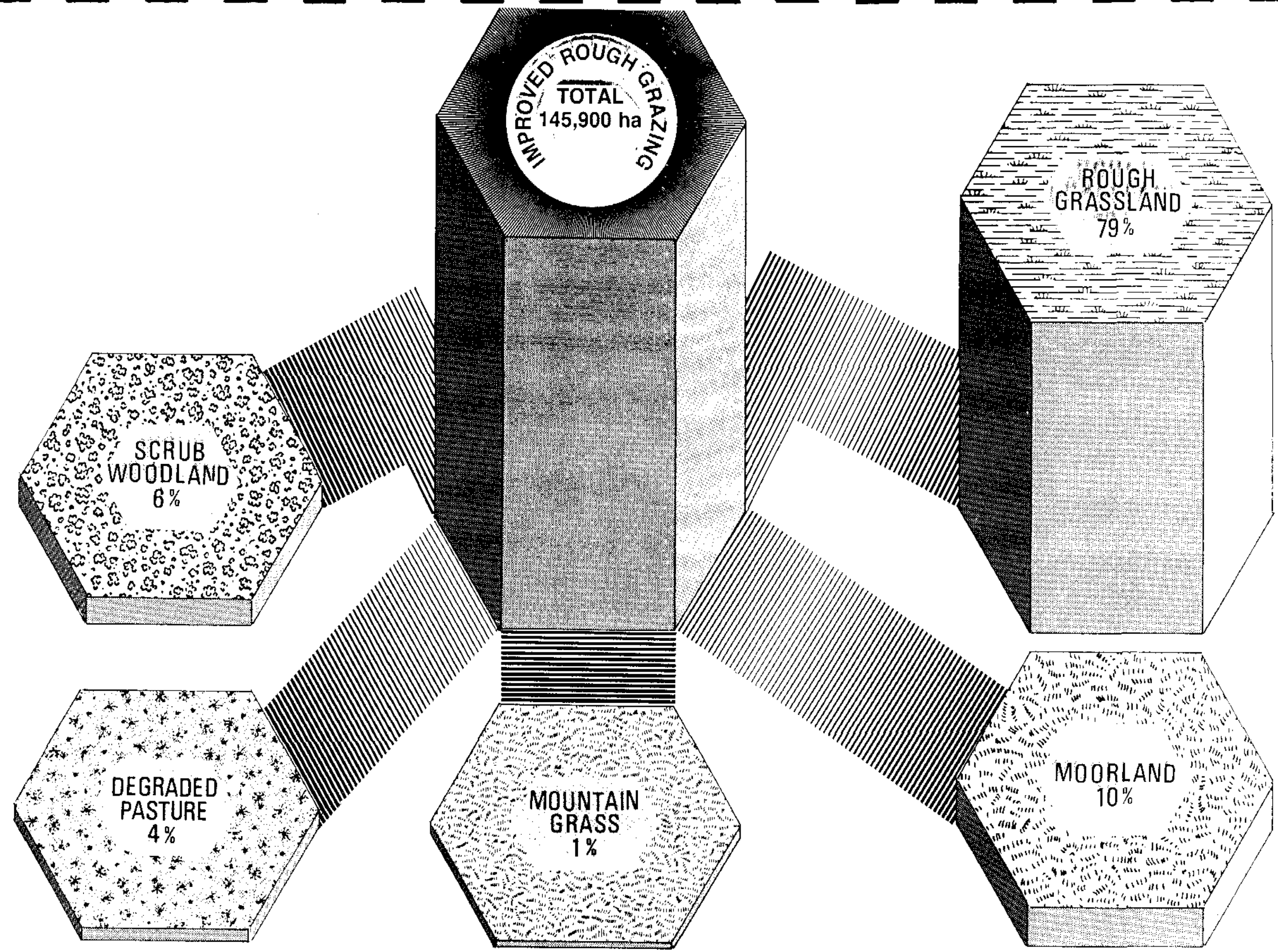


Figure 18 Improved rough grazing between 1978 and 1984. The area of rough grazing was recorded in 1978 and 1984 for 256 squares based on eight 1 km squares from each of the 32 land classes described by Bunce *et al.* (1981). The matrix of change enabled the area of improved rough grazing to be allocated to the previous cover categories.

3.1.7 Conclusion

Whilst the potential ecological implications of gains or losses of land cover have received much publicity, it is the ecological composition within different land uses which have undergone the greatest change (Fuller 1987). Thus, especially within grasslands, the loss of wild flower meadows is a well-documented qualitative change which is of direct concern to policy advisers, together with the expansion of improved grasslands into upland heaths.

3.2 The application of remote sensing

3.2.1 Introduction

The objectives of the remote sensing element of the ECOLUC project were (i) to determine the range of land cover types that can be mapped from high-resolution satellite imagery, particularly the Landsat Thematic Mapper, (ii) to develop techniques for the analysis of land cover change, and (iii) to identify methods for defining pattern in the landscape of relevance to ecology (see Section 6). Information is required, at both national and regional levels, to interpret the relationship between land use and ecology, and to measure the ecological effects of land use change. The programme was mainly carried out in co-operation with the National Remote Sensing Centre (NRSC).

3.2.2 Sampling system

The ITE land classification system was used to select sample areas, ten km X ten km, for measuring land cover and land cover change. Those land classes which were known from previous surveys to have undergone rapid land cover change were selected from analysis, giving a total of 24 ten km blocks for the NRSC study. The 24 blocks were divided between land classes 19, 22 and 27 in the northern Pennines and southern uplands, and land classes 3, 10 and 11 in East Anglia and the Midlands. ITE (Bangor) was responsible for a parallel study involving an equal number of sample areas, mostly situated in Wales and the south-west of England.

Ground data for calibration of the satellite imagery were collected in 1987 for two 1 km squares within each ten km sample area, supplemented by air photography, Ordnance Survey (OS) maps and additional field work for more extensive areas.

3.2.3 Availability of data

There are significant variations between regions and between years in the acquisition of cloud-free imagery within Britain. Other factors apart from climate must also be taken into account. Variations in the orbital track and repeat cycle of the Landsat satellites (1-5) over the period of interest, the number of satellites in operation at any one time, and the operational efficiency of each satellite all have significant effect on the rate of clear-view acquisition for each reference point. Because of relatively high latitudes, the British Isles have a large degree of overlap between adjacent Landsat paths. The degree of overlap between paths of Landsats 1, 2, 3 and Landsat 4 and 5 increases northwards, to the extent that most of Scotland is covered by pairs of adjacent paths, thus increasing the probability of a clear view. With a repeat cycle of 16 days for Landsat 4 and 5, clear-view acquisition can vary: from 23 imaging opportunities per year for a site covered by one satellite and one path, to as many as 91 per year for a site covered by two sites when two satellites are operating. As a result of differences in the reliability of different satellites and of the same satellite over time, the imaging potential is not always reached. An essential prerequisite of any study, therefore, is to assess the imagery available for previous years, and then to estimate the likely coverage, which will inevitably vary from year to year depending on the time of year concerned.

3.2.4 Land cover mapping from satellite imagery

The date of image acquisition determines the number of cover types that can be mapped, with no single season being optimal for all cover types. Results have demonstrated that, by using a combination of single-date and multi-season imagery, Landsat TM imagery can be used to map the

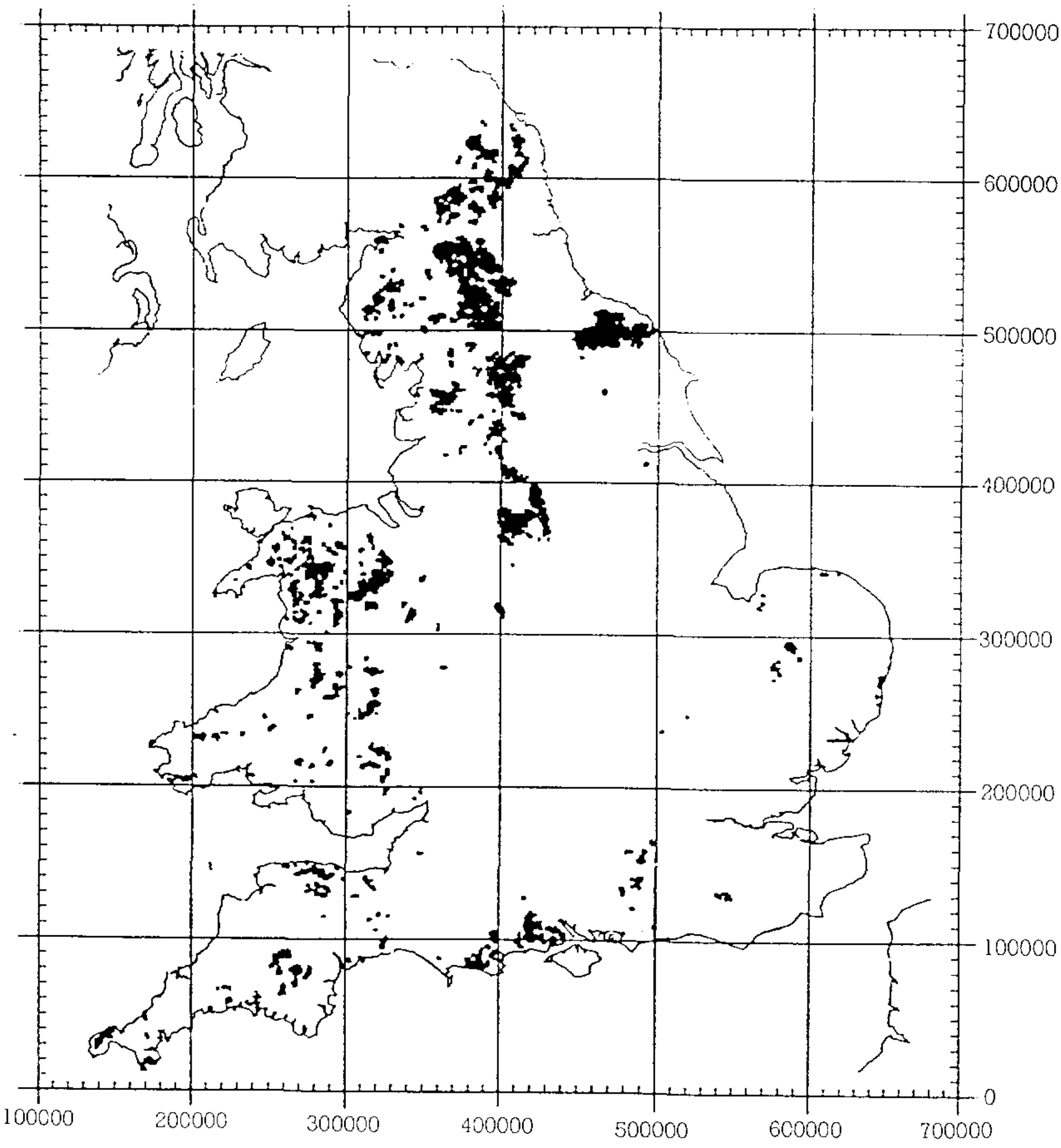


Figure 19 Distribution of heather in England and Wales from LANDSAT TM (1984) imagery. Appropriate images were obtained and the boundaries from the 100 000 scale maps were drawn directly on to the satellite image. These boundaries were then digitised and mapped on a 1 km square basis.

broad land cover types characteristic of the British countryside, such as arable land, coniferous and broadleaved woodland, agricultural grassland, andmoorland. The strength of the imagery lies in mapping such broad cover types, rather than the detailed subdivision according to species, land use or management practice. For example, it was not possible to subdivide agricultural grassland into improved or permanent grassland, or to subdivide broadleaved woodland by species. In areas of upland semi-natural vegetation characterised by a spatially complex mosaic of vegetation species, techniques have been developed, and are currently being assessed for classifying mixed vegetation communities.

Various techniques have been used to classify the image data, including visual interpretation, supervised and unsupervised classification.
The most accurate results were obtained from visual interpretation, in which pattern and context, as well as tone, are used. However, visual interpretation is only practical when the area to be interpreted is relatively small, or, for a large area, when the number of cover types are few. As an example of the latter, visual interpretation techniques were used to map heather-dominated moorland in England and Wales from 1:100,000 scale satellite imagery (Figure 19). In conjunction with staff from the Lake District National Park, the maps produced from the satellite imagery were compared with the heath and moorland maps compiled for the National Park, and were found to be broadly consistent, except in local detail. Where a large number of cover types are to be interpreted, statistical classification techniques are important, allowing for the consistent and rapid classification of spectrally separable cover types.

In practice, the optimum solution is to combine the statistical classification of spectrally separable cover types with the visual interpretation of the remaining cover types, a hybrid technique that was widely adopted in the present project. Wherever possible, image classification was supplemented by thematic information derived from OS maps and aerial photographs.

3.2.5 Mapping land cover change

The detection of land cover change requires highly accurate mapping, particularly when the amount of change is small. Because of the fairly short period since the completion of TM satellite coverage for the UK (1984 approximately), there was relatively little change in most of the sample areas. Automated techniques such as image differencing proved unsuccessful, and change was detected visually from a baseline classification.
Change maps were produced, showing the increase or decrease in the area of a particular cover type, and change matrices showing the rate of change of different cover types were compiled.

As the period for which Landsat TM data increases, it should be possible to define a period of 2-3 years as the baseline against which to measure future change. With a longer baseline period, the chance of acquiring imagery from different seasons is increased, with implications for improvements in classification accuracy.

3.2.6 Integration of satellite imagery and the ITE land classification system

The study emphasised that field survey and satellite imagery can be used as complementary techniques. At a regional level, such as a National Park, the large areal coverage of the imagery enables a census of land cover without the disadvantages of sampling error. Field survey provides much more detailed information than can be derived from satellite imagery, but this level of detail can only be obtained from a relatively small number of samples. The remote sensing study explored ways in which the detailed ecological information obtained by field survey for the ITE land classification system could be extrapolated to regional levels from the satellite imagery (Figs 20-23).

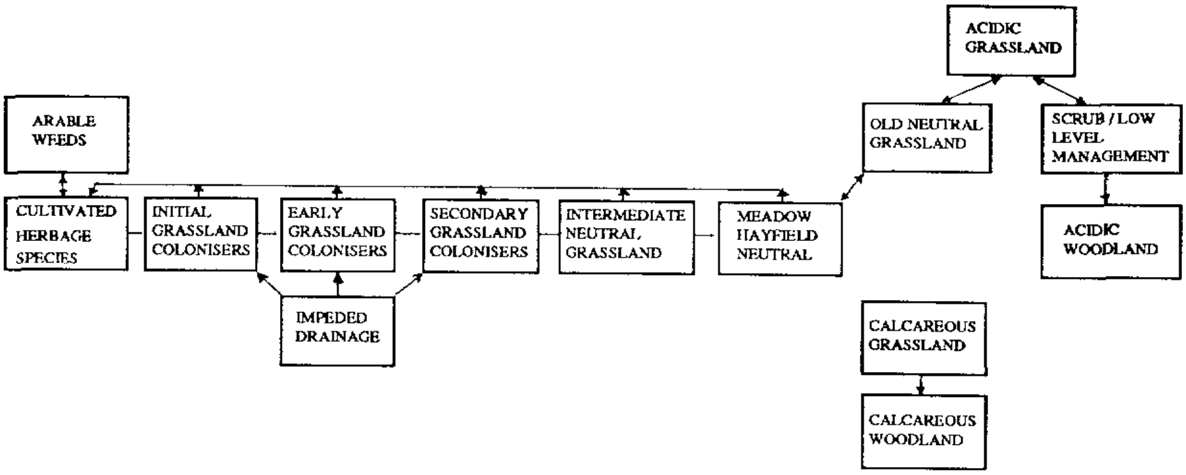


Figure 25 Potential directions of change in agricultural grasslands in response to management. Groups of species were determined by multivariate analysis of quadrat data. The composition was interpreted into the titles given in the diagram. The derivation of the groups and their full composition is given by Bunce & Jenkins (1989). The arrows show the potential movements over time.

An alternative approach to species diversity is to assess the relative abundance of each species, attributing greater importance to the more prevalent species. A classification has been devised which uses rules relating to the cover of dominant species, to allocate each quadrat to groups — called intensity categories, because they reflect the intensity of management inputs (eg ploughing, reseeding, drainage, organic and inorganic fertilisers, grazing). Leys, permanent pasture and rough grazing are each divided into three intensity categories, using rules based on the cover of different species. The leys range from high-input systems (L1) — those typically dominated by *Lolium multiflorum* (Italian rye-grass) — to less intensive ones (L3); the permanent pastures range from old leys (5 years) or highly fertilised grassland (P1) to unimproved pasture (P3). The rough grazing categories are not strictly intensities but are related more closely to soil type and hydrology: R1 comprises upland grasslands and bracken, R2 unpalatable moorland grasses, and R3 heather moorland and peatland. This system is described in more detail, with illustration, in Appendix II. It is possible to allocate quadrats or parcels of land to these categories on the basis of dominant species, because agricultural improvement favours certain 'preferred' species. For example, *Lolium multiflorum*, which is frequently sown as a ley, will only persist for two or three years, and is therefore indicative of recent ploughing and reseeding. Similarly, an increase in use of nitrogen fertiliser will be reflected by an increase in the cover of *Lolium perenne* (perennial rye-grass), together with a decrease in indigenous grasses and many broadleaved species. In contrast, the dominance of indigenous species such as *Agrostis* sp. (bent grass), *Festuca rubra* (red fescue) and broadleaved plants indicates that grassland is of low productivity, receiving little, if any, management input other than grazing (Hopkins *et al.* 1988).

The intensity categories can be related to those used for agricultural statistics, allowing the link to be made between management intensity, in terms of inputs, and its effects on the vegetation. This system was developed within the context of *Implications of Changes in the Common Agricultural Policy on the Countryside* (DOE/MAFF contract to the Centre for Agricultural Strategy, Reading University). It is designed to aid in interpreting the ecological consequences of outputs from agricultural economic models.

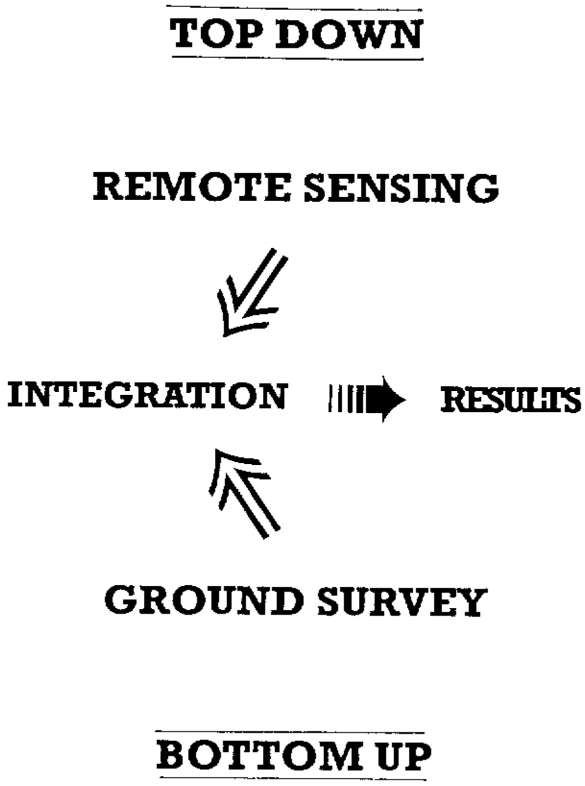


Figure 20 Diagrammatic representation of the linking of remote sensing with ground survey.Remote sensed imagery is at a high level of detail and offers complete coverage. Ground survey offers great detail but in limited areas. The diagram emphasises the necessity of integration.

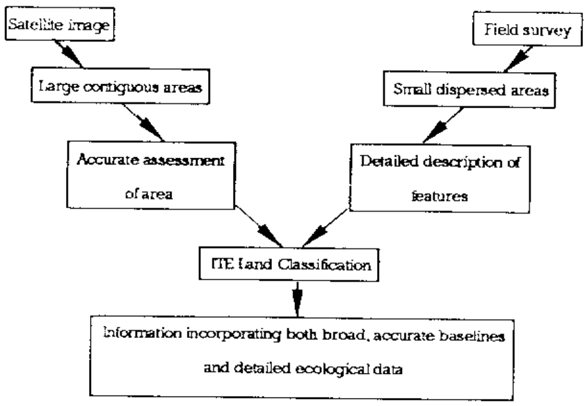


Figure 21 Satellite information and ITE land classification system. Diagrammatic representation of a system for combining satellite derived estimates of broad land cover types with the detailed ground ecological information provided by the sample squares within the ITE land classification system series for Great Britain.

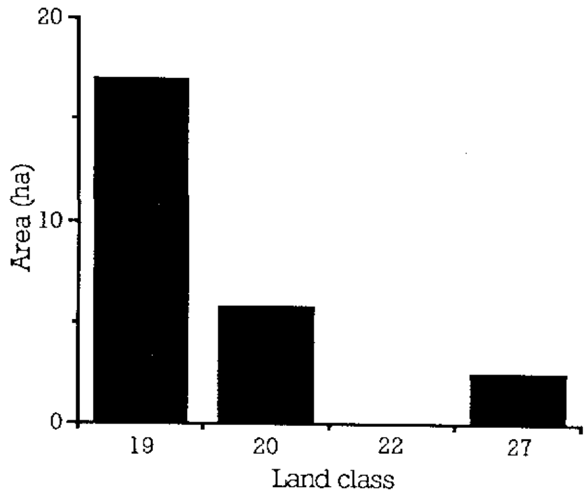


Figure 23 Practical example of incorporation of imagery data with that from the land classification. The area of coniferous woodland within the inner Innerleithen sample area derived from a classification of the satellite imagery subdivided by species from the ITE national estimates according to the proportion of land classes 19, 20, 22 and 27. The area in hectares is presented for the whole 100 km square block.

At a national level, satellite imagery can be used for increasing the number of samples, thus providing more accurate estimates of distributed or less common features. The precise number of samples and the size of each sample to provide the optimum results for different cover types are the subjects of continuing research, although results from several studies have suggested that a larger number of small samples is the most efficient strategy.

Future work will concentrate on developing techniques for integrating satellite-derived estimates of land cover with the ITE land classification system. This work will be undertaken within a project at NRSC to supply data on land cover change within selected water catchments for the Institute of Freshwater Ecology (IFE), as part of its research programme on the relationship between land use and aquatic communities.

3.2.7 Remote sensing and landscape pattern

The ecological characteristics of a region are affected by the spatial arrangement of different land cover types, as well as by their area. Measures of landscape pattern can be

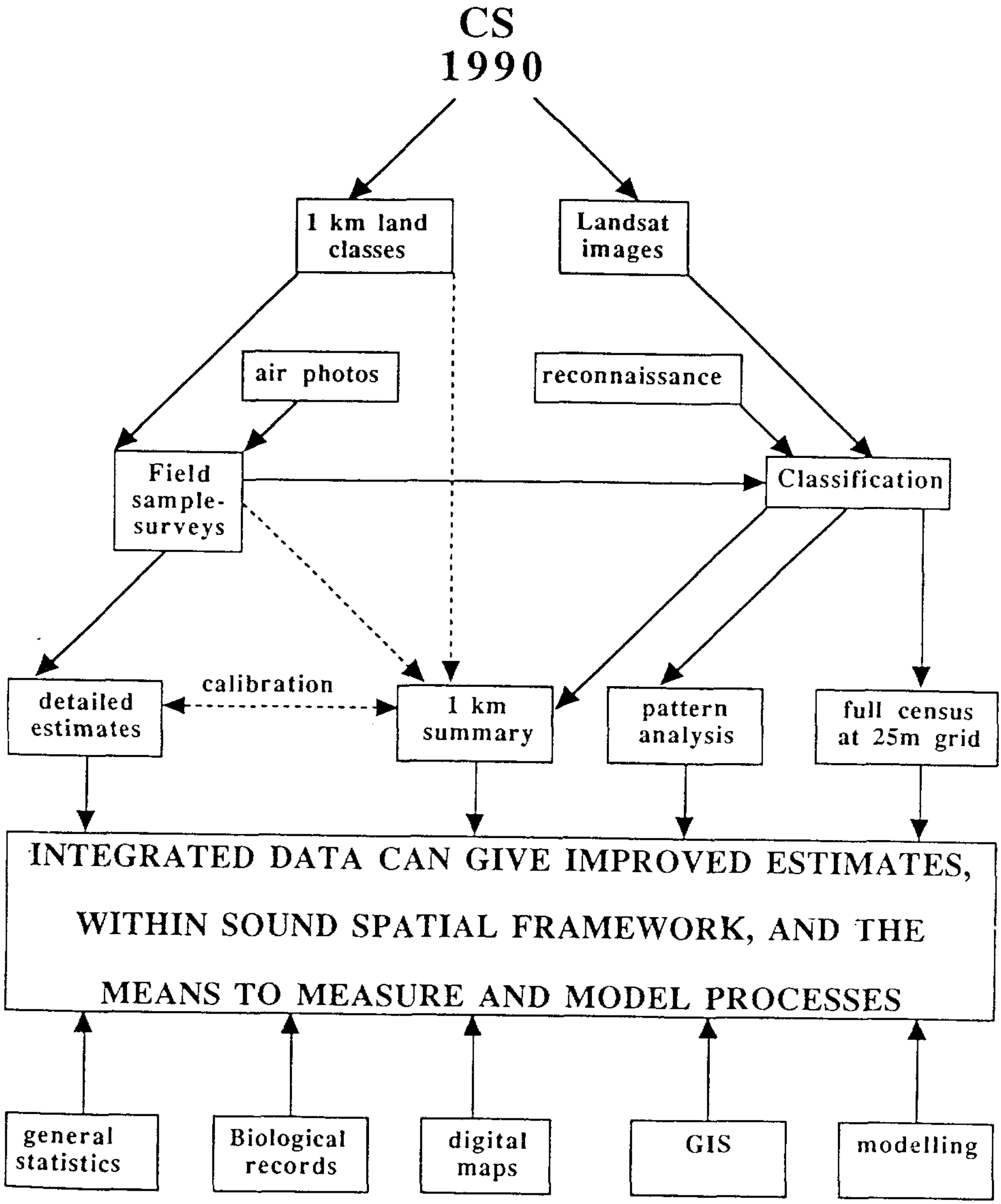


Figure 22 Interrelationship between elements of survey and imagery. The Countryside 1990 Survey programme was based on the procedures developed within the ECOLUC programme. The diagram demonstrates the complete range of activities involved and the way that integration can take place.

used to analyse differences in the spatial characteristics of different landscapes, and to model the relationship between spatial pattern and ecology.

The large areal coverage and digital nature of satellite imagery allow for the rapid measurement of differences in spatial pattern at a wide range of spatial scales and for widely divergent landscapes. Several different measures of landscape pattern and techniques for their display were developed and applied to the classified satellite imagery, including patch size and frequency, fragmentation and isolation, boundary lengths, and diversity. Future work will differentiate between landscapes on the basis of their characteristic patterns. The use of the high-resolution SPOT panchromatic channel for mapping linear features is likely to be important in this respect.

Initial work Laves *et al* (in press) had shown direct correlation in the flow country with satellite imagery and dunlin numbers and the way these can be used to assess change. Within the programme there was co-operation from ITE with the Royal Society for the Protection of Birds (RSPB) and NRSC to estimate the correlation between satellite imagery and bird population. The sites were selected from the basic land classification and covered a range of vegetation types. Various habitat variables were recorded that were likely to be of importance to the main bird species. The approach to the study was to classify the imagery into a number of land cover/habitat classes for correlation with bird census data. An alternative to image classification, mixture modelling, NRSC (1990) was also considered. The spatial pattern of cover types has also been shown to be an important determinant of the diversity and abundance of food species. Two pattern variables were chosen for study — proximity to agricultural land and number of heather patches. The methodology adopted was:

a. Classification of land cover for 1988 bird census sites.
b. Derivation of landscape pattern measures from classifications.
c. Derivation of areal land cover statistics for each 1 km square.
d. Correlation of land cover and the bird census statistics for 1980 sites and model formulation.
e. Production of land cover and pattern statistics for 1989 sites.
f. Production of bird numbers for 1989 census sites.
g. Estimate of predictive potential of image derived variables.

Examples of the classification are presented by Avery in press. Ten upland bird species had sufficiently large census populations for correlation.
Stepwise multiple regression analysis was used to select the smallest number of variables which explain the greatest amounts of variance in the bird numbers. Preliminary results showed the results of the correlation of land cover and bird census statistics. The introduction of pattern measures into the analysis explained the variance in numbers of golden plovers, curlews and lapwings. All three birds favour habitats with more heather, and curlews and lapwings prefer areas closer to agricultural land. This analysis shows the way in which the land classification structure can be used to develop sampling strategies for bird populations, incorporating both ground survey and remote sensing.

3.2.8 Conclusion

The poject has therfore demonstrated that a combination of the strategies can be used to develop predictive patterns that enable more efficient estimations of change to be made.The procedure now advocated should incorporate the strength of sample ground data with the complete coverage of remote sensed imagery. This methodology has now been combined into an intergarated system within the Countryside Survey 1990 project to provide information on land use cover and change in Great Britain.

4. BOTANICAL CONSEQUENCES OF LAND USE CHANGE

4.1 Review of vegetation monitoring procedures

4.1.1 Introduction

Published information on the long-term strategic monitoring of vegetation change in Great Britain is limited and inconsistent. Over the years there have been few significant publications presenting quantitative results from long-term studies of change in vegetation (Hill 1982). Individual authors such as Hill & Jones (1978), Peterken & Jones (1989) and Thomas (1963) have made use of data collected earlier for different purposes which were repeatable and which could therefore be analysed to identify a change. An alternative procedure is to sample sites in chronosequences (Watt 1955; Hill 1986; Miles 1985), but this is possible only in special cases. Other relevant studies (eg the Boxworth project run by MAFF, the roadside verge projects set up at Didbury, and the long-term studies at Moorhouse NNR (Marrs *et al*1986)) have involved highly intensive work at individual sites. A register of permanent vegetation plots within ITE is given by Hill & Radford (1986). The most widely used methods of vegetation recording are various forms of grid sampling (Chapman & Rose 1989), or transect (Marrs *et al.* 1986). Photography has also been used (Bignall 1978) to demonstrate dramatic changes, but these are rarely quantifiable.

Whilst these studies present accurate information on specific sites, it is not possible to extrapolate them to obtain national figures. Detailed recording is required to detect subtle change, but at national level must come from a wide range of sites in order to obtain reasonable estimates. The discussions earlier in this report show the approaches which have been adopted for measuring vegetation as land cover, but these cannot be used to detect detailed information at a species level. The work of Sykes & Horrill (1983) on woodland monitoring is one of the important developments in the attempts to develop quantitative and objective methods of recording change. The fundamental problem is to define a monitoring method which is sufficiently general for it to meet the requirements of the future, allowing it to provide answers to questions which may not have been envisaged at the beginning of the project. The data need to cover a variety of different potential changes, and must be collected using objective procedures which can be repeated by different observers at different times. There are three levels at which monitoring vegetation change can be carried out:

1 Land use — major changes in practice within agricultural land, eg between arable land and grassland.
2 Land cover — a change in the dominant species within the land use, eg a change of crop species with arable land or a change from grassland dominated by *Festuca* and *Agrostis* to one dominated by *Lolium*.
3 Species composition, reflecting more subtle ecological changes and showing differences in the species assemblages.

4.1.2 National vegetation classification

The national vegetation classification (NVC) has been developed at Lancaster University over the last 18 years, and is currently in the final stages of publication. The classification depends upon subjectively selected quadrats within vegetation units which are intuitively identified as homogeneous. It considers mainly semi-natural vegetation, and linear features such as roadsides and hedges are related to their relevant types of vegetation in the open countryside. For example, roadside vegetation is related to meadows, and hedges to woodlands. As the basic data are in the form of species lists, the classes from the ITE analysis can be compared with the associations from NVC. Hill (1989) has produced a computer program which will automatically relate species lists to NVC types. However, the full list of types is not yet formally available, and direct comparisons are, therefore, difficult at the present time. It will be necessary to test the goodness-of-fit of quadrats located at random within types determined by the elimination of intermediates.

Whilst the majority of upland vegetation species should fit broadly into the NVC types, the highly modified grasslands, cereal fields and linear features may not be adequately represented.

Within the initial ITE data two types of information are available: from the presence or absence of species, and from the cover of the dominant species. Analyses of these data show which species are increasing or declining, and tests the trial data from 1978 against those from 1988. Theoretically there were three main systems for recording such vegetation: (i) fixed quadrats, ie quadrats permanently marked on the ground , (ii) marked sites on maps with instructions to allow relocation at a later date, and (iii) progressive random sampling whereby the population is sampled on different occasions. Kish (1965) indicates that procedures (i) and (ii) are relatively accurate because repetition at the same location involves the statistical term which includes the co-variance, ie the correlation between the two data sets and the two dates. On the other hand, the two separate random samples have separate estimates of variance. Replicating data from the same site is therefore an important way to reduce the error of the estimate of change.

The experience gained in comparing the 1978 and 1988 data sets has provided the basis for making recommendations for the stricter procedures to be followed in survey techniques in the Countryside Survey in 1990. These provided an important function for the ECOLUC study in ensuring that the survey in 1990 was carried out as efficiently as possible. The land classification provided the framework for consistently sampling variation throughout the country. Apart from statistical considerations of stratification, the actual measurements for vegetation recording are adequately covered in the literature, eg by Greig-Smith (1983). The important apect of the stratified sample is to ensure that the complete range of variation is covered within the vegetation of Britain.

The method of recording used in the ITE national survey in 1978 was designed to characterise the land classes. However, in 1988 it was decided that a subsample of quadrats would be repeated as part of an exploratory study to examine the feasibility of repeating the 1978 quadrats to identify trends in vegetation change.

Quadrat data collected in 1978 and 1988 have been analysed using the classifications described above, and the results are discussed fully by Hallam & Bunce (internal report to the DOE). In summary, the following trends have been detected. The weed flora of arable fields is quite variable, reflecting the response to different herbicide regimes as well as different ploughing times. The rotation lengths for leys have increased, with a corresponding increase in species number in some areas. Permanent pastures show the greatest change, with a reduction in species numbers and a shift in species composition. Many pastures which were unimproved in 1978, and which represented the most species-rich category on agricultural land, have been improved through more intensive management, by drainage, use of fertilisers and the application of slurry. This has lead to a decline in sensitive species and an increase in those able to take advantage of high levels of nutrients. The trends in the rough grazing categories in the uplands seem to vary — in some there has been a decline in the number of species, with little change in their composition, particularly in those areas which have been fenced and afforested.

The 1988 survey highlighted the difficulty of relocating quadrats in the uplands. This difficulty, and the effects of observer difference, can be minimised by analysing recorded change in species composition in terms of vegetation types and species groups, rather than individual species, and by grouping quadrats and land classes, where appropriate, to increase sample size. As a basis for monitoring change, the quadrat data are limited by the number of samples per square. The replication improves if grouped by land class, and moreover the land classes themselves can be further combined, eg those from north-west Scottish coasts. The major conclusion from these studies is that existing data, with the resurvey of all the 1978 quadrats in 1990, enable changes in vegetation to be identified, provided that recording procedures are standardised and monitored. The main conclusion from the botanical analyses is that the most impact over the last ten years has been from changes in management within a land use rather than a change between land uses, particularly in the case of agricultural grasslands. The exception is afforestation in the uplands, where new plantations have had significant ecological effects. On agricultural land, the ecological changes which have taken place are mainly due to the increased use of nitrogen fertilisers and the application of slurry. Qualitative changes, such as the loss of species from grasslands which have become more intensively managed, are masked by figures which only consider gross change in land use. Further work is required to assess the impact of more subtle changes, such as differing grazing pressures in the uplands, and to establish a basis for monitoring upland landscapes to confirm whether the qualitative changes which are widely perceived are actually occurring.

4.2 Concepts

The concept of diversity is fundamental to much of the work described in this document. It is important, both because richness and variety are valued for their own sake, and for scientific reasons, as summarised by Pielou (in press) who states that there are six main types of diversity:

(i) *Species* — the actual number of species present. This is complicated, because in certain genera species cannot be clearly defined, and this leads to numerous micro-species, eg in *Rubus* (blackberry). Ratcliffe has suggested that species need to be separated into those which that are important as indicators and those which are of wide amplitude. Rarity may also be involved, since rare species may be more highly valued.

(ii) *Genetic* — the maintenance of diversity of organisms and their genetic material is recognised to be of major importance. This can be considered at two levels, firstly the number of different species in a given area, and secondly the range of phenotypic diversity within a species, eg morphological and physiological variation.

(iii) *Structural* — variability in structure within similar species assemblages is also a type of diversity. Combinations of trophic levels are also related to structure, and indirectly involve the concepts of stability and food webs.

(iv) *Environmental diversity* — variation in the environment which need not be directly linked to vegetation, ie the variation in physical factors, such as salinity levels and tidal flow on mud flats, which may in turn be related to different groups of biota.

(v) *Ecosystem diversity* — variation within what are generally regarded as ecosystems, where species assemblages occupy different niches within the same habitat, eg lichens and mosses on tree trunks.

(vi) *Landscape diversity* — the complexes of ecosystems that make up landscape. A rich and varied countryside contains many different ecosystems, whereas a uniform landscape contains little pattern and variation. At one level, this is a matter of visual perception, but in the ECOLUC project it is treated on the basis of ecological data.

Many of the types of diversity described above are interrelated — the focus in this report is on genetic, structural and environmental diversity as related to vegetation. The main considerations are given to species, habitats (using the species groups and types described by Bunce (1977)) and landscape (Bunce & Smith1978). Arbitrary separation enables diversity to be standardised and compared between sites. At the landscape level, diversity can also be measured by pattern (Section 4.4). Pattern can determine the distribution of certain animal species which require a mosaic of habitats. In the conservation movement, diversity is often regarded as an end in itself (Usher 1986), because more biota are likely to be conserved within a diverse area than where the vegetation is uniform. The concept does not always apply; for example, an increase in diversity in inherently simple landscapes or ecosystems, such as the Cairngorm plateau or oligotrophic mountain lakes, represents disturbance rather than stability.

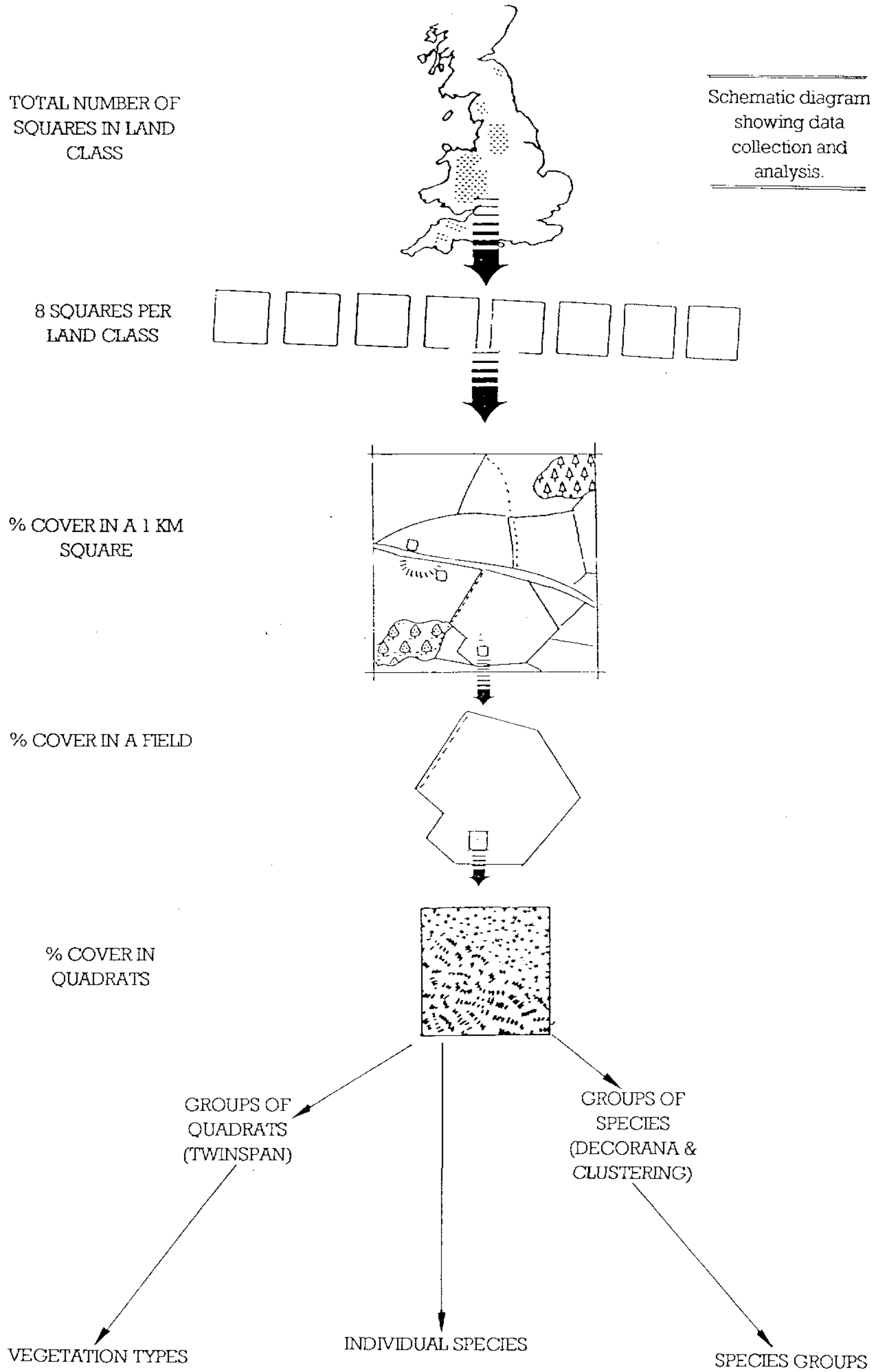


Figure 24 Diagrammatic representation of botanical data collection and analysis. Samples are stratified on the basis of the land classes and are treated at various levels, from quadrat to kilometre square and land class.

Within the ecological literature a number of diversity indices have been proposed, eg by Shannon & Weaver (1963) and Simpson (1964). However, these are statistically unreliable, in that they depend upon an adequate estimate of population means and are susceptible to changes in area and number of species. Furthermore, the scale of the values of the indices means that they do not represent a readily understood number that policy advisers can use in a given situation. In ECOLUC, species, species groups and vegetation types are used as measures of diversity, as they are largely independent of species number.

Botanical data will be presented for linear features in representative sample areas in British landscapes. It is concluded that they contain an important reservoir of species that, especially in the lowlands, are not present in the open countryside. Various methods of recording vegetation change will be discussed and their implications for the interpretation of field data considered. The available information on botanical change will be discussed and the likely trends in the future assessed.

In assessing the botanical consequences of land use change, vegetation must be studied at the level of individual species, in order to detect shifts in species composition. Such analysis can only be achieved by intensive field survey. The baseline quadrat data were collected at sites throughout Great Britain during the 1978 ITE national survey (Figure 24), a subsample of which was resurveyed in 1988. These data have been analysed in a variety of ways, to obtain species number and frequency, and using rule-based and statistical classifications to identify species groups and vegetation types. Many of the topics that follow are discussed more fully in the report to DOE on vegetation change between 1978 and 1988 (Hallam & Bunce, internal report to the DOE).

The primary purpose for the initial collection of vegetation data in the 1978 survey was to characterise the land classes, but because the procedures used were objective and repeatable, the data also form the basis for assessing vegetation change. Species presence and cover were recorded in five randomly positioned quadrats in each of 256 one km squares (eight per land class), with an additional series of linear plots placed on linear features — hedgerows, streamsides and roadside verges. These data are held in the ORACLE database, and have been processed during the project. In 1988, a subsample of 64 squares (two per land class) was repeated, using the same recording procedures and collecting full species lists for each habitat in each square.

Statistical techniques have been used to analyse the quadrat data, to obtain groupings of species as an aid to interpretation. The species presence data from quadrats placed on agricultural grasslands in 1978 produced a series of species groups (using supervised PCA and K means clustering) which can be interpreted with respect to soil type, sward age, and management practice. Figure 25 shows the relationships between these species groups and the direction of potential change in response to land use change, whether an increase or decrease in management intensity (Bunce & Bunce 1988).

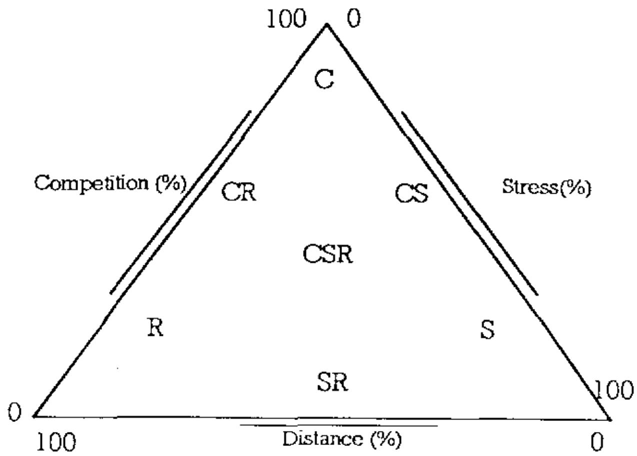
Species with similar environmental affinities have also been classified into species groups, using the quadrat data. These species groups have been described in terms of their ecology (Hallam & Bunce, internal report to the DOE). The number of species groups present in vegetation provides some indication of its diversity. For example, in arable fields, species tend to be concentrated into just one or two groups, whilst in unimproved pasture many more groups are more evenly represented. The number of groups and the proportion of species in each may also be used to detect a shift in the vegetation over time, reflecting either succession or management practices.

The quadrat data have also been used for a vegetation classification of agricultural land in Great Britain (including rough grazing on moorland). The vegetation types have been described and characterised in terms of their ecological and environmental features (Hallam & Bunce, internal report to the DOE). They can be used both to indicate the diversity of vegetation found in a locality, and as a means of detecting change.

The distinction between these categories can be used in investigating change in land cover, using data either from quadrats or from parcels of land for which the cover of the dominant species has been recorded. A change in category may represent a radical change, eg from dominance by grass species to a cereal monoculture, or it may be a more subtle change, eg from a recently sown ley with a 90% cover of *Lolium perenne* to an older one in which other grass species have become more abundant and the cover of *L. perenne* has reduced to 50%. Analysis of data from quadrats recorded in 1978 and 1988 using these categories shows an increasing intensity of grassland management, particularly in a more intensive use of permanent pasture. There has also been a shift away from reseeding because of the cost of seed and ploughing. If the change in categories shown by the quadrats is taken as representative of land use generally, then the change in land use throughout Great Britain can be estimated as indicated by Figure 24.

Another approach to species composition is plant strategy theory Grime *et al* (1988), which has been developed at the Unit of Comparative Ecology (UCPE). This theory defines plant species in terms of whether they are chiefly ruderals (R), competitors (C), stress-tolerators (S), or intermediates. Ruderals are annual weeds, typical of productive and disturbed situationssuch as arable fields. Competitors are typically fast-growing species, found on highly productive and which is not regularly disturbed, such as fertile grasslands. Stress-tolerators are typical of those situations where some environmental factor is limiting productivity, for example soils liable to drought or waterlogging, or soils low in nutrients — the plant species associated with these habitats usually have a number of adaptations which enable them to exploit the conditions. It is probable that, in many of the situations produced by modern agricultural practices, it is the stress-tolerating species which are vulnerable. This is because the management objective is to overcome environmental factors which are limiting growth, eg by irrigation, drainage, or fertiliser application.

Vegetation can be described in terms of the relative proportions of species in each of the groups. UCPE have adopted a standard triangular diagram, as shown in Figure 26. Figure 27 gives an example of the distribution of ruderals, competitors and stress-tolerators, in different habitats, in one sample square. Species following the different strategies grow in different proportions in linear features and open vegetation. A high proportion of the species in arable fields are ruderals, whereas the unmanaged area, streams and verges have more stress-tolerators and competitors. This approach can also be used to look at change in species composition over time. Figure 28 shows two examples of quadrats which were surveyed in 1978 and 1988 — both were unimproved permanent pasture in 1978 which had been improved by 1988, as reflected by increased proportions of *Lolium perenne* and the decline in species numbers.



C: Competitors
CR: Competetive-Ruderals
CS: Stress-tolerand Competitors
CSR: CSR-Strategist
R: Ruderals
SR: Stress-tolerant Ruderals
S: Stress-Tolerators

Figure 26 Representation of the CSR Strategy theory devised by the Unit of Comparative Plant Ecology. The theory defines plant species in terms of whether they are chiefly ruderals, competitors, stress tolerators or intermediates within the triangle shown in the diagram.

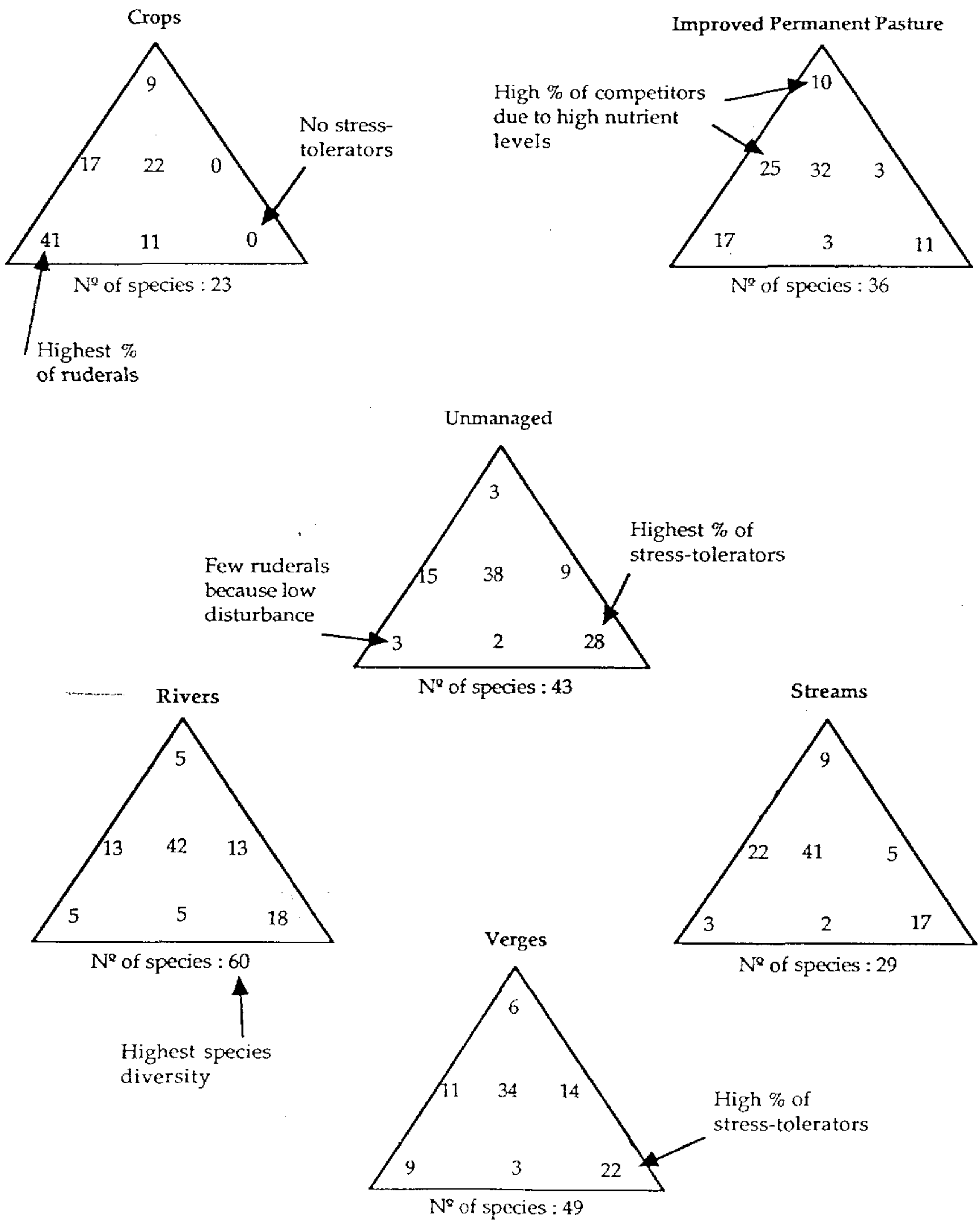


Figure 27 An example of plant strategy theory as applied to a 1 km square. A comparison is provided of the species composition of different habitats within a 1 km square in Stratcarron, Scotland. Data for crops, improved pasture and unmanaged are from 200 m square quadrats from streams, roadside rivers and verges for 10 m quadrats placed along the edge of the habitat.

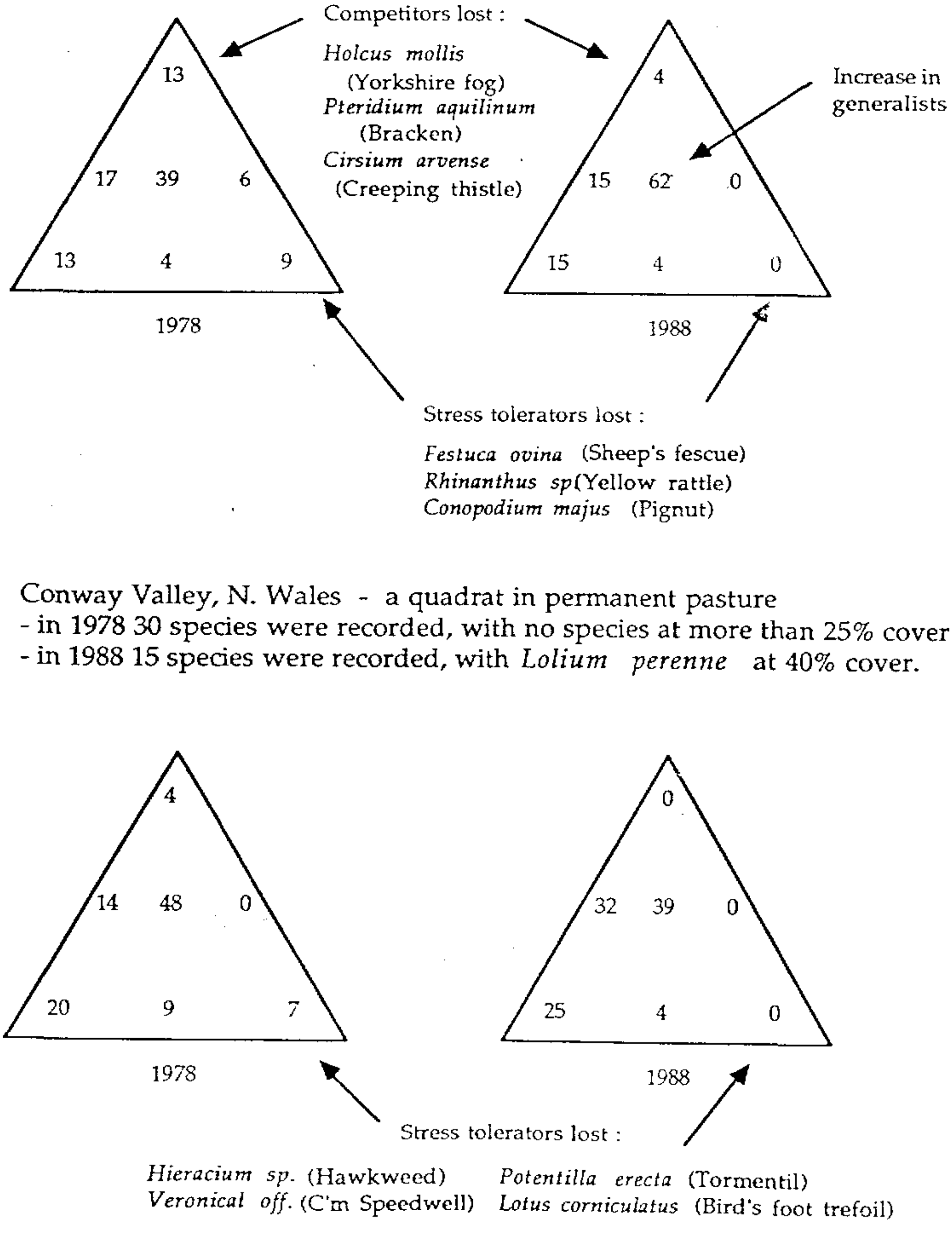


Figure 28 Change in species composition in quadrats placed in 1978 and 1988. Data were recorded from 200 m square quadrats in the same location in 1978 and 1988 and the positions of the species according to plant strategy CSR theory placed within the triangle.

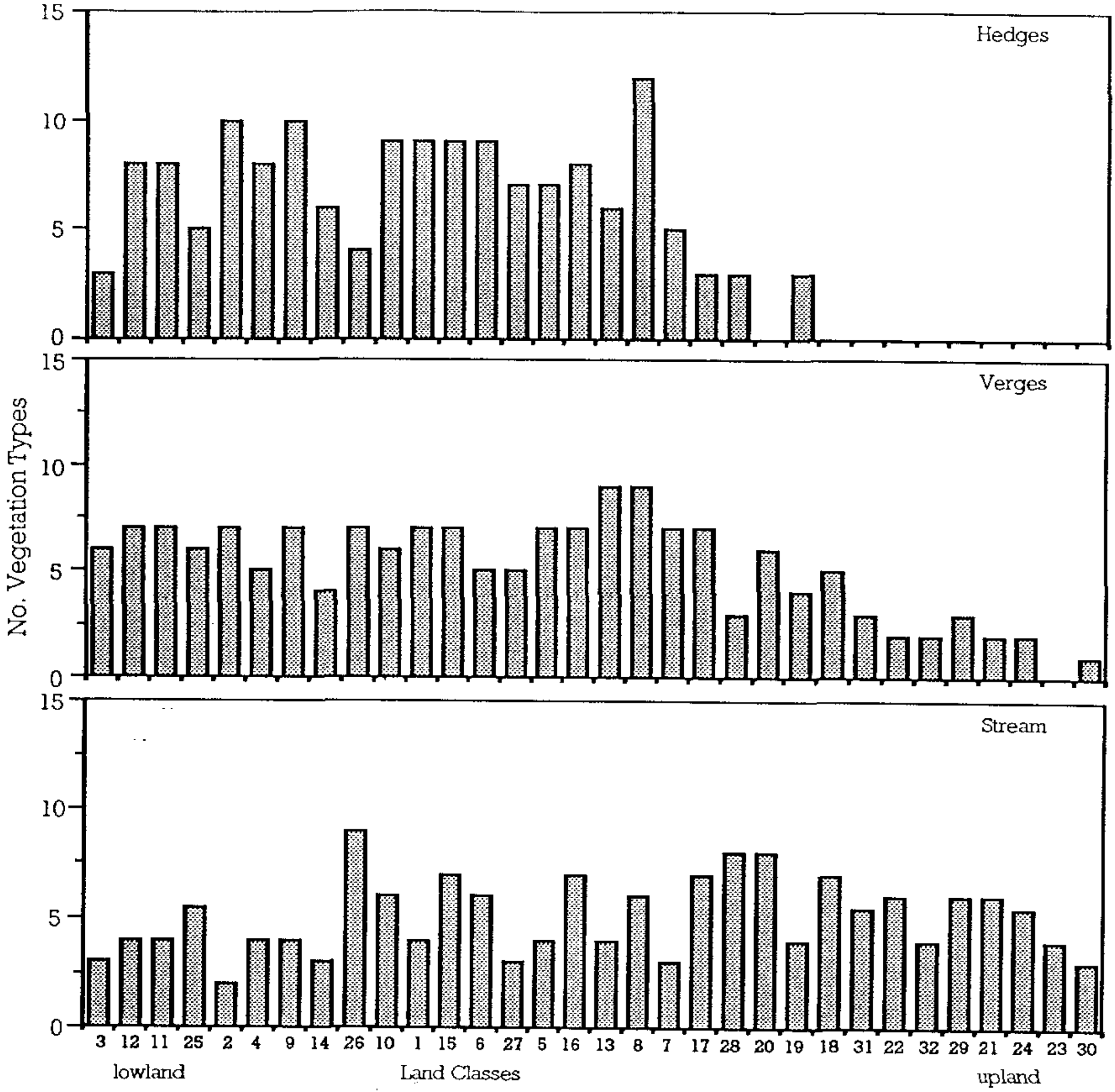


Figure 29 The number of vegetation types recorded throughout Britain in 1978, using quadrats placed along linear features. Two quadrats 10 x 1 m were placed at random along the three linear features in each of eight 1 km squares. These squares were drawn at random from the 32 land classes. The vegetation types were produced by analysis of species data using TWINSPAN.

4.3 The importance of linear features

In the initial survey carried out in Cumbria (Bunce & Smith 1978) 16 random quadrats of 200 m² were placed within representative 1 km squares. During the field survey it was observed that quadrats placed in open country missed much of the variation that was apparent in linear features such as streamsides and roadside verges. Therefore, when the land classification method was extended to cover the whole of Great Britainin 1978, data from three linear features were recorded.

Since the analysis of these data, a wider recognition of the significance of linear features has developed, with the incorporation of concepts from landscape ecology relating to connectivity and corridors. This is reflected in the wide range of literature now available on the subject, eg Schreiber (1988) and Bunce & Howard (1990).

In 1988, the study of linear features was extended by recording species from all linear features within a sample of 1 km squares. The results from the surveys in

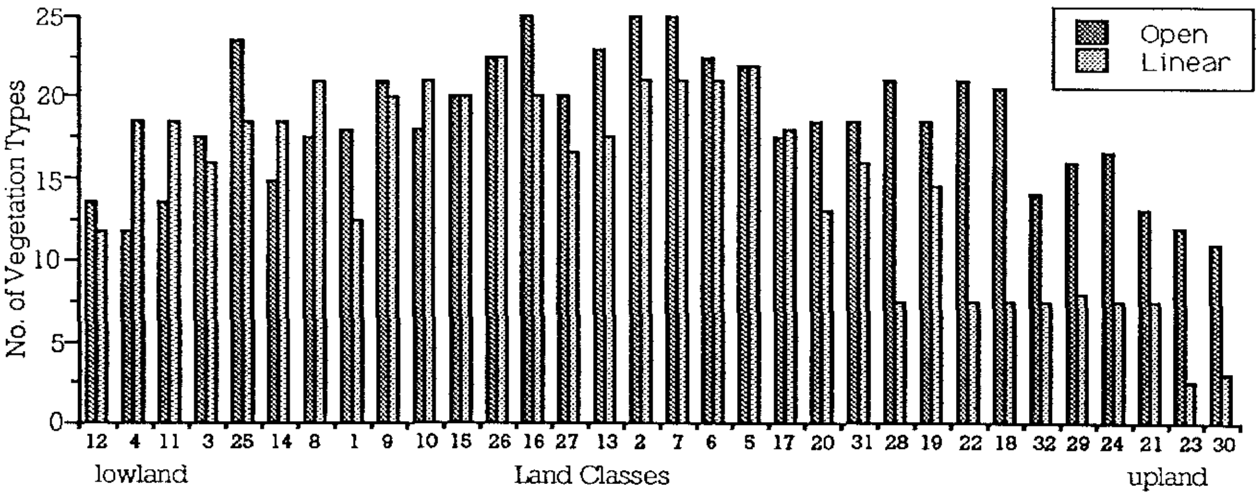


Figure 30 The occurrence of vegetation types in open habitats and linear features throughout Britain in 1978. The data were from two 1 x 10m square plots placed on each of the three linear features and are compared with data from five 200 m square quadrats placed at random in the same 1 km squares.

1978 and 1988 are used to indicate the broad ecological composition of linear features in Britain.

Figure 29 shows the distribution of vegetation types, as identified by TWINSPAN, in the different land classes.

The number of vegetation types in the hedgerows is variable in the lowlands, being related to local land management and environmental factors but with no obvious relationship to the principal environmental gradient. The length of hedgerow is related to this gradient, hedges being most frequent in the grassland areas in the west and less common in the north and uplands.

Verges are less variable than the hedges in the lowlands and in the uplands are relatively homogeneous. This is because the lowland verges are often relicts of less intensively managed grasslands, which have now disappeared from the surrounding landscapes, whereas in the uplands they are intrinsically less variable.

The streamsides are relatively uniform in the lowlands because of the effects of eutrophication and stream bank management. In the uplands, streamsides are more diverse because of localised enrichment and, in some areas, protection from grazing.

Thus, the three linear features show distinctive ecological patterns — hedges and verges contribute most diversity in the lowlands, whilst streams are a more significant source of variation in the uplands.

In Figure 30 the number of vegetation types present in all three linear habitats is compared with the number found in the open countryside. The latter show least diversity in the uplands and in lowlands dominated by arable land. Diversity is greatest in the marginal uplands where both upland and lowland habitats are present. In contrast, linear features are more diverse in the lowlands but are relatively uniform in the upland landscapes of northern Britain. There is a marked contrast between the distribution of vegetation types in the lowlands and the uplands, with the former having most variation, and the latter having less strong contrasts. Within this general pattern there is much local variation, eg the semi-natural vegetation on chalk and limestone is diverse in areas where it has not been replaced by intensive agriculture. Such patterns are the result of historic changes in land use, and would have been very different only 50 years ago.

Figure 31 illustrates the diversity of linear features, in terms of numbers of plant species.

In areas dominated by arable land, hedges have frequently been removed; where they are still present, the herb layer is often impoverished by herbicide spraying and eutrophication. The number of plant species is higher in the marginal uplands where the hedges are associated with pasture and so have been less disturbed.

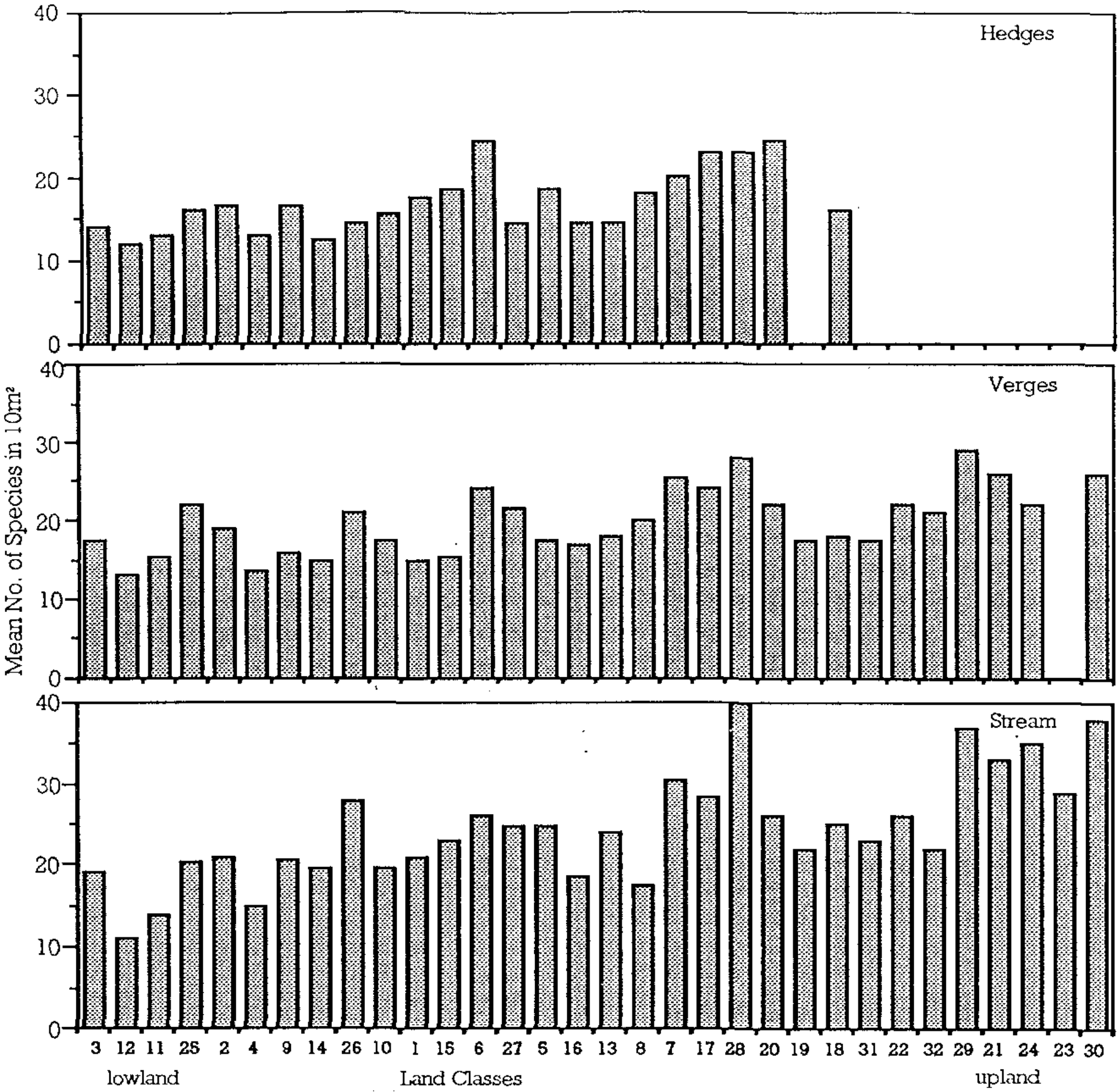


Figure 31 The number of species recorded from linear features throughout Britain in 1978. Two randomly located 1 m square plots were placed along each of the three linear features in eight 1 km squares. These squares were drawn at random from the 32 classes.

The verges have slightly more species in the upland classes — in contrast to the lesser diversity of vegetation types, showing that more than one measure of diversity is required to express the variation present.

The streams show a greater degree of variation overall, but also have more species in the uplands. This is due to localised flushing by streamwater and the more variable physical environment.

In Britain as a whole, the streams have more species than the verges, with hedges having the least number. Previously, most emphasis on the ecological status of linear features has been given to hedgerows, but these data show that other linear features also contribute significantly to diversity.

Each of the linear features investigated contains distinctive species not found in the open countryside. This is especially so in the case of streamsides, which provide a habitat for wetland species, eg *Caltha palustris*, *Iris pseudacorus* and *Glyceria fluitans*. Hedges contain many woodland species, such as *Digitalis purpurea*, *Tamus communis* and *Silene dioica*, whilst verges contain species of mesotrophic grasslands such as *Filipendula ulmaria*, *Geranium pratense* and *Galium verum*. Thus, linear features not only

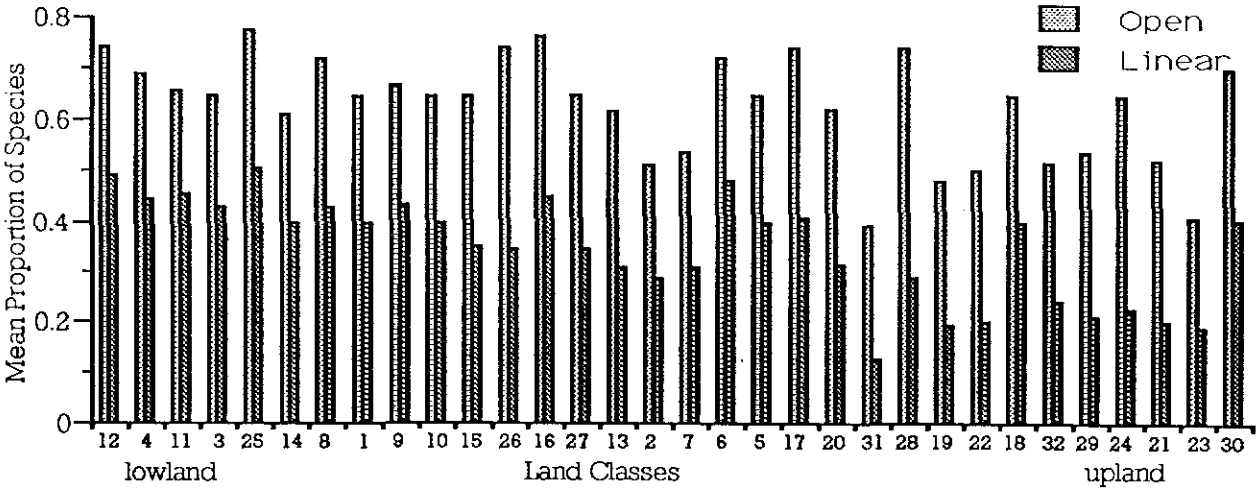


Figure 32 The proportion of plant species recorded in linear features in Britain in 1978 and a proportion found in linear plots only. The data were from 10 m square plots placed along each of the three linear features and are compared with data from the five 200 m square quadrats. These quadrats were placed at random in the same 1 km squares.

contain the species present in the open landscape, eg *Lolium perenne* and *Agropyron repens*, but in addition have their own complement of distinctive species. Although only six 10 m^2 plots were recorded in the linear features as opposed to the five 200 m^2 in the areal habitats, Figure 32 shows that the plots from linear features contain a high proportion of all the species recorded in the 1 km squares. Furthermore, many of these species were not found at all in the fields. Plant species are more evenly distributed through the upland landscape than in the lowlands, so the linear features are less distinctive.

Figure 33 shows the mean number of species found in each habitat in 1 km squares sampled throughout Britain. In general, the linear features contain more species per unit area than habitats in the open countryside. The majority of species-rich linear features are in the lowlands, where the open countryside contains very few species. Even in gaps between the crop and the field boundaries there are unsprayed areas which still contain uncommon weeds which have been eliminated from the crop, eg *Thlaspi arvense* and *Anchusa arvensis*. These fragmented patches will contribute the majority of species available for recolonisation if extensification takes place, emphasising that the management of linear features in lowland landscapes is critical for the maintenance of diversity.

This is confirmed by Figure 34, which shows that, in the lowlands, there are as many species present in the linear habitats as in the open landscapes, although the former occupy less than 5% of the land area. In contrast, in upland areas the majority of species are widely dispersed throughout the landscape — in part because most of the open habitats are less intensively managed, and in part because the linear habitats are less common. In general, the lowland habitats are intrinsically richer in species than the uplands, but intensive management has restricted many plant species to small patches of the landscape.

The results presented above indicate the botanical significance of linear features which is now emphasised by the paucity of undisturbed semi-natural vegetation in intensively farmed lowland landscapes.

Linear features are not only important for flora but also for fauna. Some species such as phytophagous insects are directly dependent upon plants; others depend upon them for shelter and movement. Examples of these interrelationships are presented by Bunce & Howard (1990) and Schreiber (1988).

Linear features are also important for the role they play in linking elements of the landscape, especially where semi-natural habitats are small and fragmented. Dispersal along linear features has been widely observed previously, eg the spread of *Senecio squalidus* along railway lines, and *Chamaenerion angustifolium* along verges to colonise marginal derelict areas. More

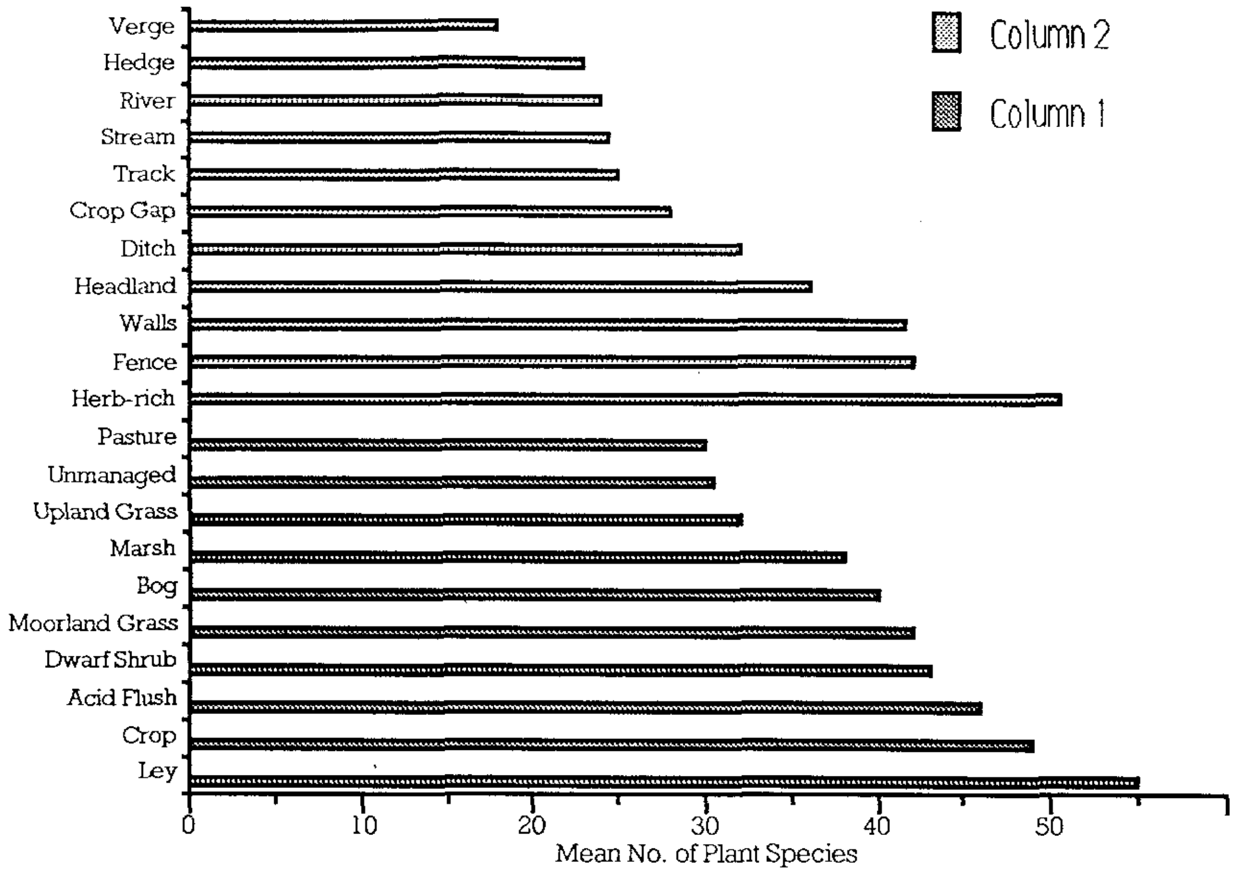


Figure 33 The mean number of higher plant species recorded in different habitats from two 1 km squares drawn at random from each of the 32 land classes. Complete lists were made from the habitats throughout the 1 km squares in 1988.

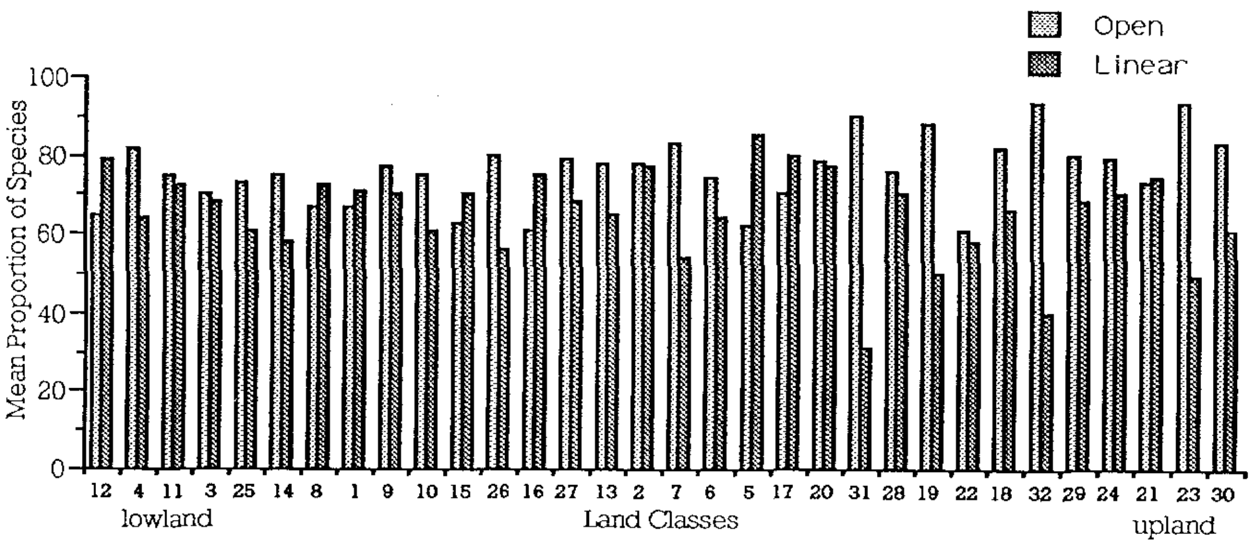


Figure 34 The mean proportion of higher plant species recorded in 1 km squares which grew in linear features and open habitats. Data were recorded from two squares drawn at random from each of the 32 land classes in 1988.

recently, oilseed rape has been seen spreading along roadside verges. This potential for dispersal provided by roadside verges may allow movement of species following climate change; for example, the major drought in southern England in 1990 killed much roadside vegetation and produced bare areas which became available for colonisation.

The role of many linear features, as a refuge for species which have not been able to survive in the fields, is important in terms of the response of vegetation to changes in agricultural practices, such as 'set-aside'. For example, a decline in management of grasslands could lead to the expansion of species from field boundaries, as seen in the derelict areas in the Pyrenees. The mobility of different species, and their ability to colonise existing vegetation, will determine which are successful.

Linear features still retain much botanical capital that can replace species lost from open landscapes. They therefore need to be incorporated into the development of the landscape design to maintain and enhance ecological diversity. Whilst it is recognised that designated conservation areas for specific habitats are essential, the above work shows that even intensively farmed landscapes still contain a surprising range of species that offer opportunities for conservation.

4.4 Seed banks

Following the identification of the significance of linear features, it was considered important to assess further the botanical capital. A study was carried out in 1988 to examine the seed banks of soils from the main habitat types, ie streamsides, roadside verges and hedgerows, as well as crop fields, temporary and permanent pasture, moorland and bog. The results showed that there was a strong positive relationship between the numbers of species in a seed bank and the number of species growing in the habitat (Figure 35). However, there are indications that seed banks were larger, relative to the number of species recorded above ground, in permanent pasture and linear features. This

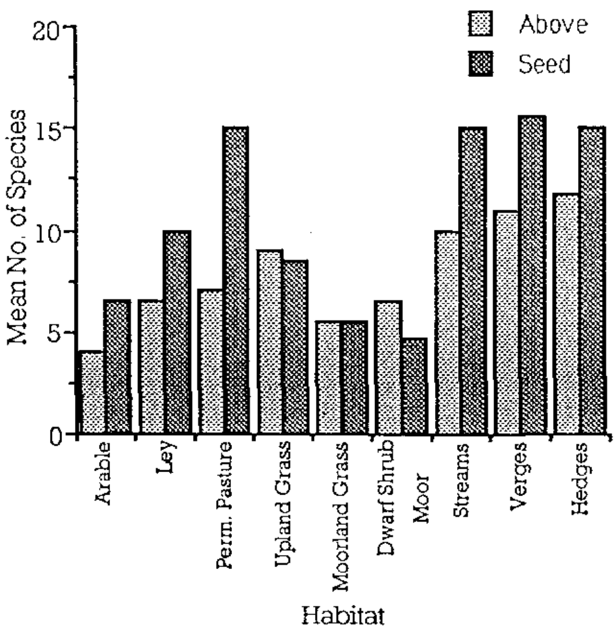


Figure 35 Seed bank species. Comparison of a number of species in a seed bank with the number of species growing in a similar habitat from which the sample was taken. Samples were drawn at random from 1 km squares throughout Britain in 1988 and soil samples brought back into the greenhouse, and grown and recorded through the summer period.

'reserve' of species indicates that changes in land use which would allow germination of seeds in the seed bank of permanent pastures, and linear features, would also produce a more species-rich vegetation. Some areas of the lowland agricultural landscape, ie crop land and intensively managed grassland, have fewer species present not only in the vegetation but also in the seed bank, so that the effects of changes in management are likely to be restricted by the already marked reduction in species numbers in the fields. The colonisation of species in these areas will probably be slow and mainly dependent on dispersal.

Results indicate that the seed bank contains fewer species in upland vegetation and unenclosed habitats than in the lowlands, where the environment is not as stable and where man has had a greater impact through intensification of agriculture. This pattern reflects the evolution of species, in that natural selection in the stable upland habitats does not require species to be adaptable in their reproductive strategies. By contrast, the conditions in disturbed habitats have favoured the natural selection of those species with long-lived seeds because of their change of regeneration through soil disturbance.

The UCPE plant strategy theory has been used to compare the species composition of the seed bank in different habitats, and has demonstrated that the seed banks of arable fields contain ruderal species which are able to colonise rapidly, whereas less disturbed habitats such as verges, hedges, and streams contain more stress-tolerator and competitor species (Figure 36).

4.5 Underlying causes of vegetation change

4.5.1 Factors causing decrease

Reduced grazing and abandonment — areas of grassland which have a long established balance between grazing regimes and sward constituents show a marked decline in the number species after grazing or other management ceases (Asselin 1988; Thomas 1963). Such areas are particularly important on limestone or chalk, where steep slopes have often been left ungrazed because of a decline in shepherding. Decline and abandonment is also taking place in Scotland (Watson 1988), with consequent invasion by trees. Tree cover at first reduces diversity, but this eventually increases again with invasion by woody species.

Increased use of nitrogen fertilisers — the effect of nitrogen fertilisers increases the proportion of vigorous grasses at the expense of smaller forbs (Hopkins *et al.* 1988; Fuller 1987). Such impact is widely accepted and is incorporated into Environmentally Sensitive Area management agreements.

Increased use of silage — although this is usually linked to increased use of inorganic fertilisers there is also an impact through the increased frequency of cutting, and the lack of seed due to non-maturation of the sward.

Increased use of slurry — expansion of zero grazing of cattle has resulted in a major increase in the production of slurry, which when returned to the land has an effect comparable to high levels of fertiliser. The nitrogen content is also likely to be in a highly mobile form.

Increased herbicide use and specification — evidence is available of the continued increase in herbicide use, particularly in cereal crops. The increased efficiency of such herbicides has resulted in a continued decline of arable weeds, but has also caused losses of grassland species. Spray drift and indiscriminate use of sprays on linear features also influences vegetation (Marrs, in press).

Drainage — although moorland gripping has declined, the increased efficiency of agricultural drainage through the use of plastic piping has lead to a decline in marshy habitats, which are often linked to streams and ditches, and also in the wider landscape.

Afforestation — planting of new conifer forests causes a loss of species through loss of grazing, shading (Hill 1986), and a change in hydrological regime.

Decline in linear features — hedges, ditches, small streams and walls are all being lost from the landscape and replaced by agricultural vegetation, causing loss of species (Barr *et al.* 1986). Increased management of adjacent land also reduces the number of species in the linear features.

Agricultural improvement — this covers a range of different activities, from ploughing and reseeding in the uplands (Parry 1977) to clearance of heathland in the lowlands (Webb 1986). The 'Monitoring of Landscape Change' project shows that agricultural improvement has been the cause of a major decline in semi-natural vegetation and its replacement by productive grassland.

Decline in moorland management — the lack of a mosaic of burning and careful moorland management has caused local decline in species numbers in part due to loss of mosaics but also to the increase in uncontrolled intensive burning (Miller *et al.* 1984).

Ammonium levels in precipitation — the decline of heathlands in Holland has been linked to high ammonia levels due to intensive farming (Heil 1984). Comparable

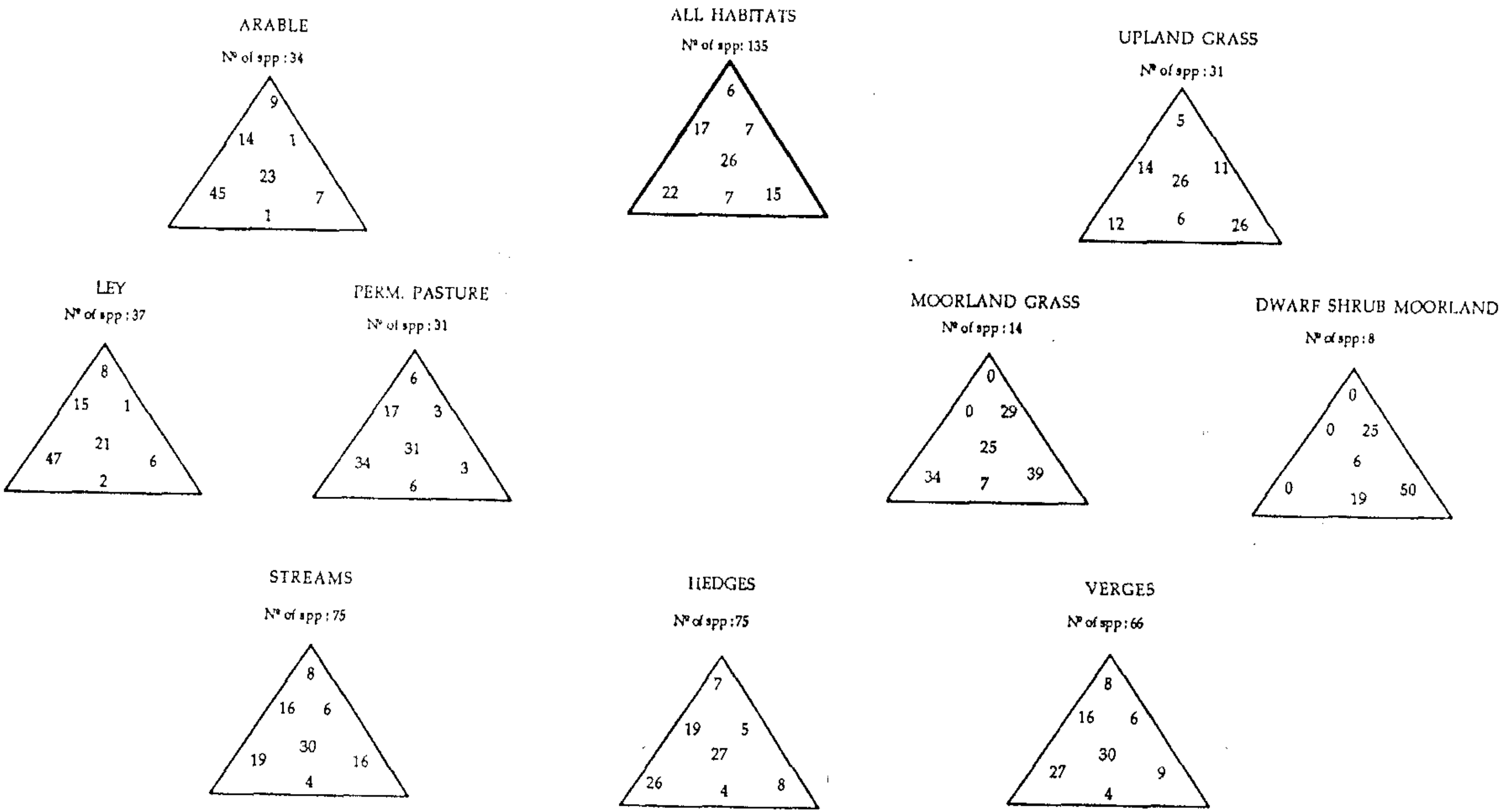


Figure 36 Seed bank strategies according to the UCPE strategy theory (Grime *et al.* 1988). 1 km squares were used to demonstrate the relative seed bank strategies of the species according to the UCPE database. All figures in the triangle are percentages.

levels are now reported for Great Britain (Williams *et al.* 1989) and add significantly to nitrogen level; they could cause effects similar to direct eutrophication.

Finally, the changes in combine harvesting may have led to more efficient collection of straw, with less seed available for recolonisation or as food for seed-eating birds.

4.5.2 Factors causing increase

Decline in verge management — reductions in council spending have caused a decrease in cutting and herbicide spraying of verges. The former has led to an expansion of woody species, coarse grasses and large umbellifers in some areas, and the latter to an invasion of mainly ruderal species locally on to bare ground.

Longer grassland rotation — the increased costs of seed and cultivation, together with research indicating that direct nitrogen application can have similar effects to reseeding, have led to an increase in the rotation length of grassland. A related factor is the decline of livestock numbers in cereal areas, which has reduced the inclusion of grassland into rotation patterns.

Changes in grazing pressure — in some cases restoration of grazing (Grant *et al.* 1987) can increase the diversity of swards, providing that reservoirs of species are available. Shifts in the types of grazing, eg from sheep to cattle, can also be important in increasing diversity, again providing that sources of species are available.

Management for conservation and recreation — the Farming and Wildlife Advisory Group has locally improved diversity through advice to farmers on vegetation management. In addition, management agreements in Environmentally Sensitive Areas (Smith 1988), and the encouragement of traditional practices such as hay making, can also bring back species. The conversion of intensively farmed land to new uses such as golf courses or horse grazing can lead to the return of additional species.

Set-aside — although currently the legal constraints on set-aside are restrictive, there is potential for conversion of crop land to more varied vegetation, provided that it is not used for agricultural production. Thus, grassland in an area near Newmarket has been established for horse gallops, replacing intensively cropped land.

Sporting pursuits — this is the management for pheasants in the lowlands (Hill & Robertson 1988), including the introduction of scrub and break crops. The work of the Game Conservancy (Potts 1986) on food supply for partridges on headlands is a further example, as is the construction of flighting ponds for ducks.

The balance between the above influences is difficult to determine without further analysis. The relative extent can be estimated to some degree, at least in respect of habitats, and in due course can be obtained from the interrogation of the main database on land cover. However, the detailed management information can only be obtained from financial and farm enterprise data from the MAFF census of Farm Business Survey, or by direct enquiries to individual farmers. Such research could lead to the development of policies to counteract the decline in species obtained during the study.

5. ZOOLOGICAL IMPACTS

5.1 Introduction

Land use and management are both important factors in determining the distribution and status of animal species. It is essential that policy advisers have information describing both the current abundance of species and their sensitivity to changes in land use. There are few national data sources describing animal populations, and the resolution of information seldom permits accurate predictive modelling. The ITE land classification is a system which will allow geographical variation in animal population densities to be estimated, and is an ideal framework for modelling the consequences of land use change on animals.

Surveyed zoological information covering the whole of Great Britain is scarce because of the difficulties of recording animals over a large area containing many different habitats. Some studies use sampling, eg the Rothamsted moth traps, but the survey sites are not usually a random selection from the whole of the country. Neither the British Trust for Ornithology's (BTO) common bird census (CBC) nor the Rothamsted moth traps sample all land classes; those omitted are usually either upland or remote, and consequently may be of considerable ecological importance. The bias may be caused by the dependence upon voluntary contributors, who are predominantly in the lowlands of England, or the requirement for carrying heavy equipment (eg moth traps). Other data sets, such as those of BRC, simply record the presence of organisms in ten km squares, and such records may exaggerate the presence of small patches of rare habitat. Conversely, because absence is not recorded, it is especially difficult to predict accurately areas where the species do not occur. The distribution is better described as that of the surveyors, rather that the organisms in which they are interested. However, the repeated recording does allow major changes in geographical distribution to be monitored.

Other data sets may be valuable for modelling distributions. For example, the occurrence of monophagous herbivores could be estimated by predicting the distribution of their host plants, and the results could be overlaid with climatic information to identify the limits of their range. Such an approach could easily be adopted by linking the ITE phytophagous database to the land classification. The results would enable predictions to be made for insects, assuming that information describing their host plant had been recorded.

Once the population has been estimated, the feasibility of predicting change is largely limited by the quality and precision of the information originally recorded and whether it is in an appropriate format for superimposing scenarios. Anecdotal or non-quantitative information is of little value in this respect, and full quantitative data are required. Where information is related to habitat, the change in species number can be predicted in response to changes in habitat areas. Unfortunately, changes in habitat quality are likely to have an equally important effect. The land classification is capable of modelling change within a land cover type (eg changes in management or the proportion of different trees in a woodland), but unless the animal autecology is understood it would be impossible to model such information.

5.2 Animal studies in the project

5.2.1 Birds

The BTO has manipulated the CBC data in the present project to estimate the densities of 41 different bird species in each of the one km squares surveyed in 1978. The population densityies for four different habitat types were predicted nationally by contouring the BTO sample sites. The numbers predicted in the ITE sample squares were calculated by multiplying the area of habitat by the contoured density. The approach allows populations to be predicted for each of the land classes, although the CBC sites occur in only 75% of them (Figure 37). The distribution and frequency predicted by the ITE land classification can

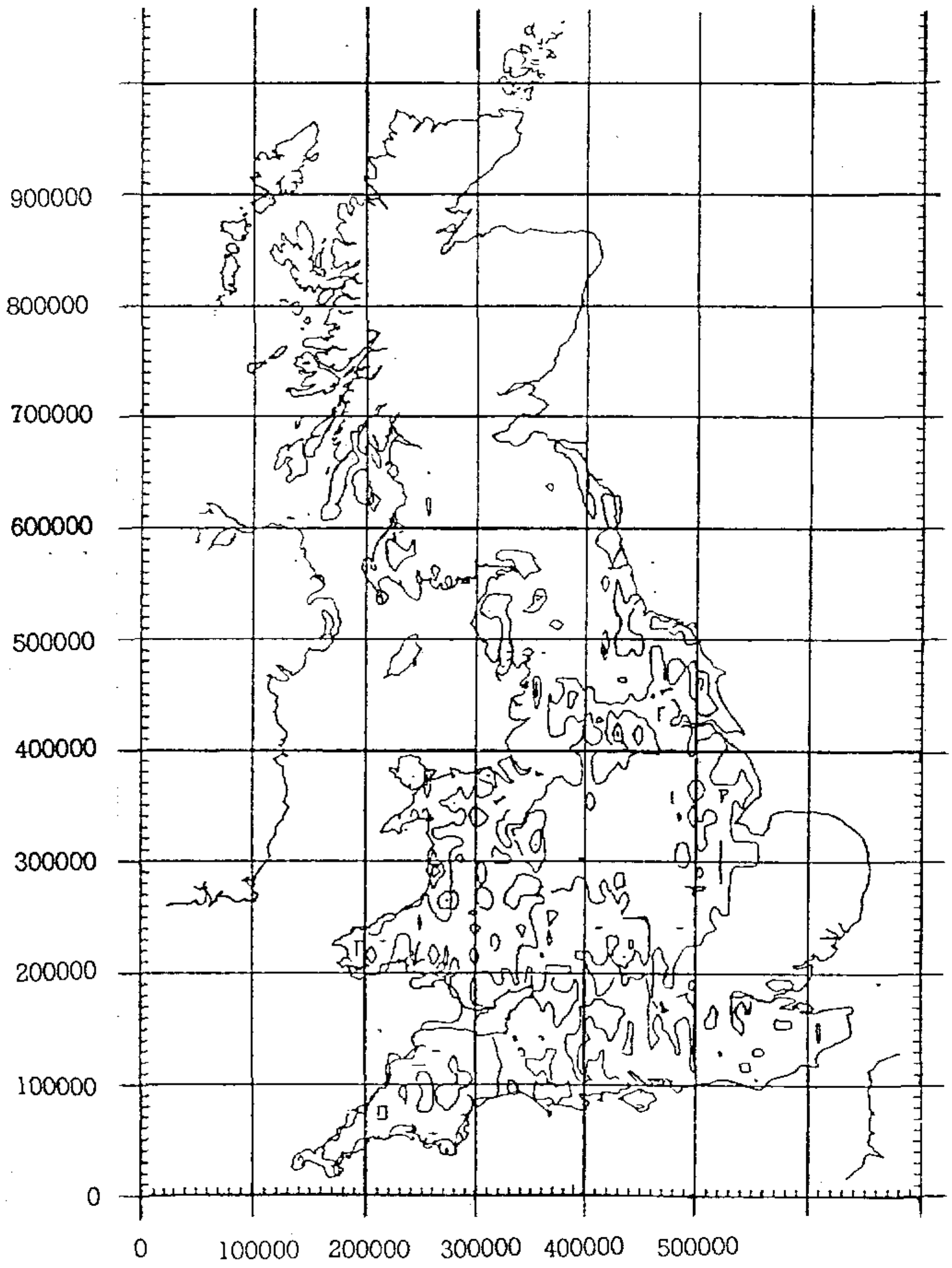


Figure 37 A comparison of BTO data and that derived from the land classification for the stock dove. The distribution and population density of stock doves were estimated from the eight squares from each of the land classes and experience and CBC data used to estimate density the of stock doves in those squares. The mean figures were then derived for each land class and contours for density interpolated.

be compared with currently accepted geographical abundance. As an example, the stock dove (*Columba oenas*) is shown to be absent from large parts of East Anglia, which contradicts information in such works as that of Sharrocks (1976). However, differences are probably due to the methods of recording and the behaviour of the bird, which is recognised as being scarce in intensive arable areas, but is likely to be recorded no matter how scarce. The resolution of the results is frequently different; for example, Sharrocks (1976) uses a ten km square grid — which is 100 times the area of the cells in the ITE system.

There are some examples of the conversion of data to national estimates, and the figures produced may be compared with those given by Sharrocks (1976). Breeding pairs form the basis for the comparison, but were only recorded by using expert judgement. The figures should not, therefore, be used as a rigorous test, but only as an indication that comparable estimates are involved. For example, for the greater spotted woodpecker (*Dendrocopos major*), the figures from the CBC were 30,000-40,000 pairs compared with 52,000 from the ITE land classification; for the tree pipit (*Anthus trivialis*), the figures were 50,000-100,000 pairs from Sharrocks and 74,000 from ITE, and for the sparrowhawk (*Acipiter nisus*) about 20,000 pairs from Sharrocks and 47,000 from ITE.

As discussed in Section 3.2.7 above, the RSPB were also involved in assessing approaches to the coordination of bird population data. Whilst the approach described above was shown to be feasible, the RSPB studies showed that data collected specifically for population estimates and as a basis for monitoring were able to detect changes with confidence. Furthermore, once the populations had been estimated, eg dunlins in the flow country, the impact of future changes such as afforestation could be superimposed upon the basic pattern, to determine their effects.

A further conclusion from these studies is that the method used must be designed according to the distribution patterns of the bird concerned. Thus satellite imagery is appropriate if stray patterns are present in the habitats of a given bird, whereas a ground survey only may be feasible for other species whose habitats cannot be detected by remote sensing.

5.2.2 Wildcats

Data for wildcats are sparse and fragmented, and it had not been possible to correlate these with habitat information. However, the land classification provided a means of coordinating the available data, and whilst there were low correlations between the endine land classes and observed occurrences, it was found that a regional grouping of the land classes into 100 km squares (NC, NM, NO) could identify the areas with the highest cat numbers (Figure 38). Although the land classification can predict the distribution of habitats which are suitable for the animal, other factors which cannot be predicted, such as gamekeepers, cause actual densities to diverge from the potential. The next stage was to use this study as a basis for determining the more detailed patterns of distribution, as described by Easterbee *et al* (1991)

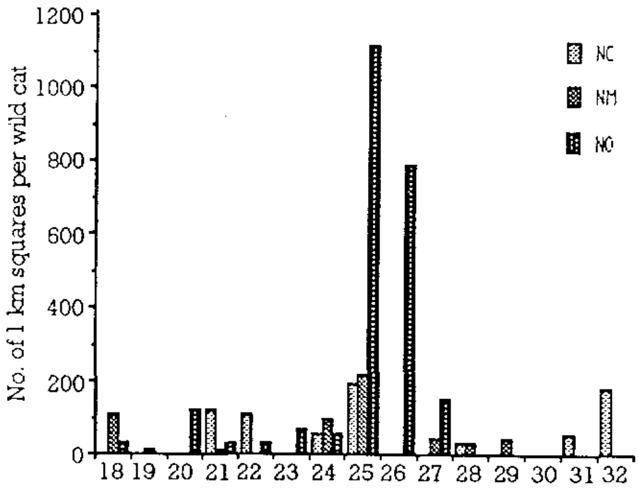


Figure 38 Association between wildcat observations and land classes (Easterbee *et al.* 1991). The land classes were split into their 100 km square blocks and the frequencies of wildcats associated with the different blocks within the land class. The number of 1km squares present per wildcat is recorded.

5.2.3 Badgers

The status of the badger in Britain has long been controversial. In 1985, therefore, the NCC commissioned Bristol University to assess the British population. The survey was stratified by using the land classification scheme to investigate its application to population estimates as part of the present contract, and to make the sampling more efficient. Between November 1985 and January 1988, 2455 one km squares in

Britain were surveyed for signs of badger activity and for the presence of setts (Cresswell *et al.* 1989)(Figure 39). In addition, a detailed habitat map was completed for each square.

The number of setts recorded in each square varied between zero and 26, and the number of active main setts between zero and six. The total badger population in the rural areas of Britain (± 95% confidence limits) was estimated to be 42,891 ± 3,851 social groups, or approximately 250,000 adult badgers, with an annual production of about 105,000 cubs.

The mean number of setts per social group was 4.10; although this mean number remained largely constant at different population densities, the number of disused main setts increased, and annexe setts decreased with decreasing population density.

The incidence of hole blocking was widespread, with 15.7% of active main setts affected. Digging was also widespread, with 10.5% of active main setts showing signs of having been dug. It was calculated that 9000 setts are dug each year by badger diggers. The incidence of snaring at setts was difficult to quantify. The results have subsequently been used in legislation, because the full extent of disturbance had not been realised.

The effects of the government bovine TB control operation in south-west Britain were discussed, and it was shown that the trapping programme removes about 1% of the south-west badger population annually. Little effect on sett activity could be detected in those squares subjected to badger control operations.

The habitat preferences of badgers in different land classes were analysed. Linear bivariate correlations between sett numbers and habitat type were then calculated, and habitat preferences for active main sett sites quantified. A discriminant analysis was used to predict the presence or absence of active main setts in each 1 km square by land class, and a multiple regression model developed to predict the numbers of each sett type in a 1 km square across all land classes.

5.2.4 Foxes

Macdonald *et al.* (1981) showed the ability of the land classification to assess fox (*Vulpes vulpes*) populations nationally, but, as with the wild cats, hunting and local management significantly affect local populations. In order to improve the predictive abilities, recent studies of foxes and badgers have applied the principles of habitat characterisation.

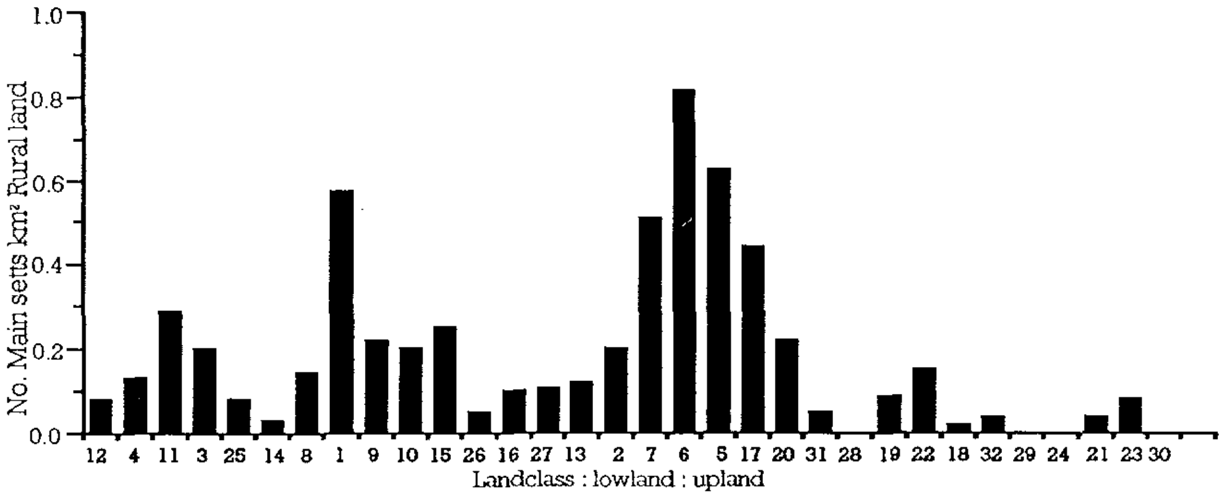


Figure 39 Density of badger setts in land classes. A total of 2 500 squares were surveyed throughout Britain, and the density of main badger setts recorded in each of the 1 km squares. The mean numbers of main setts were calculated per land class (Cresswell *et al.* 1989) and are presented by land class.

Animal numbers were predicted by assessing the availability of appropriate habitat. Although only a small amount of the variance was explained by any combination of habitat features, the study highlighted the potential of the approach, provided that more extensive data can be obtained to increases the accuracy of prediction.

5.2.5 Game animals

A further test of approaches to population estimates was carried out in the project by the Game Conservancy, who applied a similar strategy in an attempt to predict the population density of several game animals. Knowledge of the autecology of the species has allowed models (Hill & Robertson 1988) to be built for predicting populations. By applying the models to habitat information collected for the ITE surveys sites, the present populations can be predicted, and their potential for expansion and their susceptibility to landscape change can also be gauged.

The main densities of pheasant (*Phasianus colchicus*), partridge (*Perdix perdix*) and hare (*Lepus timidus*) in the eight squares within each land class were calculated. The results were sent to ITE (Merlewood), and multiplied by the total area represented by that land class in the country as a whole. The estimated number of each species within each class are given in Table 4. The figures for pheasant are based on observed data from shooting estates, most of which employ a gamekeeper. Although the figures for territorial males should be fairly representative, the others should be viewed with caution, as the extent of hand-rearing and predator control in each land class was unknown. The partridge figures represent the maximum potential number of pairs within each land class; actual densities are certainly considerably lower. For hares, the data refer to numbers in areas with a gamekeeper. In most areas they are absent, and the actual figures are almost certainly lower.

The data can be converted to national estimates (Table 3). The table also includes estimates of how these figures may be affected by the incidence of keepering, and the use of herbicides on cereal fields. As the incidence of keepering is unknown, it is probably fair to give the national estimate of partridge as between 150,000 and 350,000 pairs. G.R. Potts (pers. comm.) estimates 300,000 pairs, based on bag returns and on observed breeding densities on areas of cereals; the equivalent estimate for hares during the winter was between 1,250,000 and 1,900,000 animals.

The national figures can also be presented as distribution maps, which can then be compared with data from the national game census. Data from the latter source are presented as the mean number of each species shot per km² between 1961 and 1985 in each county. Only records detailing numbers killed on areas greater than one km² are shown, but records are also included where none of that species were killed.

The estimated distribution of territorial male pheasants throughout the country has been compared with the regional estimates from the national game census of numbers shot. Although the census includes reared birds, the two maps do show many similarities, both picking out the south-east of England as having the largest populations. However, the ITE estimate for Devon and Cornwall does seem higher than expected from the Game Conservancy data.

Two maps have been prepared for the grey partridge. The largest discrepancy appears to be for Hampshire, Wiltshire and Sussex, areas known to be amongst the best for this species. The ITE data show relatively low estimates, mainly because the random sample was lower in this region — with the further squares to be surveyed in 1990, this omission should be rectified. In contrast, the estimates for the west Midlands appear surprisingly high.

For hares, the discrepancy lies on the west coast — Devon, Cornwall and south-west Wales have much higher densities than expected from the national game census.

In summary, the ITE estimates appeared to provide a good estimate of game distribution above a line running from the Wash to Merseyside.

Table 3 National estimates of pheasants, partridges and hares

Pheasants, number alive during the breeding season	
Breeding territorial males	847826
Non-breeding males	643938
Breeding females	1586829
Total	3016079
Grey partridge, number of breeding pairs	
Maximum number	1402530
No predator control High chick mortality 10% shooting	154278
Predator control High chick mortality 30% shooting	350632
Predator control Low chick mortality 30% shooting	350632
Predator control Low chick mortality 30% shooting	497898
Brown hares winter population	
With predator control	1911444
Without predator control	1250325

5.2.6 Moths

The Rothamsted insect survey has run a network of standard light traps throughout Great Britain over the last 25 years. The traps are run by volunteers, and all the macro-lepidoptera (larger moths) are identified on a daily basis. The accumulated database now provides a unique set of quantitative data on insect abundance for ecological research.

The survey of 313 sites covered 28 out of the 32 ITE land classes, the missing land classes being in the far north or north-west of Britain, where it is very difficult to find sites on which light traps can be operated on a permanent basis. Mean numbers of the 375 species of moth which are caught every year by the survey were calculated for each site, and then a mean value per land class was estimated. In Table 4, the most common species for each land class are listed and grouped, according to four main zones. Some of these species show distinctive clines in relation to land class, eg the flounced rustic (*Luperina testacea*) and the antler moth (*Cerapteryx traminis*). Both species are grass-feeders in the larval state, but the first is very common in lowland Britain, whereas the latter is a pest of upland pasture; both are found in all the land classes monitored. The brindled ochre (*Dasypolia templi*) is an example of a species with a coastal distribution, but with has very high densities in only one land class (31); it is picked out as a strong indicator of land class in multivariate analysis. Other species, such as the yellow-line-quaker (*Agrochola macilenta*), have no obvious relation to land class categories, and are found at similar densities throughout Britain.

The data show strong relationships between the catches of a variety of species and the structure of the land classification. In Figure 40 and 41, the catches of two species — the flounced rustic and the antler moth — are correlated with the structure of the land classification. The former is a species that lives on grass roots, but it may also be able to attack cereals; its pattern of correlation affects this ability. Table 4 shows that it is most abundant in the lowland grassland land class.

The antler moth shows the opposite pattern, and feeds on more upland grass species, such as *Nardus* (moorgrass) and *Molinia* (mat-grass). It is usually found in more upland situations where it can occur in very large numbers, as reflected in Table 4, but the distribution map of its presence shows it throughout Great Britain. There is, therefore, a difference between frequency and simple

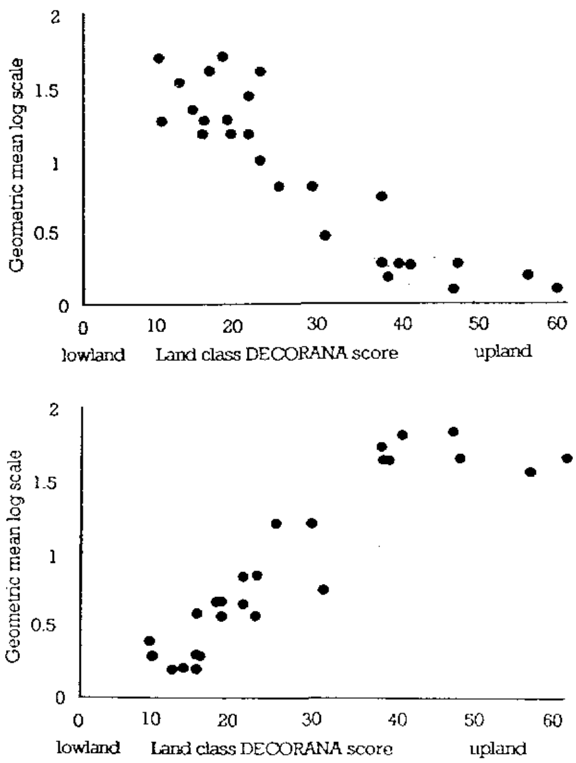


Figure 40The distribution of two moth species by land class. The geometric mean annual catch on a log scale was derived from 313 sites recorded by the Rothamsted Insects Survey. These values were then grouped by the land class in which they occured and plotted against the mean first-axis DECORANA (Hill 1979) scores from the land classification. The DECORANA scores are derived from analysis of the environmental data from the 1 km square information, and reflect the principal environmental gradient from lowland to upland environment.

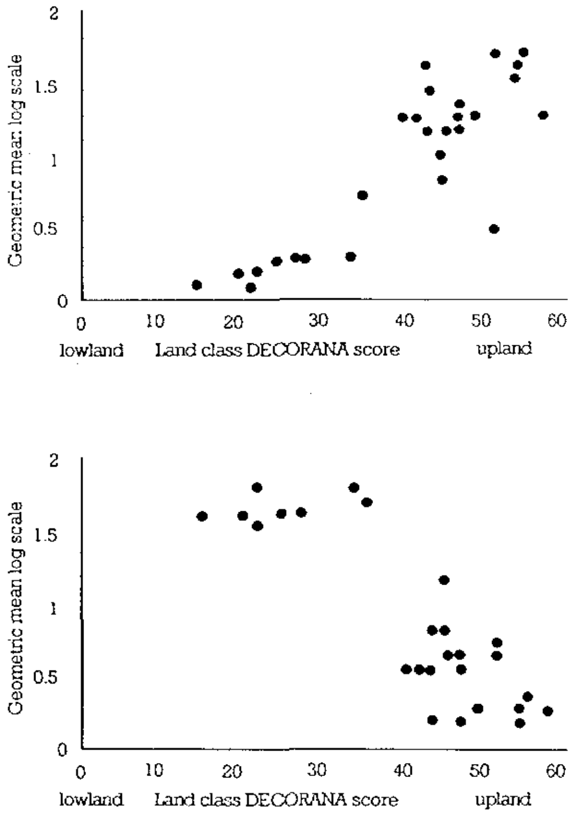


Figure 41The distribution ofmoth species with respect to vegetation. The geometrical mean annual catch on a log scale from 313 sites was recorded from Rothamsted and grouped by the land class which they occured. The analysis of vegetation data recorded in the 1 km squares were analysed by an ordination technique known as DECORANA(Hill 1979) in order to express the principal gradient in the vegetaion. The average scores for the moths. The principal vegetation gradient is from weed populations of the lowlands to heather moorland and bog in mountain areas.

presence, which is parallel to the discussion of the BTO data. Both the flounced rustic and the antler moth are common species, and could therefore be expected to have sufficient data to show correlations. Greater difficulty would be experienced with rare species.

The high correlations of animal numbers with axis scores are confirmed by other calculations using the land classification, eg the freshwater invertebrates. Such correlations probably mask variability of management and change within a class, because very high numbers can override depauperate areas, but they still form an expression of the actual species present. I Woiwod (pers. comm.) has pointed out that the sample sites tended to avoid intensively managed agricultural systems, and the results could therefore be misleading. As with the freshwater samples, the range of variation within a land class is important in determining the effect of land use change, whereas the overriding importance of the environment in the present analysis clearly determines the overall ecological pattern, regardless of local changes in management.

determined by multivariate analysis, and the catchment boundaries of each RIVPACS site drawn and digitised.

In-house software, developed by Dart Computing, and ITE's land class allocation procedures, were then used to calculate the absolute and relative areas of each RIVPACS catchment occupied by each ITE land class. The land class characteristics of each of the 25 RIVPACS site groups were calculated and summarised, and shown to have clear associations with a small number of land classes. RIVPACS groups containing sites with large catchments or sites dispersed over a wide geographic range had the most heterogeneous land classifications, whereas in small catchments the dominant catchment land class was often the same class as that in which the site was located. The land classes were then ordinated according to the RIVPACS catchments that occurred in them, showing that many of the aggregations of classes identified in earlier analyses were still apparent, although there were some exceptions.

The first-axis ordination sequence of land classes, based on their mean ordination values, was very similar to the biological ordering of land classes of the 160 special survey sites. This was despite the fact that one data set was controlled for water quality, and the other was not. The two first-axis orders of land classes, in the separate analyses of the special survey and RIVPACS data sets, had a Spearman rank-order correlation coefficient of 0.806 ($p < 0.001$). It was therefore concluded that the similarities between the order of land classes in the various analyses confirmed the fact that a distinct land class gradient exists, and this can be used to explain and predict the distribution of aquatic fauna.

A further study was carried out in order to determine the possibility of using catchment land class and land use information to predict aquatic macro-invertebrate assemblages using multiple discriminant analysis (MDA).

Catchment land use was estimated by integrating land class information with ITE statistics on mean land use in each of the 32 land classes. Land class and land use information each independently predicted about 30% of RIVPACS sites to their correct RIVPACS group (out of 25 possible groups). The best discriminating land use variables were areas of cereals, moorland, other crops and leys. These predictions were lower than expected but could be improved if better predictive variables were used. The seven variables used to predict land class at present were all climatic or locational, and the inclusion of geology and soil type would add further precision. It was also considered that landscape variables, including geographic, climatic, geological and edaphic, when used independently of land class, were likely to be better predictors of RIVPACS groups than the derived land classes and land uses.

The results of analysis to meet the second objectives are summarised below.

Information for each site was summarised by BMWP score and ASPT, and the relative abundance of each family for each of the two years of sampling. Separate lists were also compiled of the taxa that were found only in the initial survey, only in the repeat survey, and in both surveys.

On the basis of this information, and on biological and chemical data supplied by the water industry for the intervening years, generalised conclusions were drawn about the direction of changes in environmental quality, if any, at all 32 study sites.

Parish census data and ITE estimates were obtained for all eight river systems. Remote sensing studies were carried out at the National Remote Sensing Centre, and concentrated on just two catchments, the Axe (Devon) and Hodder (Lancashire).

Comparison was made between the three sources of data. Whilst MAFF data and remote sensing data were in close agreement, the concordance between MAFF/DAFS estimates and ITE estimates were less good.

In addition, National Rivers Authority (NRA) regional offices provided all their available macro-invertebrate and chemical data for the same subcatchments and time period, together with details of major pollution incidents.

The 1988survey was purpose-designed for this study. A total of 160 sites were sampled once each between June and November. Most sites were sampled by a permanent IFE field team. A small number were sampled by various ITE staff members after a short period of training.

All these sites were in 1 km squares previously sampled by ITE, for land use studies in 1978. Small streams (<4th order), drains and canals were sampled. No cognisance of water quality was involved in site selection.

Two widely used biotic index values, BMWP score and ASPT Armitage *et al* (1983), were calculated for each site, and it was found that there were distinct differences between the mean index values of the various land classes.

The lowland land classes (1-16) had generally low index values, whilst the reverse was true for the upland classes.

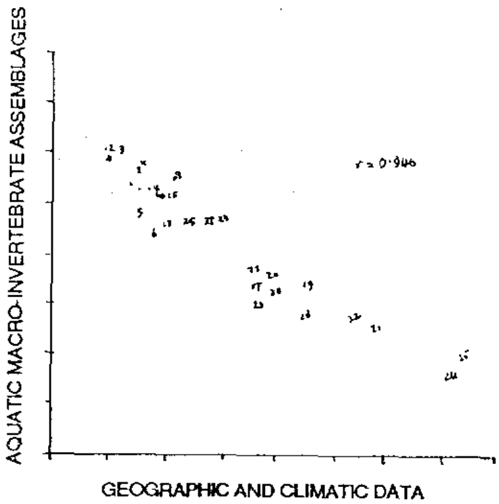
The 160 sites were then ordinated using DECORANA. The site attributes that were used in the ordination were logarithmic categories of abundance of the families.

The principal environmental gradient from the initail environment data used for the land classification was defined by DECORANA. The average gradient scores were calculated by land class and plotted against the macro-invertebrate data as shown in Figure 42.

The ordination scores of macro-invertebrate assemblages and landscape features were highly correlated (r = 0.946), indicating that a strong environmental gradient existed which could be used to predict the occurrence of the aquatic fauna.

The 160 sites were then classified according to their fauna, and this classification was compared with the land classification.

A number of outlying sites were identified from the inter-classification comparison, and it was found that these had biotic index



Fgure 42 Comparison of macroinvertebrate assemblages with the land classification. The macroinvertebrate assemblages collected in 1988 were analysed using DECORANA (Hill 1979) ot express the overall relationships in the data. The same analysis was carried out for the land classification data as in Fig 40 & 41. The axix scores are plotted against each other, and the numbers indicate the land classes.

values which departed markedly from their land-class means, and had been collected by ITE field teams early in the sampling period. It was therefore concluded that a more condensed period of sampling and better staff training would eliminate seasonal and inter-operator differences.

The data for objective, had been collected by IFE previously and consisted of 438 substantially unpolluted sites distributed throughout Britain on 77 river systems. The samples in this set were identified by IFE to a consistently high standard of accuracy and had previously been used to form the basis of a site classification containing 25 discrete groups. This classification and the environmental information from the same sites, had been used to construct a software package, RIVPACS, which is being widely used in the water industry or biological assessment of the environmental quality. It can also be used to set biological River Quality Objectives.

The land class of each 1 km square containing a RIVPACS site was then

Table 4 Average catch of the most common species of moths in the Rothamsted insect traps, grouped by land class

Land class	Flounced rustic	Heart + Dart	Buff ermine	Small square spot	White ermine	Hebrew character	Silver ground carpet	Rosy rustic	Antler moth
LC	37	33	10	6	16	31	19	6	2
LG	18	48	20	20	31	42	21	5	2
MA	0	6	0	4	15	124	69	105	94
UP	0	0	0	18	6	100	96	25	57

LC = Lowland cereals
LG = Lowland grassland
MA = Marginal uplands
UP = uplands

Two types of further analysis are required:

(i) a more detailed analysis of the individual sites and their relationship with the surrounding land cover and habitats;

(ii) a more general analysis of species-habitat relationships. As with the bird data, the importance of frequency as opposed to presence is underlined, and the necessity of detailed autecological studies is emphasised if the pattern of change in insects is to be assessed.

The species listed in Table 4 show strong patterns of distribution throughout the groups of land classes, that almost certainly reflect different abundances of their foodplants.

5.2.7 Freshwater invertebrates

The project with the Institute of Freshwater Ecology (IFE) was set up by DOE in order to assess the potential for joint work with ITE and was therefore an important part of the link project. The ITE database has been described above, whereas IFE were studying the relationships between aquatic macro-invertebrate assemblages and the environmental characteristics of rivers. Furse *et al* (1990). The potential for co-operation and mutual use of data was therefore high. The main objectives of the project are defined below.

(i) To evaluate the extent to which the topographical, meteorological, geographical and cartographic variables ("landscape variables") of the ITE land classification can be used independently, or in conjunction with physico-chemical descriptors of river type, in future versions of RIVPACS.

Two benthic macro-invertebrate data sets are being used for this purpose. The first, collected wholly in 1988, comprises 160 sampling sites within the 256 one km squares of the 1978 ITE land use survey. These sites were not selected as being unperturbed, and were of variable water and environmental quality. The second set consists of the 438 unpolluted sites used in RIVPACS Wright *et al* (1989).

(ii) To develop and compare procedures for determining land use and land use change within specific river catchments and subcatchments, and to analyse this information in conjunction with corresponding macro-invertebrate data.

Eight catchments, with 32 subcatchments, have been studied. Each was sampled for macro-invertebrates in the late 70's (predominantly in 1978) and again in 1989. Detected changes in aquatic assemblages over this period were compared with subcatchment land use changes over all or part of the same period. Four sources of information on land use change were used for some or all catchments: (i) MAFF and DAFS annual parish surveys; (i) MSS and TM satellite imagery (under separate contract to the NRSC); (iii) Land use and land use change estimates derived from the 1978 and 1984 ITE surveys; (iv) Available ground truth surveys provided by the former Water Authorities.

6. PATTERN ANALYSIS

6.1 Introduction

As the habitats within landscapes become progressively fragmented, so it has become widely recognised that spatial relationships play a key role in the functioning of landscapes. The size and distribution of patches of semi-natural vegetation in landscapes determine the way in which species, both animals and plants, are able to disperse and colonise the patches. Thus Sharp & Fields (1982) has shown that small patches of woodland became isolated in the 19th century when they became progressively fragmented. The maple trees were no longer able to cross the barrier into new patches of woodland and this has important genetic implications. Spiders show a similar feature when they are colonising patches of brambles which have originated from colonisation of old fields (Asselin 1988). Once the patches are more than 50 m apart most species of spider are no longer able to drift between them. Harms (1986) showed that red squirrels were only able to disperse between woods if they were no more than 300 m apart. McCartney (1990) showed that mathematical and physical laws could be used to estimate the wind dispersal potential of plants, provided that the aerodynamic properties of the seeds were understood. The development of such models could reveal the importance of features such as the height of the seed source. The dispersal of other species, such as certain butterflies (Webb 1986), can be determined by barriers such as roads which are perceived barriers rather than real. The conclusion from these studies is that whilst a general description of pattern can be made, individual species still need to be considered separately because of differences in their autecology.

The pattern of connectivity between the landscape patches varies through different types of corridors, eg hedgerows, ditches and even grass strips; all of these can be important in determining dispersion. Thus, Burel (1989) has shown that different species of carabid beetle move along hedgerows at different rates and through different distances according to their mobility and the character of the vegetation occupying the corridor. Some species are able to move to new patches up to 800 m away from their source in ancient woodlands. Wratten & Thomas (1990) has also shown that small grass strips less than 1 m wide can act as corridors along which insects can move through grasslands, and can be used in the control of pests in fields. Verkaar (1990) showed that *Ascorus* (a water plant) moved hundreds of kilometres over landscapes throughout Europe, along waterways. In Holland,Van Dorp Groenendal (1991) has shown the movement of plant species along the banks of rivers. Similarly, the Oxford ragwort (*Senecio squalidus*) dispersed throughout Britain along roads and railways. Dispersion along communication routes is common knowledge, and demonstrates the significance of such pathways. Thus, oil seed rape seedlings can be seen along motorways, and foxes and badgers can be readily observed using railways as corridors; smaller animals are likely to behave similarly. Traditional landscapes with many corridors will therefore not only tend to have more species present, but will also have a wider potential for movement of species along the corridors and linkages present within them. The evidence throughout all the studies of MLC and ITE, discussed elsewhere in this report, demonstrates that these complex patterns are being broken down. The observations emphasise that there must be an accompanying loss of movement of species, and a loss of adaptability of populations within the landscape.

6.1.3 The size of the patches (as shown above) is also of importance for many species — for example, a golden eagle occupies a territory of several square kilometres, whereas a robin may be able to survive within a back garden of only 50-60 m^2. Such patterns depend not only on the inherent territorial characteristics of the bird or animal concerned, but also upon the food supply, which may also determine the territory size for many species. The various studies of red grouse (Watson *et al* 1984) have shown that these factors are complex and depend upon food supply, structure and territorial behaviour, which differ widely between species and also in time and space.

The island biogeography theory (McArthur &Wilso1967) forms the basis of much of the discussion above, but it was originally designed for the relationship between the size of islands in terms of species numbers rather than for habitats in an agricultural landscape. However, the inherent ecological characteristics of the landscape make it impossible to provide a model of the relationship between patch size and diversity which applies to the whole of Great Britain. For example, Bunce (1982) showed that the larger woodlands in East Anglia contained more species than smaller woodlands, which tended to be secondary in nature. By way of contrast, in north-east Scotland the small woodlands tended to be by small streams, and contain many species, whereas the large woodlands occupied the morainic slopes and were more uniform. Within uniform ecological conditions, however, it is generally true that there is a positive relationship between size and species number; this has been much used as a basis for nature reserve selection (Margules & Usher 1984) on the principle that larger sites contain more species. However, in very fragmented landscapes a larger number of smaller sites may contain more ecological variation, and could lead to the conservation of more species. An appropriate strategy must therefore be designed for the ecological characteristics of the area concerned, and it is not possible to make generalised rules which apply throughout Britain. Such problems have been emphasised in the present project (see section 4.3), where different landscapes contain different combinations of linear features with contrasting patterns of diversity.

The progressive loss of habitats demonstrated by MLC and by many other publications (eg Webb1986) is inevitably associated with the loss of pattern and also with loss of species. In the final stage each 1 km square becomes a single field with no pattern. For small habitats such as ponds, this decline will result in complete extinction, whereas in fragmented habitats small populations may remain, although these will be progressively threatened.

6.2 Methodologies

6.2.1 Assessing pattern

There are three generally recognised levels of assessing pattern:

(i) The frequency of object characteristics (eg sizes of woodland or fragments of heath). Such measurements can be automated through the use of remote sensing or through geographical information systems (GIS) from cartographic data. Both approaches have been used in the present project.

(ii) The relationship between elements in the landscape, eg to show that woodlands may tend to be next to cereal fields, or in one type of landscape or grasslands in another situation. Remote sensing has been used to detect this pattern in the present project, but for future work the ARCINFO GIS is particularly important in this respect, especially in examining the field boundaries associated with habitat and field type.

(iii) The relationship between objects and the space they occupy, where certain habitats exert a sphere of influence around them, as in the case of shade around a woodland with its associated rain of propagules. Again, these types of analyses have been demonstrated by remote sensing in the present project, but in due course they will be available through the GIS system.

Each of these methods has been assessed in the project, and the results are presented below.

6.2.2 The size and frequency of patches

Two approaches to patch size and frequency were used.

Firstly, the area and frequency of land cover parcels (patches within the landscape) were determined by using remote sensing to look at the frequency of histograms of size distribution, to compare the fragmentation which has taken place in woodlands and other habitats within landscape. Figure 43a shows the size frequency distributions for classified patches of woodlands in two sample areas representing different landscape types. The dominant woodland size in each sample is between 2 and 10 hectares, but there is a much higher proportion of small woodland patches in sample A than in sample B. The technique is applicable to different cover types and for a range of size classes depending upon the species, the study, and the spatial characteristics of the landscape.

Secondly, the data from the 1 km squares of the ITE sample frame were compared for the size of parcels present, as shown in Figure 43b. The lowlands have larger blocks of relatively uniform vegetation; upland habitats, particularly in the north-west of Scotland, have fragmented units of scattered vegetation with closely interlocked mosaics of different species. In contrast, the open landscapes of moorland have large areas of relatively uniform habitat where groups of species do not interact in the same way.

It is therefore possible to link the patterns of analysis by remote sensing and field survey because they measure the same basic features in the landscape but in slightly different ways. Remote sensing has the advantage that it can cover much larger areas efficiently, and can therefore determine pattern on a large scale, whereas the detailed data from ground survey can reveal more local patterns and more detail appropriate to ecological factors.

6.2.3 Relationships between landscape elements

The second type of classified land parcel display can be assessed using the digital images from the satellites. In this procedure, higher values are assigned to pixels at greater distances from the class boundary. Such proximity images demonstrate the degree of fragmentation that has taken place. Proximity images can also be used to find ecological gaps within the landscape which do not contain suitable habitats within the threshold distance of a population refuge, as described below.

Whilst each species has its own specific pattern, general views can be obtained. In the present project, the procedure was to use high values, light tones at the first edge from each of the woodland patches; these are clearly shown in the example displayed by Griffiths & Wooding (1988). The type of cover adjacent to a patch may also be important in determining the movement of species within the landscape. As stated above, such analyses can also be carried out on a more local scale by using the field data. As in the initial description of remote sensing, therefore, the two approaches are complementary.

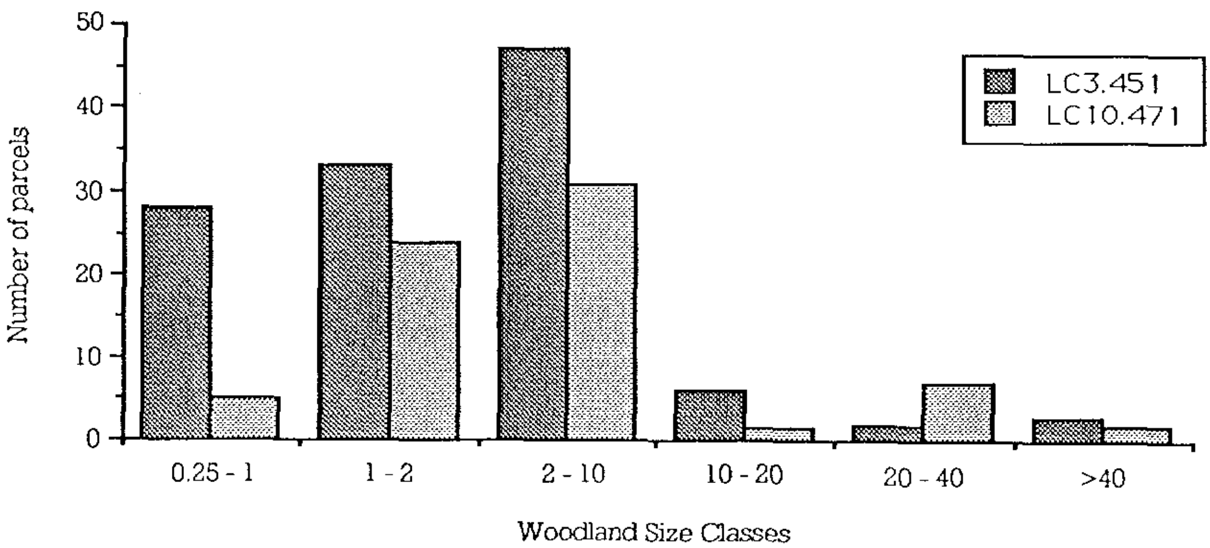


Figure 43a Size distribution and frequency for woodland in two lowland land classes. Data were derived from two 10 km squares from areas in the country, and the total frequency of woodland patches within those areas assessed.

Figure 43b The frequency of land cover patches in uplands and lowlands. The total area of eight 1 km squares from each of the two classes was assessed, and the frequency of the patches in those classes determined.

6.2.4 Relationships between objects

The third method is demonstrated in Figure 43c. In this figure the area of four cover types are shown at different distances from the edge of coniferous woodland in an upland sample area. The largest cover type within the 500 m edge of the woodland is improved pasture, with heather moorland also occupying a significant component in this zone. Such measures of distance from a habitat edge can be important in determining the breeding success of certain bird species nesting close to new afforestation, and are discussed further by Griffiths & Wooding (1988).

Another measure of such patterns can be diversity measure, where the number of different cover types within 1 km squares for a moorland area A can be compared with an agricultural area B. These types of measures can be used to compare the texture of different landscapes, with varied landscapes containing a higher portion of types per unit area than uniform ones. These measures are discussed further by Griffiths & Wooding (1988).

6.2.5 Land classification

A further development on a much larger scale is in the use of ARCINFO to combine the classes of the land classification into units which express their contiguity. Some land classes, eg land class 3, show that although there are over 14,000 squares of this class, using ARCINFO these can be aggregated into only 900 separate units. By contrast, the squares from land class 20, a marginal upland class, can only be reduced from 6000 to 2000. The demonstration of patterns at a higher level of resolution can therefore be determined not only from the remote sensed images but also by using the land class distribution as a basis for comparison.

6.2.6 Analytical techniques

Two suites of programmes have been prepared for the detailed analyses of pattern from cartographic data.

(i) In the first, various procedures are used to record the size of the parcels using a grid system overlaid upon the individual kilometre square.

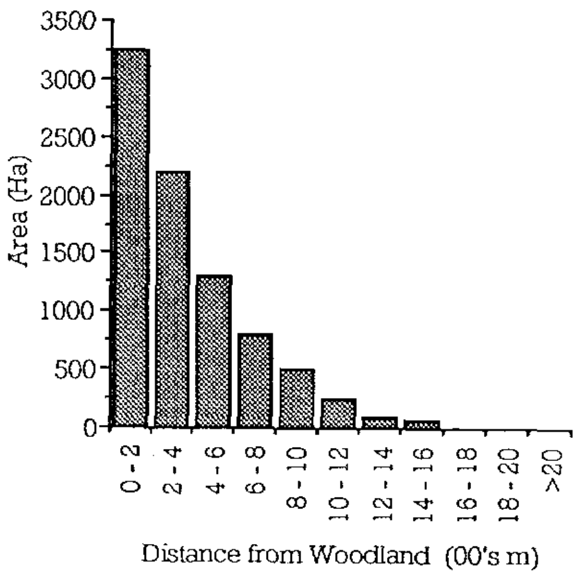


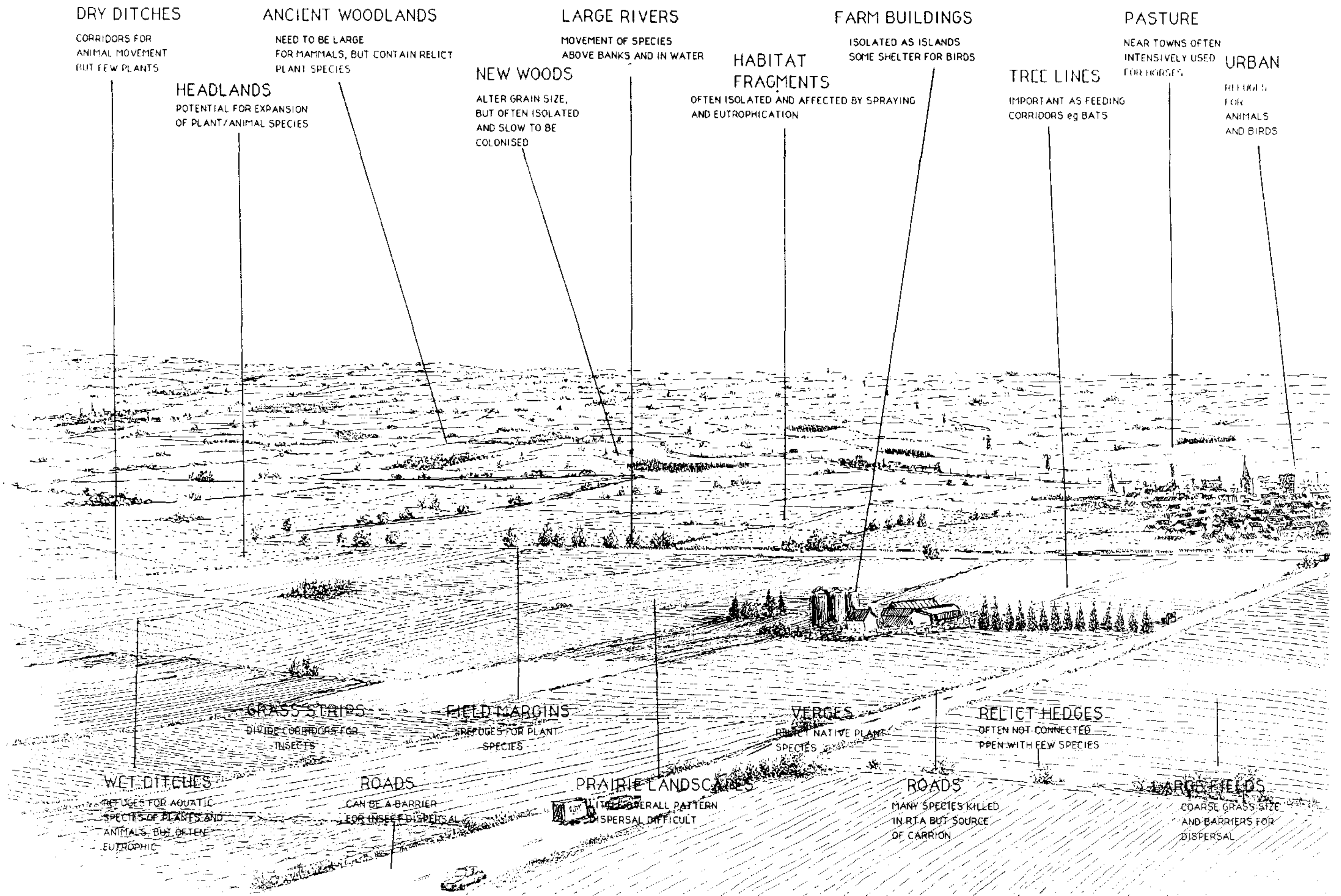
Figure 43c The number of different cover types within 1km2 to provide a measure of diversity within the landclass

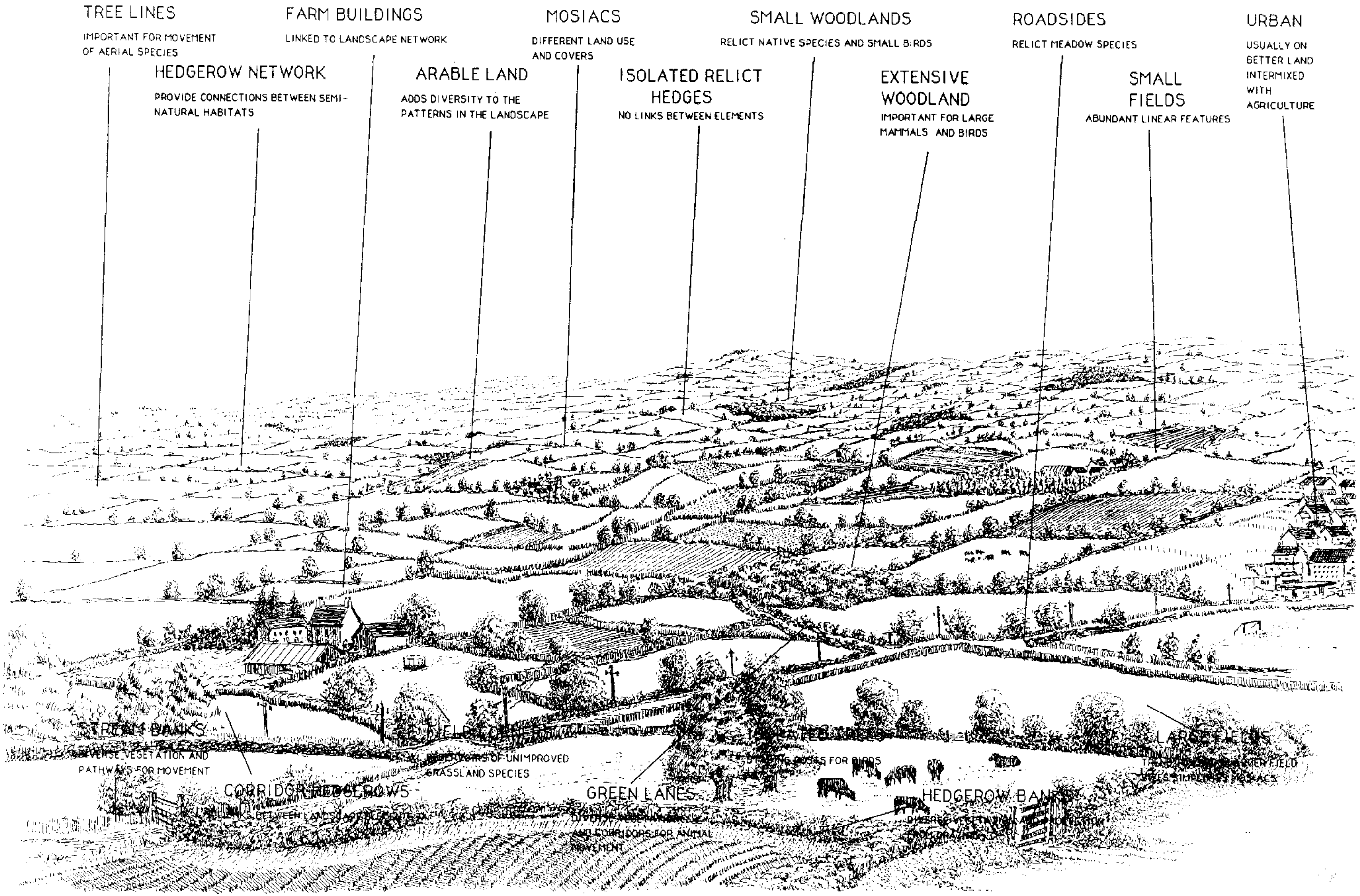
(ii) *In the second, a procedure is used to* follow linear features through the landscape and determine the intersections, so that the degree of connectivity and linkage can be assessed within the landscape.

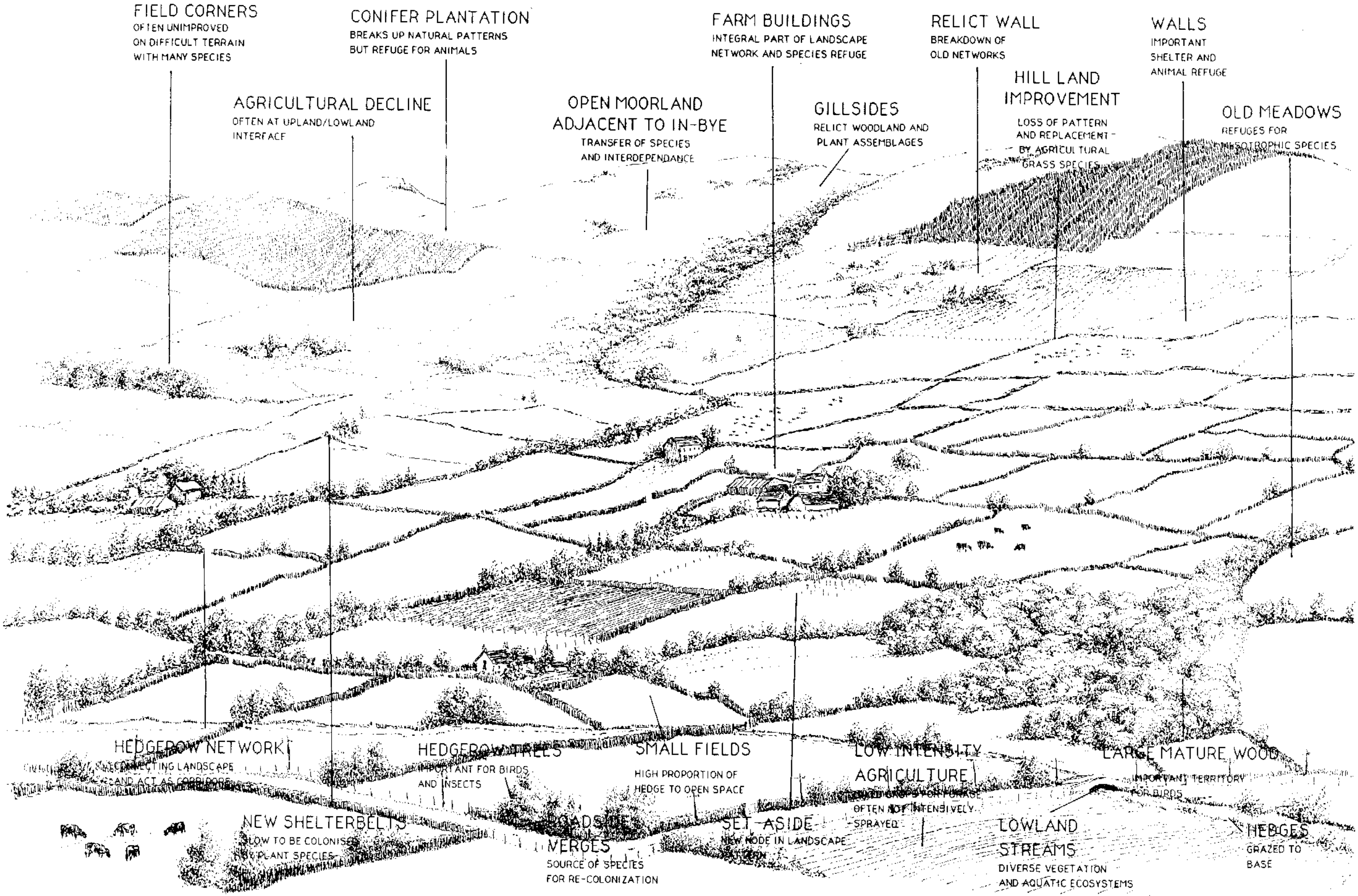
These programmes are now available and are currently being used in conjunction with Newcastle University to analyse the data from the ARCINFO images available from the Countryside Survey 1990.

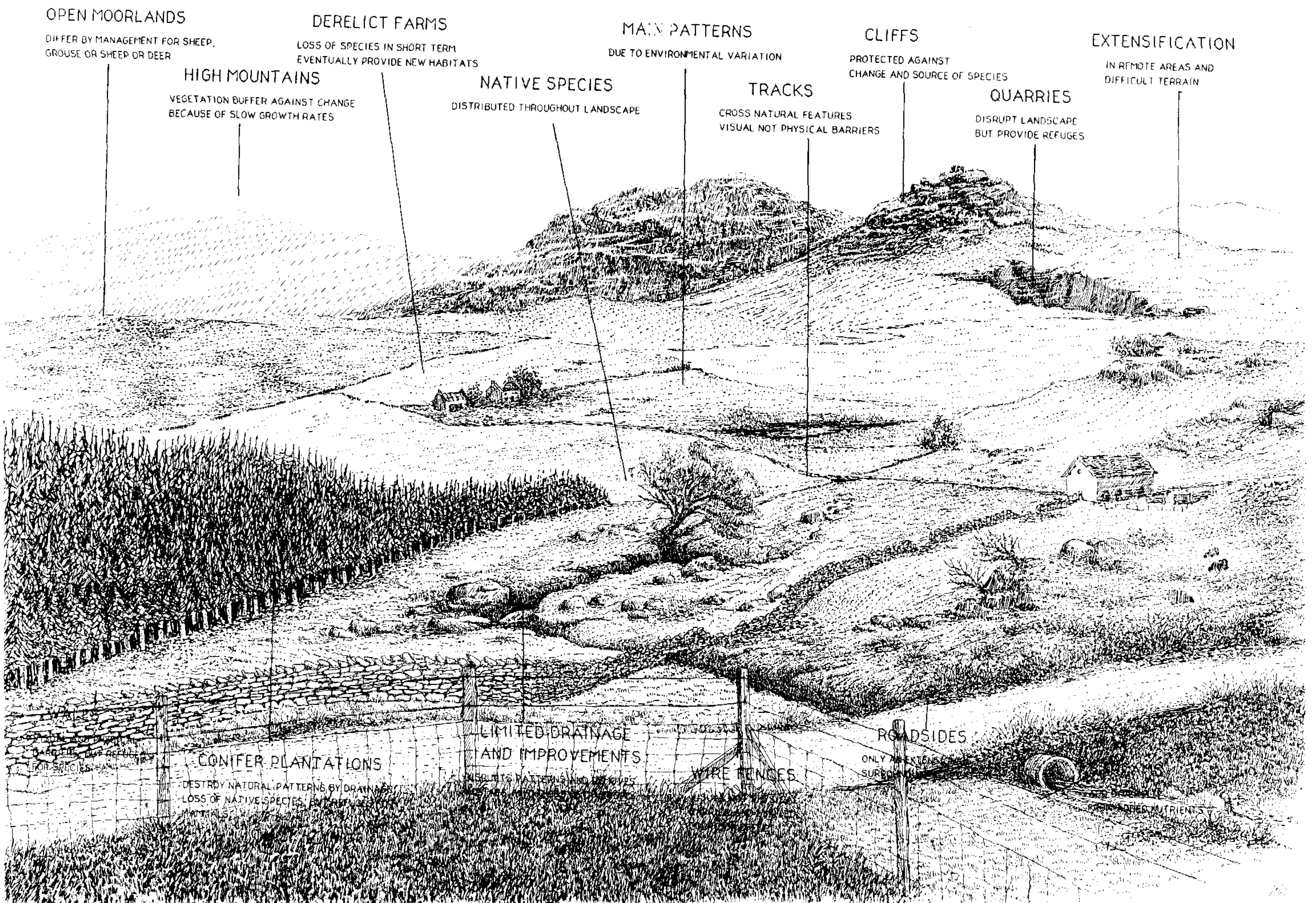
6.3 Definition of pattern in British landscapes

Within the time-scale of the present project it has not been possible to develop fully quantitative measures of pattern for entire landscapes. However, the experience derived from the work in the project is sufficient to make generalised statements regarding the four broad types of landscapes in Great Britain. These descriptions define the current principal feature of pattern and involve current and future studies. They could eventually be expressed by specific dynamic models, say, of the movement of species through such landscapes. In some respects, therefore, the following diagrams indicate future research projects but are also intended to define the appropriate parameters concerned. The characteristics of the four landscapes are summarised in Figures 44-47 and accompanying notes.


DRY DITCHES
CORRIDORS FOR ANIMAL MOVEMENT BUT FEW PLANTS
ANCIENT WOODLANDS
NEED TO BE LARGE FOR MAMMALS, BUT CONTAIN RELICT PLANT SPECIES
LARGE RIVERS
MOVEMENT OF SPECIES ABOVE BANKS AND IN WATER
FARM BUILDINGS
ISOLATED AS ISLANDS SOME SHELTER FOR BIRDS
PASTURE
NEAR TOWNS OFTEN INTENSIVELY USED FOR HORSES
URBAN
REFUGES FOR ANIMALS AND BIRDS
HEADLANDS
POTENTIAL FOR EXPANSION OF PLANT/ANIMAL SPECIES
NEW WOODS
ALTER GRAIN SIZE, BUT OFTEN ISOLATED AND SLOW TO BE COLONISED
HABITAT FRAGMENTS
OFTEN ISOLATED AND AFFECTED BY SPRAYING AND EUTROPHICATION
TREE LINES
IMPORTANT AS FEEDING CORRIDORS eg BATS
GRASS STRIPS
DIVIDE CORRIDORS FOR INSECTS
FIELD MARGINS
REFUGES FOR PLANT SPECIES
VERGES
NATIVE PLANT SPECIES
RELICT HEDGES
OFTEN NOT CONNECTED
WITH FEW SPECIES
WET DITCHES
REFUGES FOR AQUATIC SPECIES OF PLANTS AND ANIMALS, BUT OFTEN EUTROPHIC
ROADS
CAN BE A BARRIER FOR INSECT DISPERSAL
PRAIRIE LANDSCAPES
OVERALL PATTERN
DISPERSAL DIFFICULT
ROADS
MANY SPECIES KILLED IN RTA BUT SOURCE OF CARRION
LARGE FIELDS
COARSE GRASS SIZE AND BARRIERS FOR DISPERSAL


TREE LINES
IMPORTANT FOR MOVEMENT OF AERIAL SPECIES
HEDGEROW NETWORK
PROVIDE CONNECTIONS BETWEEN SEMI-NATURAL HABITATS
FARM BUILDINGS
LINKED TO LANDSCAPE NETWORK
ARABLE LAND
ADDS DIVERSITY TO THE PATTERNS IN THE LANDSCAPE
MOSIACS
DIFFERENT LAND USE AND COVERS
ISOLATED RELICT HEDGES
NO LINKS BETWEEN ELEMENTS
SMALL WOODLANDS
RELICT NATIVE SPECIES AND SMALL BIRDS
EXTENSIVE WOODLAND
IMPORTANT FOR LARGE MAMMALS AND BIRDS
ROADSIDES
RELICT MEADOW SPECIES
SMALL FIELDS
ABUNDANT LINEAR FEATURES
URBAN
USUALLY ON BETTER LAND INTERMIXED WITH AGRICULTURE
PATHWAYS FOR MOVEMENT
GRASSLAND SPECIES
GREEN LANES
AND CORRIDORS FOR ANIMAL MOVEMENT


FIELD CORNERS
OFTEN UNIMPROVED ON DIFFICULT TERRAIN WITH MANY SPECIES
CONIFER PLANTATION
BREAKS UP NATURAL PATTERNS BUT REFUGE FOR ANIMALS
AGRICULTURAL DECLINE
OFTEN AT UPLAND/LOWLAND INTERFACE
OPEN MOORLAND ADJACENT TO IN-BYE
TRANSFER OF SPECIES AND INTERDEPENDANCE
FARM BUILDINGS
INTEGRAL PART OF LANDSCAPE NETWORK AND SPECIES REFUGE
GILLSIDES
RELICT WOODLAND AND PLANT ASSEMBLAGES
RELICT WALL
BREAKDOWN OF OLD NETWORKS
HILL LAND IMPROVEMENT
LOSS OF PATTERN AND REPLACEMENT - BY AGRICULTURAL GRASS SPECIES
WALLS
IMPORTANT SHELTER AND ANIMAL REFUGE
OLD MEADOWS
REFUGES FOR MESOTROPHIC SPECIES
HEDGEROW NETWORK
CONNECTING LANDSCAPE AND ACT AS CORRIDORS
HEDGEROW TREES
IMPORTANT FOR BIRDS AND INSECTS
SMALL FIELDS
HIGH PROPORTION OF HEDGE TO OPEN SPACE
LOW INTENSITY AGRICULTURE
OFTEN NOT INTENSIVELY SPRAYED
LARGE MATURE WOOD
IMPORTANT TERRITORY FOR BIRDS
NEW SHELTERBELTS
SLOW TO BE COLONISED BY PLANT SPECIES
ROADSIDE VERGES
SOURCE OF SPECIES FOR RE-COLONIZATION
SET-ASIDE
NEW NODE IN LANDSCAPE
LOWLAND STREAMS
DIVERSE VEGETATION AND AQUATIC ECOSYSTEMS
HEDGES
GRAZED TO BASE



OPEN MOORLANDS
DIFFER BY MANAGEMENT FOR SHEEP, GROUSE OR SHEEP OR DEER
HIGH MOUNTAINS
VEGETATION BUFFER AGAINST CHANGE BECAUSE OF SLOW GROWTH RATES
DERELICT FARMS
LOSS OF SPECIES IN SHORT TERM EVENTUALLY PROVIDE NEW HABITATS
NATIVE SPECIES
DISTRIBUTED THROUGHOUT LANDSCAPE
MAIN PATTERNS
DUE TO ENVIRONMENTAL VARIATION
TRACKS
CROSS NATURAL FEATURES VISUAL NOT PHYSICAL BARRIERS
CLIFFS
PROTECTED AGAINST CHANGE AND SOURCE OF SPECIES
QUARRIES
DISRUPT LANDSCAPE BUT PROVIDE REFUGES
EXTENSIFICATION
IN REMOTE AREAS AND DIFFICULT TERRAIN
CONIFER PLANTATIONS
LIMITED DRAINAGE AND IMPROVEMENTS
WIRE FENCES
ROADSIDES

7. SCENARIOS OF CHANGE

7.1 Introduction

A central issue in the discussions surrounding land use change has been the wide range of different options which have been presented as alternatives. Many of these are strongly contrasting, and a major theme in ECOLUC has therefore been to compare available scenarios, to investigate future methods and to assess the current situation in regard to the general countryside.

Four main approaches were adopted within the project.

(i) *Current status and trends* — the application of available figures from the present study and from other projects. The majority of these data have already been presented in Section 1 above as the extrapolation of trends from such data is the most widely used method but, as Harvey *et al* (1986) has pointed out, such a procedure is unlikely to be realistic.

(ii) *Potential changes* — an examination of the potential of land for growing different crops or for various other changes, eg urban growth.

(iii) *Individual land parcel comparison* — in this procedure the actual individual fields or units in open landscapes are overlaid with different scenarios of change.

(iv) *Predictive scenarios.* A true predictive model enables a fully automated procedure to be used to assess the potential for change rather than making broad global estimates.

7.2 Current status and trends

Table 5 shows examples of current land use estimates and the potential for change. These figures vary from 0.5 up to 5.7 million hectares. The various figures differ according to the criteria used in their determination, but none are able to account for adjustments within the agricultural pattern that might take place through positive feedback mechanisms. Currently, there is little evidence in Great Britain of abandonment, except in isolated areas in the lowlands, due usually land designated for building, or in isolated places in the western Highlands. These figures are theoretical, and emphasise the difficulties in extrapolating from trends. For example, in the case of the Wye College project, the continued increase of efficiency in agriculture was extrapolated to the year 2000. The assumption that previous trends will continue is one that is not supported in general terms. Nevertheless, the pattern of figures indicates that under the current land use pattern, land is considered to be surplus to the current agricultural requirements in all the scenarios considered.

7.3 Links between environment and socio-economic factors

It is generally recognised that the characteristics of the land surface are only one part of assessing change, since the decisions of individual farmers determine what actually takes place at a given location. Therefore, within the present project it was decided to assess the potential for combining socio-economic data with the land classification framework, to see if links could be made. The Centre for Agriculture Strategy had an extensive database on the socio-economic characteristics of farms and their farm businesses in Great Britain from a variety of projects, as reported by Tranter *et al.* (1988). A variety of farmer characteristics such as age, the date they began farming, training, farm size and the activities involved in the farming, was assessed. Farms were located by their grid reference, and the class to which they belonged was identified by using the indicator species method. In all, 221 farms were identified in the lowland cereals, 265 in lowland grass, 105 in marginal upland, and 50 in upland. Because of the small number in the last category, the classes within it were combined.

Table 6 shows that the proportion of farmers in age groups did not differ greatly between the land class groups. Table 7 shows that the length of time they had been farming on their own account also did not differ. However, farmers in the lowland land classes are more likely to have had some form of agricultural training than are their

Table 5 Showing examples of current land use estimates derived from texts available in 1987.

	Area studied	Land use estimated	At what date	Area range (m ha)	Main estima (m ha)
Wye College	United Kingdom	Area availabe for other uses	2000 with sensitivity tests	1-6	3-4
Laurence Gould	England, Scotland & Wales	Surplus to needs	1990 & 2000		1.1
		Low gross margin area equivalent of the reduction in intensity required	5 years of various scenarios	0.2-2.2	1.3 (price) 1.9 (quots)
North	Britain	Farmland requirements	2015	5.40-5.42	5.5
Agriculture EDG	UK	Land displaced from tillage	Mid 1990's	0-1	0.7

Source: Bell, M. 1987. The future use of agriculturasl land in the United Kingdom. Presented to The Agricultural Economics Society Conference.

Table 6 The proportion (%) of farmers in each land class category by various age groups.

	Land class category			
Age group	Lowland cereals	Lowland grass	Marginal upland	Upland
20 - 30	3.6	3.4	4.0	0
31 - 40	19.0	16.4	17.0	13.4
41 - 50	33.9	30.5	27.0	39.9
51 - 60	26.2	29.8	29.0	33.3
61 & over	17.3	19.9	23.0	13.4
Total	100.0	100.0	100.0	100.0

Table 7 The proportion (%) of farmers in each land class category by length of time farming on own account

Length of time farming on own account (years)	Land class category: Lowland cereals	Lowland grass	Marginal upland	Upland
Up to 5	4.5	7.9	9.5	20.0
6 - 10	9.5	11.7	16.2	6.7
11 - 15	11.8	6.0	11.4	20.0
16 - 25	30.2	27.6	22.0	6.7
26 & over	44.0	46.8	40.9	46.6
Totals	100.0	100.0	100.0	100.0

Table 8 Farm size, owner-occupied and rented areas per farm in each land class category.

ITE Land Class Category	Mean farm size (ha)	Mean proportion owner-occupied (%)	Mean proportion rented (%)
Lowland cereals	173.8	63.6	36.4
Lowland Grass	142.0	60.8	39.2
Marginal upland	380.0	59.2	40.8
Upland	5428.2	93.7	6.3

Table 9 The proportion (%) of farm businesses in each Land Class Category by type of farm/production system

Farm type/ production system	Land Class Category: Lowland Cereals	Lowland Grass	Upland
Cropping	25.1	6.0	3.2
Mixed	56.3	57.3	34.5
Stock	18.6	36.7	62.3
Totals	100.0	100.0	100.0

upland colleagues, but with the lowland cereal category having by far the larger proportion. The use of the chi square test showed these differences to be significant. The incidence of off-farm income also increases with a movement from the high-intensity lowland systems to more extensive upland.

Table 8 shows the farm size in each land class category, and the mean proportions that were owner occupied and rented. It is fair to conclude that the upland categories are much larger in farm size. Lowland cereal land also has the lowest frequency of wholly owned farm businesses, and the highest frequency of wholly rented businesses. This picture is reversed for the marginal uplands, where over 50% of the farm businesses are wholly owned by the occupier. The total number of full-time and part-time workers, however, showed only a slight significance between the land class groups with the number of part-time workers lower than expected in the lowland cereal categories and higher than expected in the marginal upland.

Table 9 shows that, as expected, the proportion of farm businesses in each land class category by type of farmer production system differs between the four groups in an expected way, with the lowland cereals being dominated by cropping, and the upland farms by livestock.

The project therefore successfully established the link between socio-economic characteristics and the environmental classification, and gives an idea of the extent to which factors specific to land class influence these characteristics. The project demonstrated that further observations were required, particularly in the upland land classes, to give a more precise set of information. The work by Potter & Gasson (1988) and Bell & Warnock (1987) also used the land class structure to collect socio-economic data. More recently, Queen (1990) demonstrated significant differences between the attitude of farmers and the different types of land which they occupied. There is, therefore, considerable potential in extending the socio-economic analysis in order to assist with the determination of the changes which are likely to take place at farm level.

7.4 The assessment of potential

7.4.1 The potential for agricultural intensification

The agricultural land classification (ALC) of the Ministry of Agriculture uses the characteristics of the soil and climate, and when combined with the crop requirements gives a measure of land capability for individual fields. Wye College examined the data on the soils, and assessed the

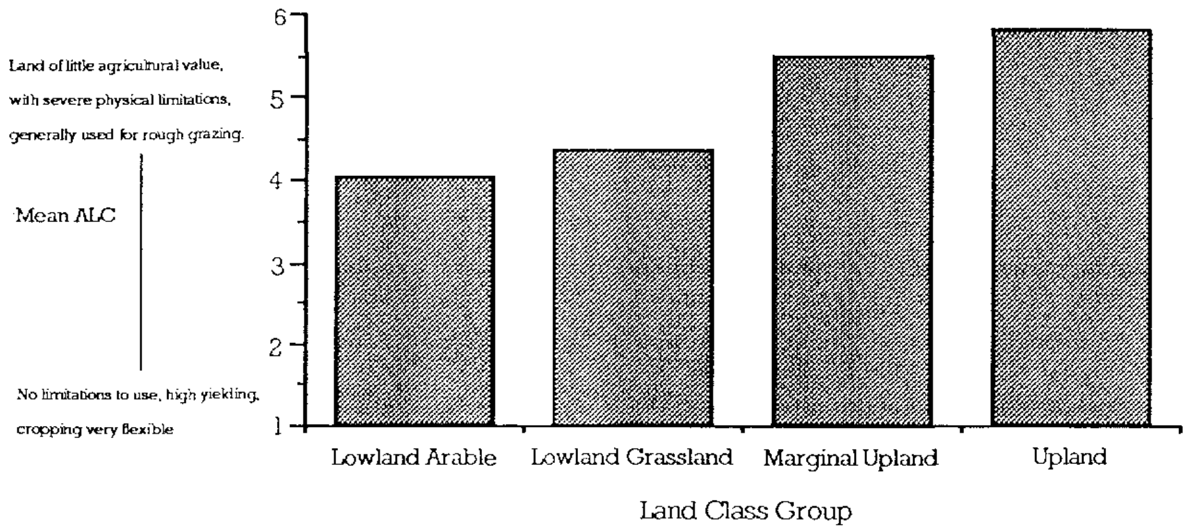


Figure 49 The relationship of the agricultural land classification (ALC) classes to the land class groups. The agricultural land classification was derived from the data available on the soils and climate within 256 one km squares of the 1978 survey. The average ALC score was calculated for the four land class groups.

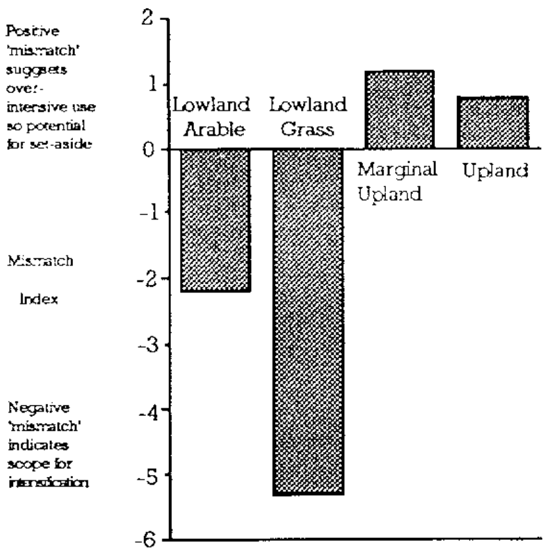


Figure 50 Mismatch between actual and optimal distribution of arable land. The positive mismatch of the potential for growing crops is matched against the actual area. A negative mismatch indicates scope for intensification, whereas a positive mismatch implies that there is already too much cereal growing in the land concerned. The figures are grouped into the same four land class groups.

agricultural land classification for the initial ITE sample of 256 squares. A comparable approach was used for Scotland, although the ALC is only available for England and Wales. The results are presented in Figure 49. As expected, the lowland arable land has a much higher potential for different crops than the upland group. This demonstrates that the lowlands have a greater potential for alternative crops than uplands, and therefore are most likely to have their agricultural patterns modified as changes in support mechanisms proceed. Wye College also examined the mismatch between the land capability of each land class group as it is at the present time in comparison with the potential for growing cereals. This approach enables the scope for intensification to be assessed, and the results are shown in Figure 50. The lowland arable group still has potential for intensification, but the lowland grass has the highest potential because cereals could still expand into many of these grassland areas. This echoes the expansion which took place in the late 1970s and early 1980s after the increase in CAP support. It suggests that further changes could take place in this area, and that support systems are critical in the determination of the patterns. By contrast, the marginal upland and upland areas are unlikely to be intensified further, because cereals do not grow well these areas.

7.4.2 The potential for alternative crops

The ALC is designed as an overall measure of capability for farmers but other crops could also become important. In another sub-project, Tranter *et al.* (1988) therefore examined the potential for unconventional alternative crops, to examine whether their take up could replace crops which are in surplus. Eight crops, or crop groups, were selected on the criteria of an existing demand, that appropriate cultivated methods were available, and that a range of environmental requirements were shown to be available. The crops or crop groups

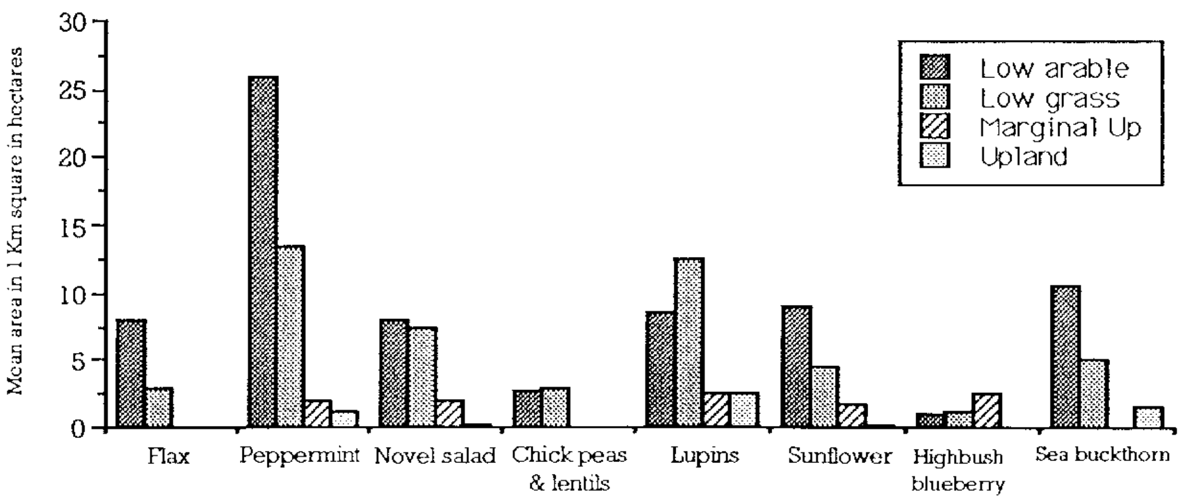


Figure 51 Alternative crop potential in Great Britain. The data were derived from the 256 squares used in the 1978 and soils, climate and interpretive information used to estimate the potential for the crops in the individual kilometre squares and then calculated according to land class and grouped into the land class groups of Figures 1 - 8.

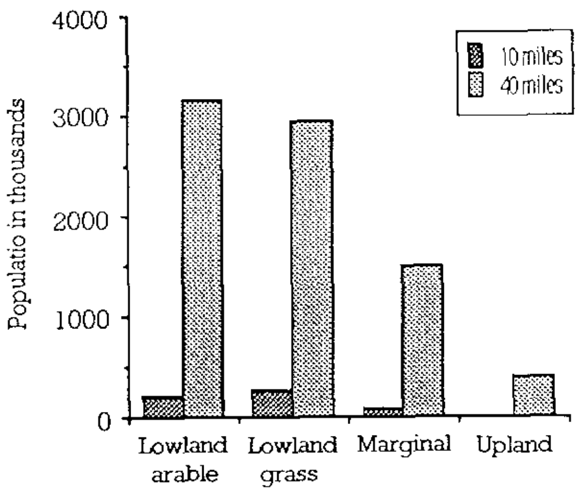


Figure 52 The mean population and catchments for land class groups. The data were derived from population census figures for the 256 one km squares, before being grouped into the land class groups. The mean population was calculated both within 10 miles and within 40 miles of the individual squares.

chosen were flax, peppermint, novel salad groups, chickpeas, lentils, lupins, sunflowers, highbush blueberry and sea buckthorn. The environmental requirements of these crops were determined from research institutes and are summarised by Tranter *et al.* (1988). The basis for the assessment were the 256 one km squares from the 1978 ITE field survey. The available information was used to identify parcels of land which had the appropriate requirements, and the results are shown in Figure 51. The majority of the alternative crops favour the better land in the cereal belt. Some considerable potential is also available on the lowland grassland, with a few crops such as highbush blueberry favouring marginal uplands.

7.4.3 The potential for recreation

Recreation is also an important alternative use for agricultural land. Accordingly, Edwards & Tranter (1990) carried out a project with three main objectives: (i) the identification of existing countryside recreation and tourism activities taking place in the 1 km square samples, (ii) an assessment of the future potential for countryside recreation and tourism activity in the same 1 km squares, and (iii) the provision of summary information on the ecological implications of such activities in the future. The emphasis in the approach used to forecast potential was placed on the supply side, relating in particular to the inherent characteristics of the land resource as expressed by the land classification squares, the availability of suitable buildings for conversion, and the existing levels of accessibility in relation to the local communication network. The basic data relating to the population catchments of the squares is presented in Figure 52. It reveals for the majority of land classes a significant range between the highest and lowest population figures, especially for those within a 10 mile radius. Over a 40 mile

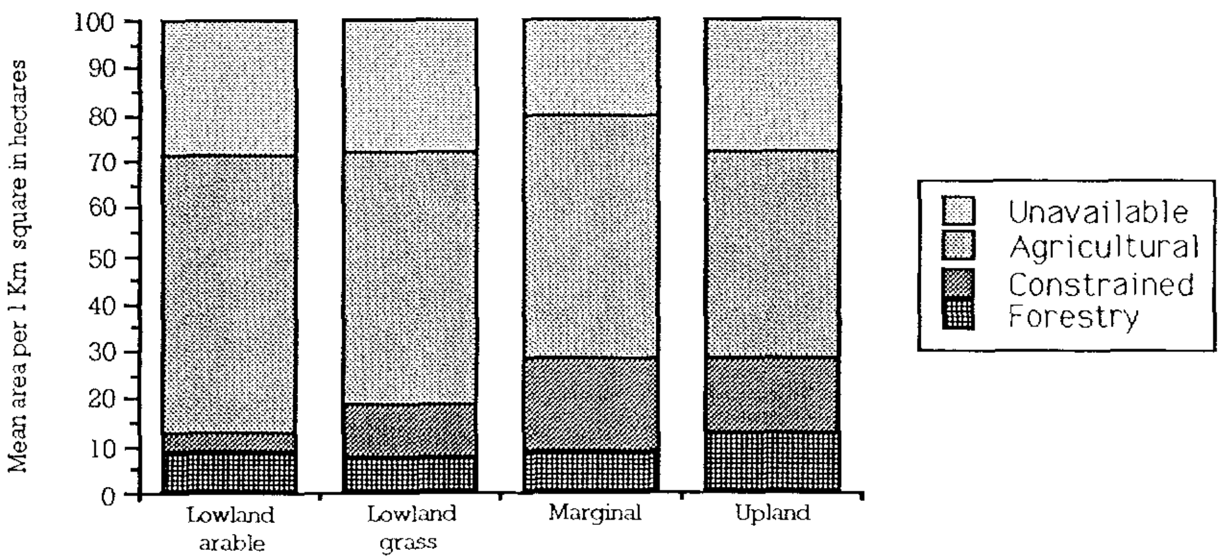


Figure 53 The potential for forestry in the four land class groups. The data were derived from the land availability study (Mitchell *et al.* 1983). The assessment of forestry is based on the estimate of forest potential in the 256 one km squares at a 5% discount rate and compared with the actual net present value of the current agricultural crops in the 1 km squares. The figures were derivedfor each kilometre square and then grouped according to land class and land class groups.

catchment the range is rather less, as local variations become evened out. Whilst much potential exists for increased recreational and tourist activity in the countryside as a whole, the ecological impact is unlikely to be severe except in very localised specific areas. The recreational and tourist impacts need to be put into perspective, although this does not minimise their consequences. In principal, the conflicts between recreation and conservation can be solved by sound management and planning, so there is very considerable potential for further development of recreation in the countryside. However, the extent to which this affects the ecological patterns in the countryside remains undetermined, although it is likely that it will be on a fairly small scale.

7.5 Land potential by individual parcels

7.5.1 The potential for forestry

The main study described is that which was undertaken by the Department of Energy in 1986, to look at the availability of land for wood energy plantations in Great Britain, but modified to examine conventional forestry only. The individual parcels from the 256 one km squares were assessed according to their relative economic performance. The areas of land that were more productive in financial terms for forestry than agriculture were identified through the whole series for the 256 squares. In this way, the total availability for wood energy plantations in Britain was determined, as shown in Figure 53. Within the lowland arable area, extremely small areas were available because of the efficiency of agriculture as opposed to forestry. Lowland grass shows a significantly larger increase in woodland area because of the relatively high area of marginal land, which is further exemplified by the marginal uplands. Here, very large areas of land are technically more suitable for forestry than for agriculture. This does not apply for the Scottish uplands — although a significant area was identified it could well be that the terrain is too difficult for forestry.

The original study on wood energy plantations by Mitchell *et al.* (1983) showed that the comparison of individual areas within different sample squares could be used to extract the critical information about the potential for a particular parameter, in this case wood energy plantations.

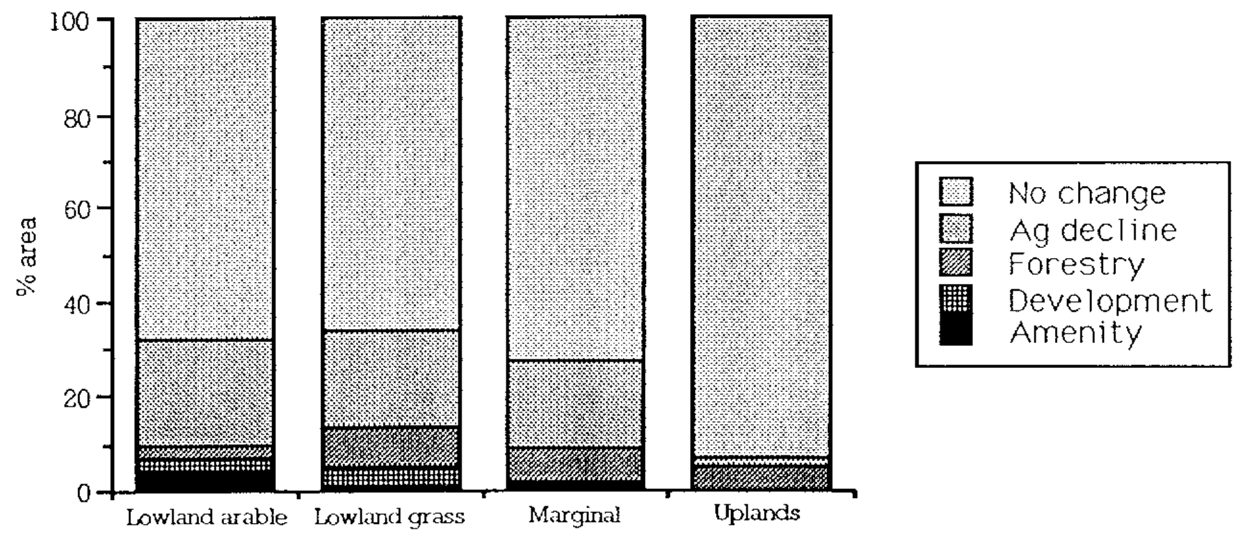


Figure 54 The potential for change in the rural environment. Data were derived by Laurence Gould Consultants Ltd (1989) and estimated by land class and then grouped according to the land class groups.

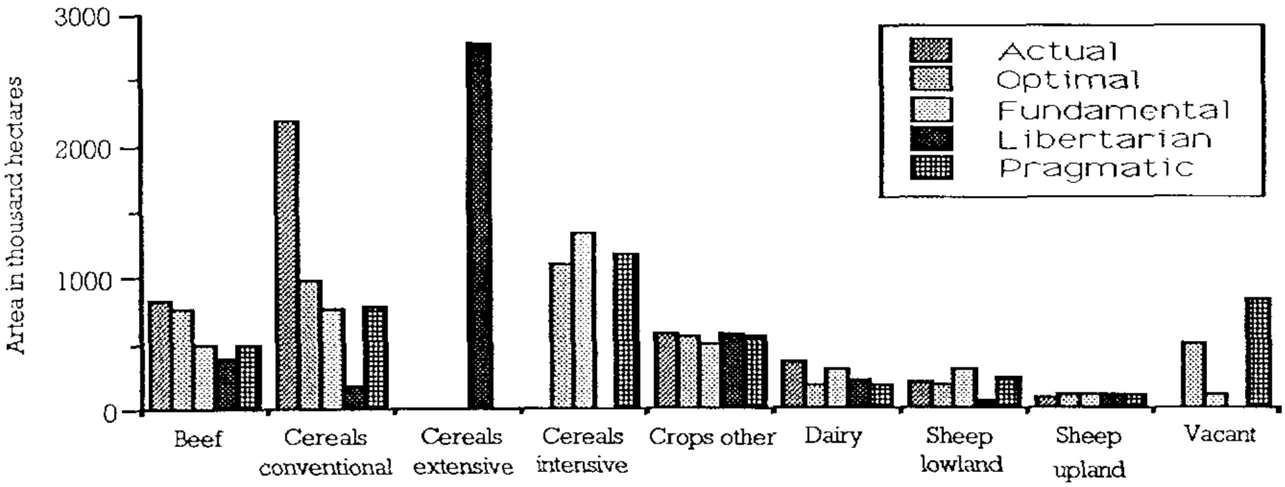


Figure 55 Potential changes in the arable land class group. Four scenarios are described by Harvey *et al.* (1986). Data were obtained from the mixture of enterprises within the 256 one km squares, and the linear programme model was used to determine changes that would result from the superimposition of the scenarios.

7.5.2 The potential for change

Lawrence Gould carried out a study for the Nature Conservancy Council to identify the proportion of land which might become available funder various scenarios. Accordingly, Lawrence Gould were subcontracted in the present project to identify the changes which might take place under given scenarios. The results are shown in Figure 54. As with the other projects, the major changes are most likely to take place within the lowland arable areas.

As in the previous studies, the lowland arable land classes have a wide range of options, with a significant area of amenity potential which is not reflected in any other of the land class groups. It is clear, therefore, that lowland agricultural landscapes have a wide variety of options which are not open. Surprisingly, the Lawrence Gould results confirm other data in the present project that the agricultural landscapes, in particular the lowland arable areas, are most susceptible to change.

In this project the relative financial returns are linked through a linear programme to different scenarios for change. In Figures 55-57, the results of the initial scenario runs carried out in 1986 are shown. In the lowland land classes dominated by arable farming, the changes for cereals are very great. The model is extremely sensitive to changes within the agricultural scenarios, but in lowland land classes dominated by grassland the main arable enterprises are still extremely variable. However, the animal enterprises show much less variability, suggesting that it is the cereal enterprises which are most susceptible to change, particularly in the grassland areas. As the model was concerned with England and Wales, the marginal uplands are dominated by sheep production. This is the optimal use in that zone, so the use of the land for sheep remains constant. However, the subsequent expansion of sheep into the lowlands has underlined that constraints on models can be restrictive, as the early means showed that if sheep were to move extensively into the lowlands, it would affect upland production.

7.6 Predictive scenarios

7.6.1 The land use allocation model

The most important project, which has linked the potential for change with individual parcels of land, is that of the land use allocation model of Reading University.

7.7 The potential for land abandonment

All the scenarios above suggest that at least some land is likely to go out of agriculture. Evidence is beginning to accumulate (eg Watson 1988) that land is in fact now beginning to go out of agriculture.

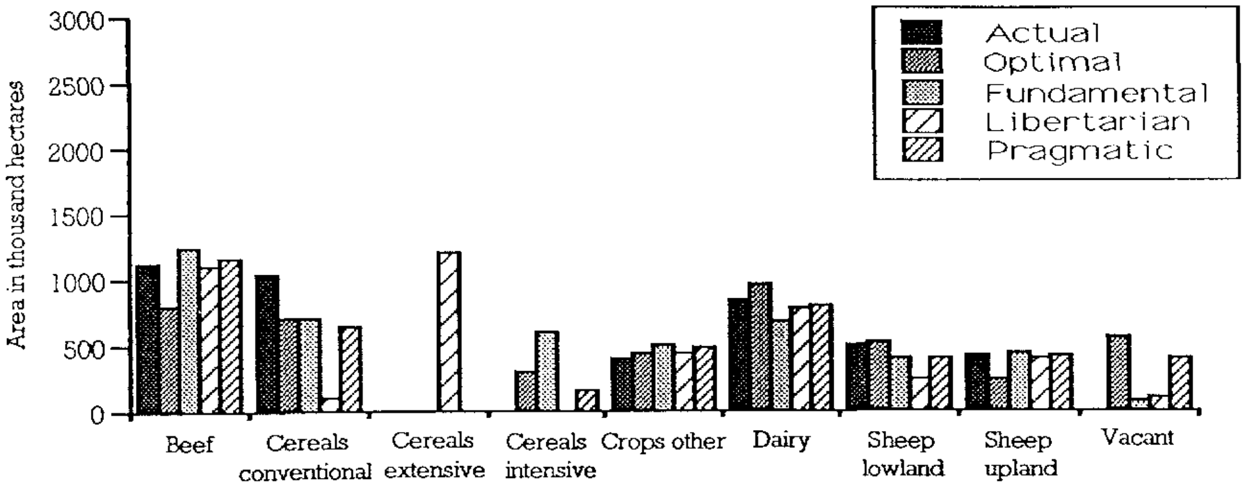


Figure 56 Potential changes in enterprises in the grassland group of land classes. The scenarios are described by Harvey *et al.* (1986) and were superimposed upon the basic 256 squares of the 1978 survey, with optimal patterns being determined by a linear programming model.

Abandonment is of particular interest, firstly because it is the endpoint of the intensity gradient, secondly because of the ecological interest, and thirdly because of its emotive significance. Although the recent set-aside scheme is designed to take land out of agriculture, it involves a relatively small area, probably only a few thousand hectares, and also requires statutory management procedures. The likely ecological consequences of set-aside are relatively minor, in that weed populations are likely to dominate the situation. Baudry & Bunce (1991) indicate that at the present time there is little abandoned land in Great Britain, but the current crisis in the agricultural industry could well be changing this situation. However, some areas which have been indirectly affected by other activities, eg forestry, are now virtually abandoned from agricultural activity. Thus, high mountain areas within bounds of large new forest, such as the Cairnsmore of Fleet in southern Scotland, may no longer be farmed; elsewhere small isolated areas have been left with no management.

In Britain, a major distinction can be made between the lowlands with crop plants where soils have been agriculturally improved by the addition of nitrogen and phosphate, and those in the uplands, largely in the north and west where soil nutrient levels are low and where the vegetation is dominated by native species. In the lowlands, the classic sites for studies on

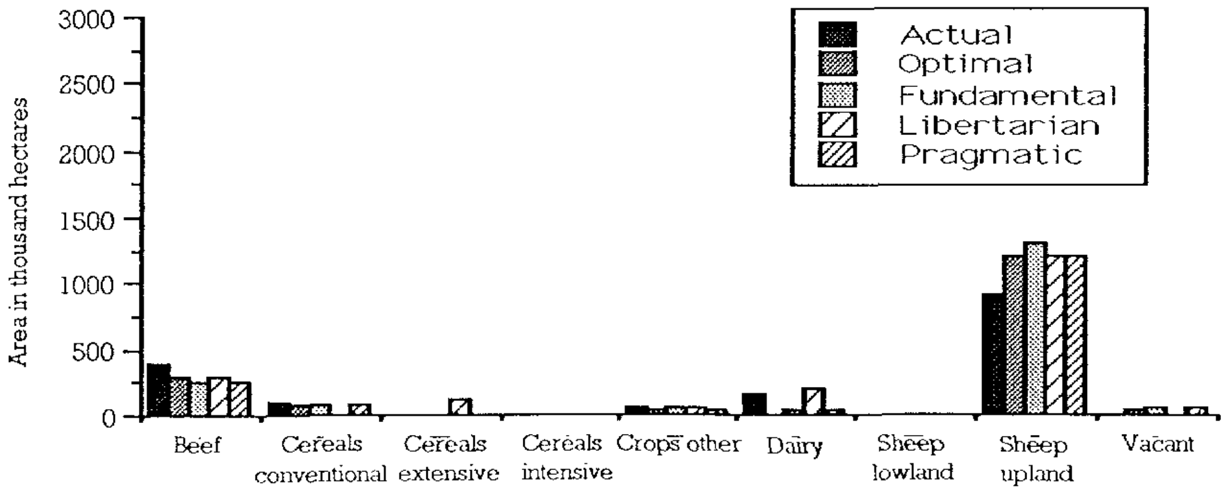


Figure 57 The potential changes in enterprises in the marginal uplands of England and Wales. The scenarios are described by Harvey *et al.* (1986) and were superimposed upon the basic 256 squares from the 1978 survey, with optimal distribution patterns being determined by a linear progamming model.

abandonment are the Broadbalk and Geescroft wildernesses at the Rothamsted experimental station. These sites were associated with experiments to examine the effects of fertilisers, and were a result of the failure of crops in treatments with no added nutrient. The sites were fenced and left without cultivation in 1881 and 1886. Eventually, the areas were progressively colonised by shrubs and trees, leading to forest cover.

Miles (1988) summarises the information available on the colonisation of *Betula* and open heather moorland, and Watson (1989) suggests that significant colonisation is taking place, as has Webb in the heathlands of southern England. The majority of studies in the uplands have used fenced experiments to exclude grazing. Initially, in general terms, species are lost, but a new balance is gradually achieved, although trees rarely manage to arrive, mainly because of lack of seed sources. Changes in upland areas are less dramatic compared to the overall structure of the vegetation in the lowlands, because of the paucity of woodland species, but the structure within dwarf shrub vegetation changes significantly.
Where succession follows abandonment, the pathway and eventual composition depend upon the initial vegetation and the associated environment. he following factors need to be considered:

(i) The species cover and human activity at the time of abandonment, which eventually determines the pathway of the succession.

(ii) The availability of seed from the seed bank, which provides new species that may not be in the current vegetation.

(iii) The dispersion of propagules from surrounding vegetation.

(iv) The structure of the landscape, which affects the dispersal and availability of propagules.

(v) The speed of the colonisation depends upon its ecological status at the time of abandonment. Important differences are present when individual fields are abandoned, as opposed to the whole landscape.

8. INFORMATION SYSTEMS

8.1 Introduction

The idea of developing an interactive system for conveying information was initially stimulated by a visit to a group called Farmlink. Farmlink provided farm data and accounts through PRESTEL, as well as interactive models for control of pests. The rapid transfer of information, together with interrogative geographical information, suggested that a comparable approach would be useful to policy advisers in the DOE. Initially, the necessity of adopting a suitable approach for specified users was not appreciated, and much of the effort early in the project was concerned with the identification of the appropriate form. An integral part of the approach is to identify a user community, and difficulties were experienced in this exercise in the early stages. It is significant that the recent GIS demonstrator project sponsored by the DOE at Bristol University identified a similar group of users to that of the present project, concentrating on the presentation of geographic information, but using vector rather than raster systems.

The development of computer-based information systems has been rapid during the period of the contract. Indeed, many of the concepts and methods which are now being used did not exist when the contract was first defined. It is not surprising, therefore, that some of the ideas which were written into the contract proposal have been overtaken by events.

Because there are important differences between the alternative computer-based systems for transferring information from research to practical decision making, this section of the report concentrates on providing a description of the essential features of four of those systems: expert systems, knowledge-based systems (KBS), information systems, and decision support systems. This will enable the reader to locate the ECOLUC information system within this hierarchy of systems.

8.2 True expert systems

The term 'expert system' refers to a computer program that is largely a collection of heuristic rules (rules of thumb) pertaining to a particular subject area. A feature which distinguishes an expert system from other methods of solving problems, eg mathematical modelling, is that the expert system can explain to the user how it reached the recommended solution.

An expert system essentially consists of:
(i) a knowledge base containing facts, rules, heuristics and procedural knowledge;
(ii) means of deriving inferences from the information in the knowledge base to solve a specific problem by emulating the reasoning process and problem-solving strategies of a human expert;
(iii) a user interface providing communication with the user through written or spoken language, or by interactive graphics;
(iv) an explanation generator which provides answers to queries made by the user.

Today's expert systems are the result of applying research on artificial intelligence (AI), a field of research that has for many years been devoted to the study of problem-solving by the use of heuristics, to the construction of symbolic representations of knowledge about the world, to improved understanding of the process of communicating in natural languages, and to how individuals learn from experience. The complexity of expert systems is such that they usually require the interaction of two very different people: an experienced and practising expert in some technical field, and a knowledge engineer — ideally an AI specialist skilled in analysing an expert's problem-solving processes and encoding them in an appropriate computer language. Knowledge engineering has thus become a new field of expertise which makes possible the building of sophisticated and complex expert systems, but which involves a major time commitment.

Because expert systems are essentially a representation of human expertise, careful evaluation, whether informal or formal, is an important element in their development. Evaluation enables a feedback process to take place, whereby the comments serve as a basis for iterative refinements of the system, and as a test of the accuracy and utility of the advice it provides. Evaluation also determines whether the expert system meets its intended requirements and goals.

An expert system can also be a good way of pooling the expertise of several — perhaps many — specialists, in order to produce a system that is more effective than any one expert working alone. Where they are dependent upon several kinds of expertise, decisions then can be obtained more reliably and consistently. Explanation of the proposed solution to the problem by such systems is of added importance because the system can balance the differing opinions of experts and attach relevant 'certainty factors' or 'health warnings' if the answer to a particular question is not clear-cut. Developing an expert system is often a good strategy solvin g a complex problem, and one which can often be used in training.

To satisfy the explicit requirements for knowledge representation within the knowledge-base of the expert system, different techniques have to be used for different types of knowledge. Selecting appropriate knowledge-representation schemes, particularly for such a broad and diverse field as ecology, is very important. AI research has shown that the problem-solving strategy depends heavily upon the representation, so selecting an appropriate representation is crucial for the success or failure of an expert system. The choice of the form of knowledge representation can effectively limit what the system can perceive, know, or understand.

8.3 Knowledge-based systems (KBS)

Knowledge-based systems are software programs, supplemented by man-machine interfaces, which use knowledge and reasoning to perform complex tasks at a level of performance usually associated with an expert, but not necessarily by means of the heuristics that are characteristic of human experts. The knowledge base comprises a database containing the rules and facts from a particular field of expertise, from which an inference engine can deduce the solutions. It is often helpful to recognise four levels of expertise, each one built out of elements of the next lower level:

Concepts — Representation of specific aspects pertaining to some field of expertise, with both abstract classes and concrete instances; complex interrelationships can usually be represented and used in making inferences and constructing similarities. In many instances, such knowledge can be obtained from textbooks, and often includes the basic terms of the problem area.

Rules — Empirical associations linking causes and effects, evidence and likely conclusions, situations and desirable actions to perform, etc. This level of knowledge is the main form that is obtained from an expert, and is based on experience. The knowledge may be empirical (difficult to obtain from textbooks), and may have associated with it 'certainty factors' indicating degrees of belief in its applicability. Experts may not agree on knowledge at this level.

Models — Collections of interrelated rules, usually associated with particular hypotheses and incorporated into formal mathematical expressions. An essential step in the use of the models for making decisions is the estimation of the critical parameters of the model, and these estimates may be derived from the rules, or elicited by directed questioning of the user.

Strategies — Rules and procedures to assist in the use of the rest of the knowledge base, eg by guiding the search process and resolving conflicts when several equally plausible rules apply to a given situation. At this highest level of expertise the knowledge-base may appear as a 'black box', but it should always be possible to question the basis for the choices that it makes, or to ensure that the concepts, rules, and models which contribute to strategies are made explicit.

Knowledge-based systems are, therefore, more broadly conceived than expert systems, and incorporate AI techniques within the more traditional scientific approaches of hypothesis formulation, modelling and systems analysis. While they do not entirely overcome the difficulty of extracting information from individual experts, they are less dependent on rules-of-thumb and they make wider use of published and codified information.

8.4 Information and decision-support systems

The most important difference between knowledge-based systems and information systems is that knowledge-based systems manipulate 'knowledge', while conventional information systems manipulate 'data'.

Comparison of data processing (information systems) and knowledge engineering (expert and knowledge-based systems)

Data processing	Knowledge Engineering
Representation and use of data	Representation and use of knowledge
Algorithmic	Heuristic
Repetitive process	Inferential process
Effective manipulation of large databases	Effective manipulation of large knowledge bases

All three of the above systems are now being combined into decision support systems — interactive computer based systems that help decision-makers to utilise concepts, models, and data in the solution of unstructured problems. The characteristics of decision support systems have been described as:

(i) They assist in the making of decisions in unstructured or semi-structured tasks, for example in deciding on priorities in planning conflicts, or in choosing between a range of possible options.
(ii) They support and enhance, rather than replace, the managerial judgement of the decision maker, who retains the responsibility for decision-making, and does not feel forced into a decision by 'experts'.

(iii) They concentrate on improving the effectiveness of decision making rather than on its efficiency, ideally by clarifying the conflicting goals of the various participants in the decision-making process.

(iv) They combine the use of simulation models, information systems, expert systems, and knowledge-based systems, and help the user to make the most appropriate choice of technique at each stage of the decision-making process.

(v) They emphasise flexibility and adaptability in respect of changes which may occur in the context of the decision-making process. By recognising the importance of incremental or adaptive approaches to development of any kind, the decision-maker is protected from being placed in the position of having to make decisions which are unstable.

(vi) They focus on features which make them easy to use interactively, even by relatively inexperienced users.

However, it was not possible to produce a decision-support system within the time-scale of the present project — this will be the next section of work.

8.5 Modules developed during the project

Initially, three modules were developed as true expert systems. They are at different scales of resolution and serve very different purposes. A forestry module was designed to operate at the national scale, but gives only qualitative information on forestry effects without detailed quantitative data or prescriptions for action. Two modules have been written to advise on establishment of

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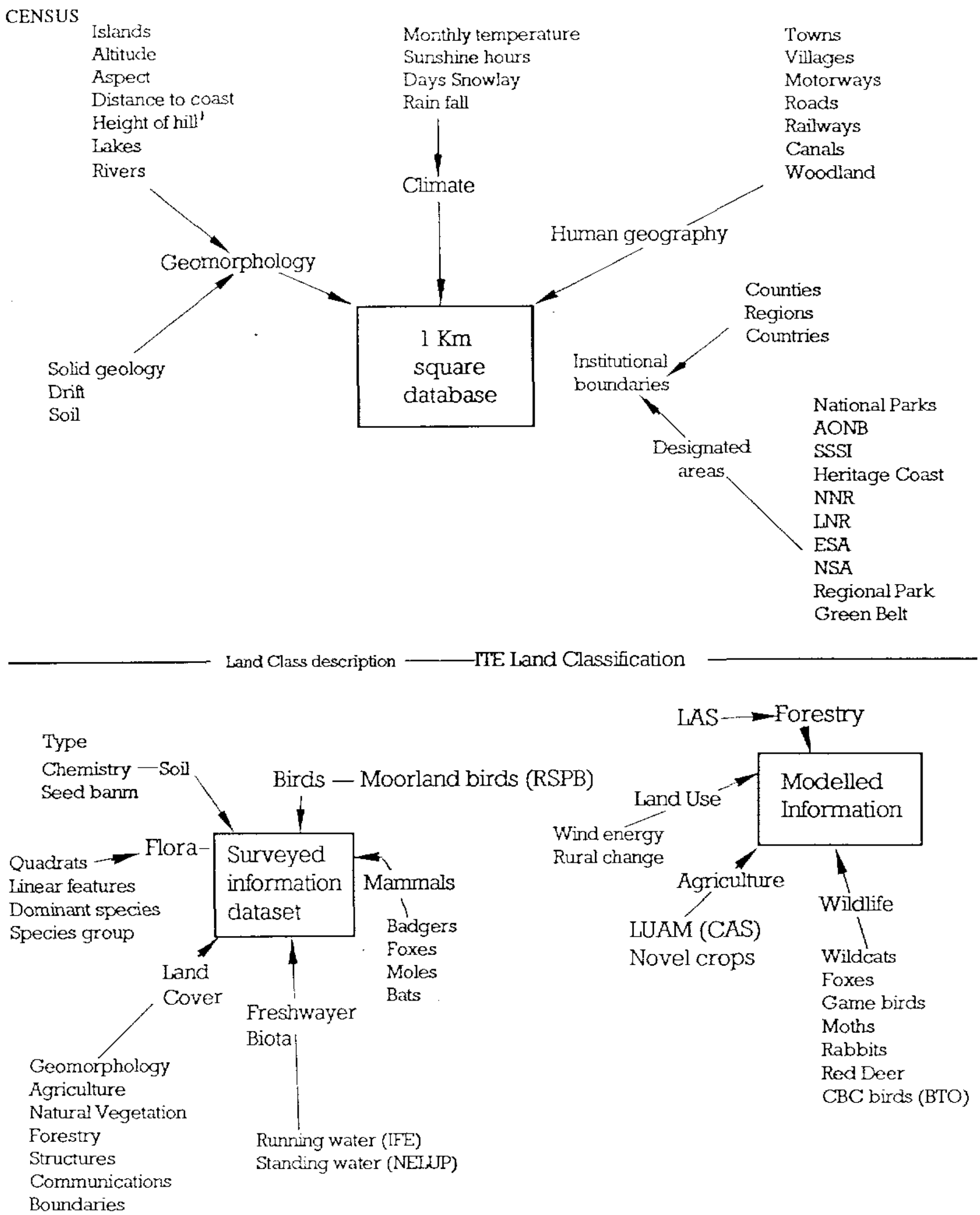

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wildflower meadows. These are site-specific. One gives quantitative information of seed mixtures and costs; the other gives prescriptions for meadow establishment.

8.5.1 The forestry module

Forestry practice, especially afforestation, has large ecological effects. These vary according to region of the country, existing land use, soil type, size of forest block, tree species, thinning regime, and a variety of other factors. A non-specialist, confronted with the problem of what will happen when a forest is planted or new management is introduced, needs guidance on two points. First, it is necessary to know what components of the ecosystem are likely to be affected, then information is needed on the kind of changes to expect.

The forestry module, codenamed FOREST, enumerates effects that are likely to occur in a given area by identifying forestry options and listing their effects. In most instances, effects on soils and water, on plants, on fungi, on birds, on mammals and on insects are briefly outlined. Other phenomena, notably effects on the atmosphere and microclimate, are not considered.

Much of the information in FOREST is derived from the expert knowledge of ITE staff, particularly M O Hill and R G H Bunce, together with data obtained from the scientific literature, including ITE and Forestry Commission publications. The information is mostly at a broad level of generality, and does not depend on a large database or on detailed site information. Thus, FOREST is not designed to be used by an expert ecologist, except for getting a rapid checklist of points to consider. Its intended user is a moderately well informed non-expert, possibly a planner or policy adviser.

FOREST presents verbal information in a hierarchical structure, which would often start with the district of the country and then move on to types of forestry and their effects. Most of the hierarchy consists only of headings, but there were short blocks of text provided at the lower levels and especially the lowest.

The user explores the hierarchy by choosing a topic, and then proceeds using a series of prompts.

The simplest route down the hierarchy goes straight to the type of forestry. If this route is selected, then "Types of forestry" becomes the heading, with topics ranging from "Large conifer blocks on unimproved land" through to "Small willow coppice". If, for example, the enquirer selects "Small amenity woodlands", the response is a message stating that such woodlands are most often planted on good grassland, and suggesting three topics, one of which is "Ecological consequences of small amenity woodlands".

The information for FOREST has been loaded into a special-purpose "shell" program called BRAINSTORM. This program has a rather rigid structure, and is designed for rapid data entry rather than for elegance or ease of presentation. It is also exclusive to micro-computers running under the DOS operating system (IBM compatible), and cannot readily be linked into a larger expert system with database interrogation. It therefore has to operate as a stand-alone module.

8.5.2 Meadow management

A detailed module was also developed to achieve a wildflower meadow. Intensive grassland management is geared towards maximum production of grass for silage and grazing. It requires large inputs of fertiliser, frequent reseeding, and spraying with selective herbicides to control broadleaved weeds. Under such management, attractive meadow flowers are eliminated and the habitat becomes unsuitable for most animal species.

Farmers and nature conservation agencies have become increasingly interested in re-establishing herb-rich grassland, and several methods for doing this have been proposed (Wells *et al* 1981). However, there are many possible options. The species and options were explored by the modules MEADOW and FINDSEED.

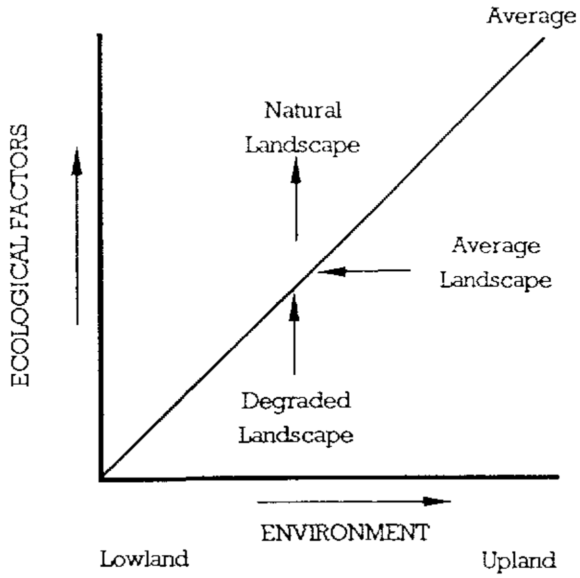


Figure 59 Relationship between the environment as expressed by the land classification and ecological factors, eg vegetation composition or invertebrate fauna.

The module MEADOW gave prescriptions for establishment of herb-rich grassland, given various objectives and site types. Most of this information derives from the pioneering work of an ITE scientist, Terry Wells (Wells 1981), who has provided much useful documentary material as well as commenting on the module.

Information for FINDSEED is also derived in part from Well's work. In addition, seedmen's catalogues were consulted, together with a monograph on the habitat of grassland plants compiled by NERC's Unit of Comparative Plant Ecology (Grime *et al* 1988).

The user of the program is envisaged to be a farmer, or an adviser to a farmer, and the program interrogates the user on a variety of matters relating to the site, starting with the management objectives.

Other questions that the user has to answer relate to existing and projected use, size, time-scale, soil reaction, soil moisture, soil fertility and shade. Once this information has been gathered, prescriptions are generated, covering site preparation, species introduction, date of sowing or planting, site management after establishment, and weed control.

FINDSEED, in contrast, was designed to answer a single technical question: "What seed mixture should I sow in order to create a herb-rich grassland?" The program quizzes the enquirer on the location, drainage, soil reaction, soil fertility and shading of the site, and asks if there is any preferred flowering time and whether the flower names are to be given in English or Latin.

Given this information, the program works through a list of species to extract those that have the right characteristics for the site.

FINDSEED offers a small amount of advice on establishment, noting particularly that a high proportion of herb seed increases the initial cost, but may not make much difference after three years. Finally, there is textual information on the merits of the grasses, if the enquirer wants it. For example, of red fescue, one may learn that it is "a highly recommended grass for all but the poorest acid heathland soils; spreads by rhizomes and does not need to regenerate from seed once established."

FINDSEED is written in Microprolog, a dialect of the specialised programming language PROLOG. However, the program follows a very straightforward decision tree, and makes simple cost calculations based on information in the species database, so it could have been written in almost any programming language.

The three programs FOREST, MEADOW and FINDSEED are all to some extent experimental. Only MEADOW could count as an expert system in the strictest sense. However, in the broader sense — of an expert system as an "automated knowledge-based problem solver" — all three can be regarded as expert systems.

In constructing them, a technical difficulty soon became clear — namely that the problem of linking them to other databases and other bodies of knowledge cannot be ignored if they are to become fully effective. Both EXSYS and Microprolog can, in principle, be linked to subprograms written in the programming language "C".

However C is a language that is little used except by professional programmers, so this presents practical difficulties to a scientist trying to construct an expert system as a offshoot of his own work.

This and other technical difficulties can, with some effort, be overcome. The major obstacle to constructing small expert systems is that they mostly solve problems that users consider marginal or irrelevant. In the case of herb-rich meadows, FINDSEED, which solves a specific technical problem, was quite unsuccessful.

There are therefore two major conclusions to be derived from the experience of constructing expert system modules. These are that progress will be uncertain unless a definite community of "end users" can be identified, and that, without plenty of user feedback, small expert systems are unlikely to satisfy a clear human need. For the general broad-scale problem, such systems are too detailed and specific, and are not generally applicable to the problems of policy advisors.

8.6 The ECOLUC knowledge-based system

Because of the above problems, the ECOLUC knowledge-based information system structure, as shown in Figure 58, was developed.

Following various seminars and the application of exploratory expert systems, this system was designed to convey the principle features of the databases developed during ECOLUC. The system is based on windows, icons, mice and pull-down menus (WIMP) and is set up on a DOS-based system written in the programming language C. It is run under Windows 3.0, and can be used on any IBM compatible.

Using a mouse to select screen symbols, rather than typing at a keyboard, enables more ready access by users unfamiliar with computer keyboards. The results produced by the system are not limited to text, but can be presented as maps, graphs and pictures.

8.7 The presentation of visual information

Although visual information (Benefield & Bunce 1982) has not yet been fully incorporated, its conversion to computer readable format has been demonstrated. The next section provides a presentation of the way such information could be incorporated into a more sophisticated KBS.

An important concept in planning control is that of the comparison of an individual site with a standard. Such comparisons would form an important element of a more sophisticated information system and examples are presented below in order to show their application.

The basic landform and topography of each landscape type is relatively homogeneous, as it is derived from unequivocal and constant attributes from maps. However, within each landclass, the number of 'transient' features (trees, boundaries, buildings, etc.) is variable, depending mainly upon management. The original illustrations of the land classes (Benefield & Bunce 1982) were based on the average number of features recorded for that land class, and thus represents a typical square. The range of the number of features recorded has not previously been examined, but has an important influence in the demonstration of landscape change, in that landscapes with no changes need to be contrasted with those where there is a high level of change.

The relationship between the environment and the natural features of the landscape has a regression base. That is, the relationship between the ecological factors and the environment is the crucial one in determining what happens in a particular situation as shown in Figure 59. The landscape at a particular location will contain an average number of features. However, a policy advisor needs to know the range of variation which could be present, because it is sometimes necessary to conserve a more variable landscape — on the other hand, if a development was going to be taking place in a degraded landscape, then it may well be permitted. In order to express this variability, the series of diagrams shown in Figures 60-67 has been developed.

The following exercise was carried out to demonstrate the variation in the range of landscape features within a land class, as a basis for comparisons of the possible effects of different policies.

The total number of landscape features recorded in 1984 was calculated for each of the squares for the land classes.

The basic landform was derived from the previous analysis described by Benefield & Bunce (1982), and is shown as the middle sketch in the following pages, with the average number of features superimposed.

The square with the highest number of features recorded was used to construct the landscape shown in the top sketch.

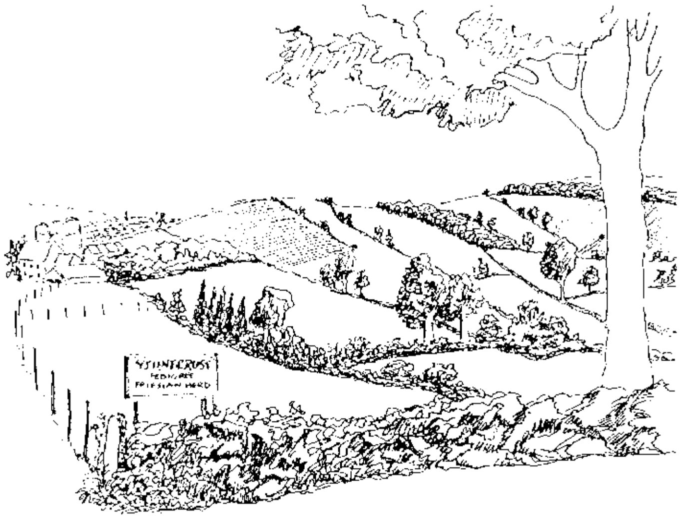
The bottom sketch shows the basic landform with the smallest recorded number of features placed in the landscape.

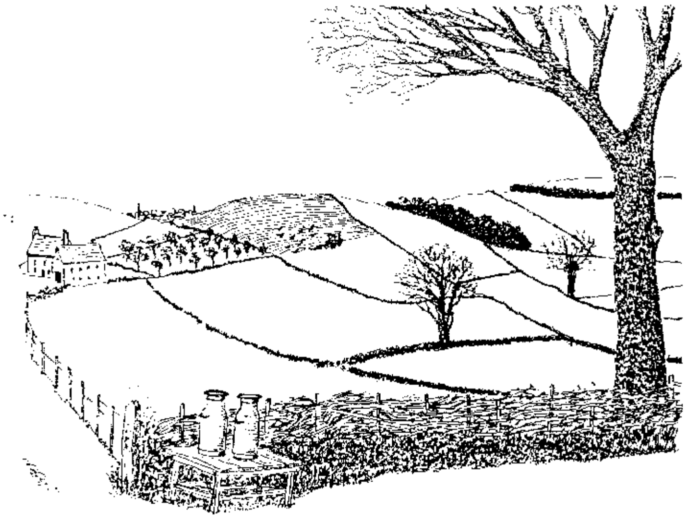
The sketches illustrate that variation is due to different factors in different environments, and that the characteristics of the countryside need to be taken into account when formulating policy. For example, grazing is necessary to maintain chalk grasslands in the south, but in the northern heather moorlands it may need to be reduced.

1(1) A mosaic of small fields bounded by hedgerows, with many hedgerow trees, small copses, patches of scrub and traditional habitats. Mainly grassland, but also with small areas of other crops, such as turnips, potatoes and cereals.

1(2) The typical landscape has larger fields with fewer trees present around their margins. The number of copses and small corner patches of trees is also smaller, and other landscape features such as buildings are less common. The main character of the land use is grassland with dairy and beef, but cereals are important locally.

1(3) In the degraded landscape, large fields are present with few hedgerows and trees, giving rise to an open landscape, mainly dominated by cereal production. Few natural habitats are present, partly because of removal and partly because of the inherent character of the landscape.

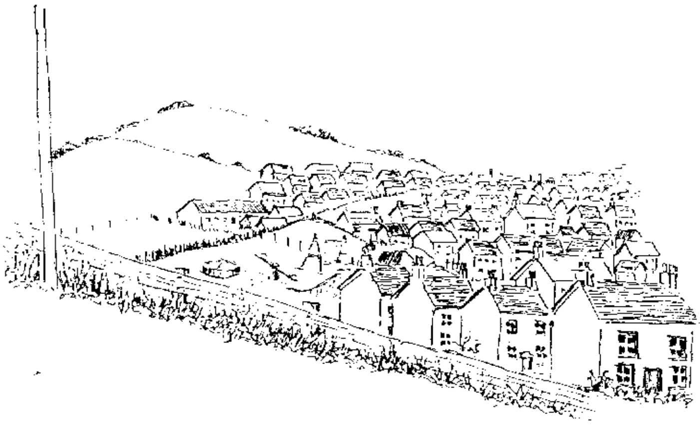

PEDIGREE
FRIESIAN HERD



5(1) The more varied landscapes in this class tend to be those that have been highly perturbated with non-rural features. Therefore, although a large number of landscape features are present they are generally not of a rural nature.

5(2) The average square still retains a range of rural features, with extensive hedgerows and small woodlands, typical of the major valleys of central England. Field size is average, with hedgerow trees and small copses scattered through the landscape in quite high frequency.

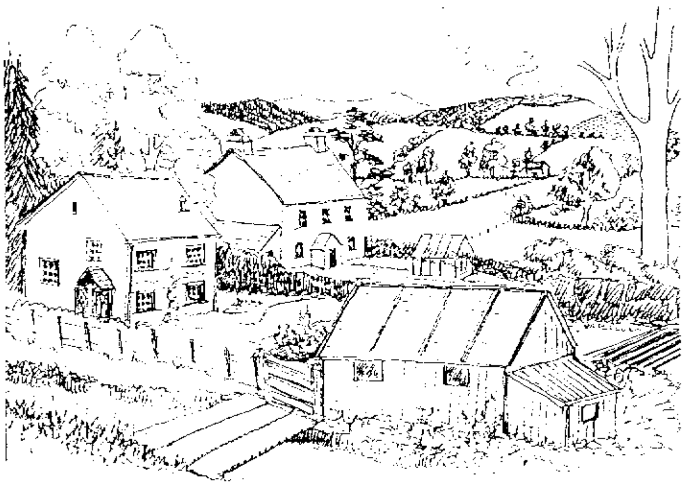
5(3) Field sizes in poorer landscapes are larger, with fewer trees and woods, and the landscape therefore has a very open appearance. Such differences are important in that erosion is present because of the increased windspeed; this is in part due to inherent soil differences, but also to increased or intensive agricultural farming, mainly involving cereal production.

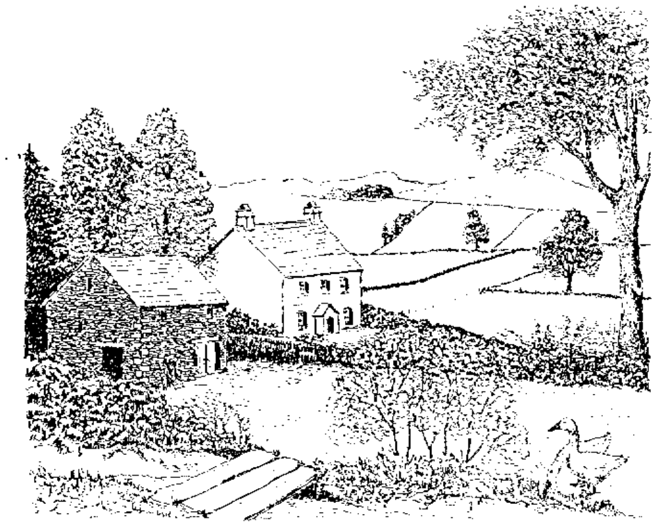


15(1) The most highly developed landscapes in this class contain complex mosaics of land uses as well as trees, hedgerows, with afforestation on the lower slopes. Traditional buildings as well as conversion of barns for tourism and their replacement buildings are often present.

15(2) The average landscape contains a relatively wide range of features in comparison with most British landscape. However, there are fewer trees and somewhat larger fields than in the most diverse landscapes. This is due, in part, to practice in agricultural systems, but also to local topographic variation.

15(3) In this open landscape there are few hedgerows and trees, with very large fields. In this land, there is widespread grazing as opposed to more mixed agriculture in the more diverse landscapes, with more complex mosaics that are most widely present in this class.

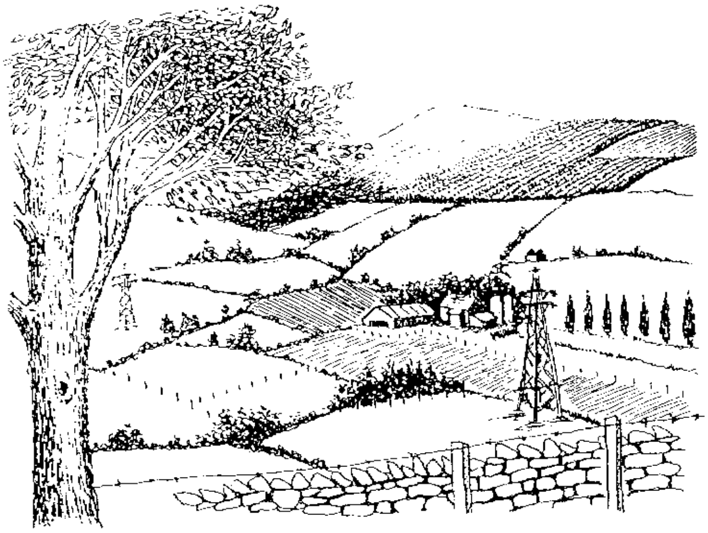




20.1 Afforestation has diversified the open upland moorlands, in comparison with the smooth landscapes usually present. The more diverse landscapes have many small fields bounded by walls, hedgerows and trees. Scattered small arable fields may be present, with traditional hay meadows adding to variability.

20(2) The average landscape contains less complex mosaics, but still has a wider variation than most land classes in Great Britain because of the contrast between upland and lowland characters. Fields are generally small, with combinations of walls and hedges, depending upon the substratum.

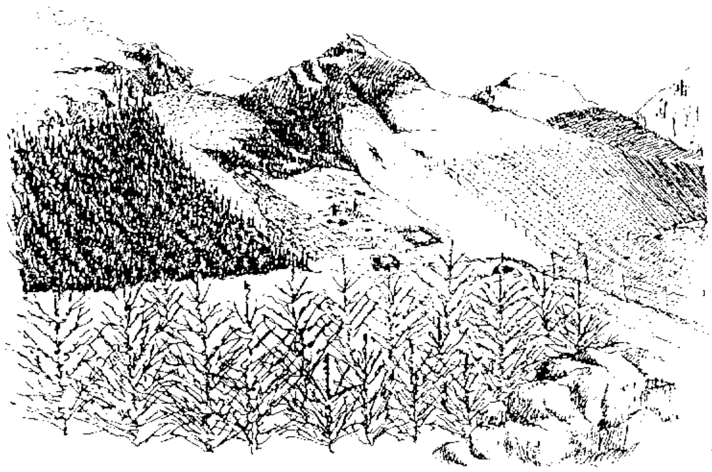
20(3) The marginal uplands have generally maintained variability, as they are on the interface between open moorland and enclosed land. However, some landscapes, often in more exposed situations or on poorer rock types, are more open, with relatively few landscape features.

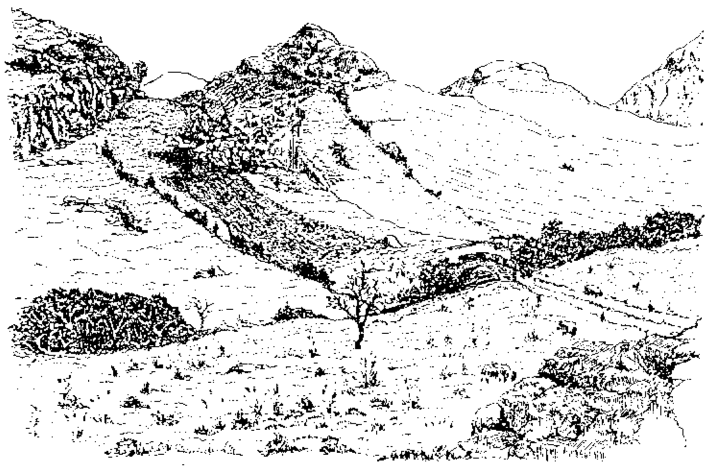


24(1) Afforestation, with associated fences, ploughlines and landscape disturbance, adds features on to the basic pattern of this class because they are generally absent from such extreme upland environments. Locally, the montane environments are masked by trees, but the features, such as scree and rocks, are usually still present either on the open ground above the treeline or between plantations.

24(2) The high mountain landscapes are dominated by range grazing, principally sheep, but also deer, and therefore have few boundaries between them. The landscapes have the classic high mountain features such as corries, screes, cliffs, and open rock slopes. In general, there are relatively few trees, usually in small patches of scrub, at lower levels, or along ghyll sides.

24(3) On geological series that either have not been so strongly eroded, or are more resistant to erosion, the landscapes of this class have relatively few natural features and sometimes have a monotonous appearance with few features to break the horizon.

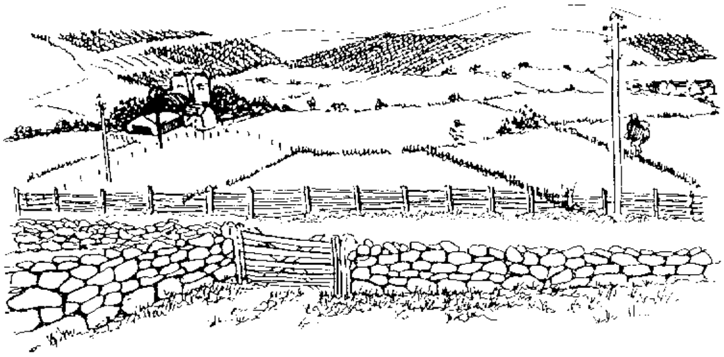


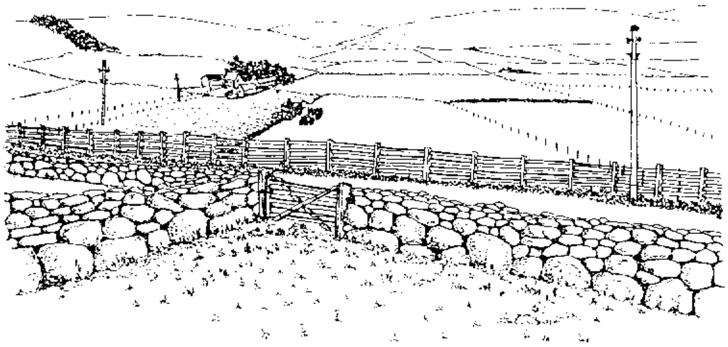


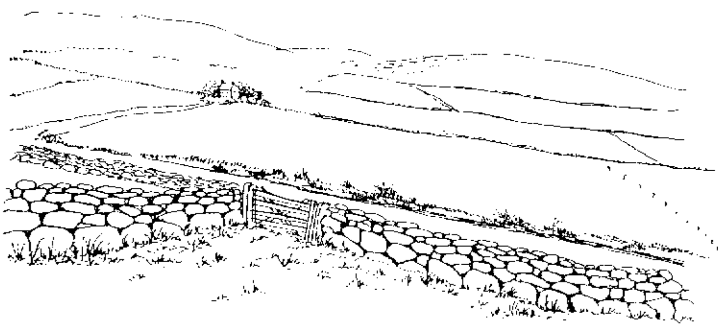
25(1) In general, these Scottish landscapes are open and rather windswept, but in some areas with poorer soils, patches of forestry have encroached. In areas with more variable characteristics, there are more walls, hedgerows and individual trees, giving the landscape a more varied appearance.

25(2) The typical landscapes of this class are still rather open, with few trees but with intersecting walls and fences. The fields are relatively large, and are dominated by cereal production, with grass being relatively infrequent.

25(3) In more exposed situations, there are no hedgerows, few walls and fences enclosing large fields. The landscape thus has a prairie appearance, and is one of the most open landscapes in Britain.



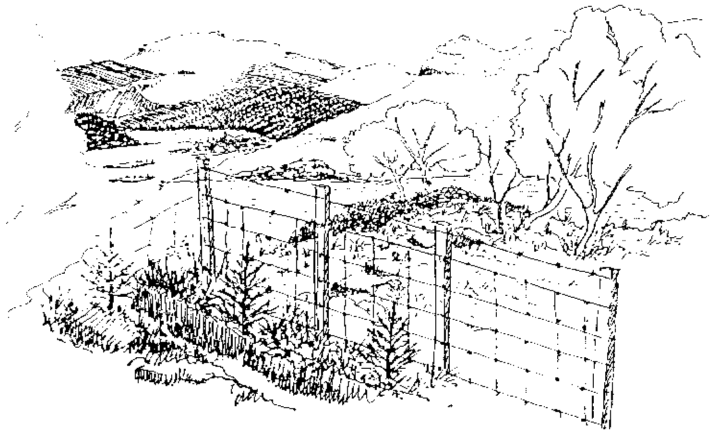




29(1) The diverse landscapes in this class have a wide variety of features, but tend to be disturbed rather than the traditional patterns. Small-scale afforestation and scrub development has tended to distort the traditional patterns and add landscape features to countryside, which is normally consistently diverse in its own right.

29(2) The above contrasts are expressed in the traditional west coast landscape that have complex mosaics of natural and semi-natural habitats in a delicate balance. The trends in such landscapes are towards abandonment, and towards a loss of the diversity of the variability in the land class.

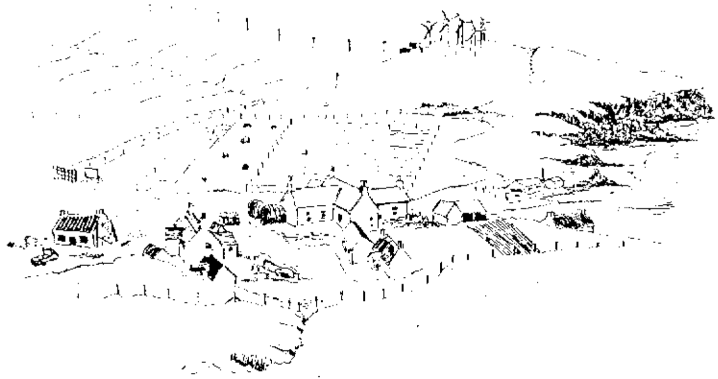
29(3) Within this land class, exposure is a critical factor in determining the degree of variability present. The more exposed sites on the outer coasts have relatively few features, and are dominated by heath and moorland vegetation. Not only is the landscape less diverse, but also there are restricted habitats.

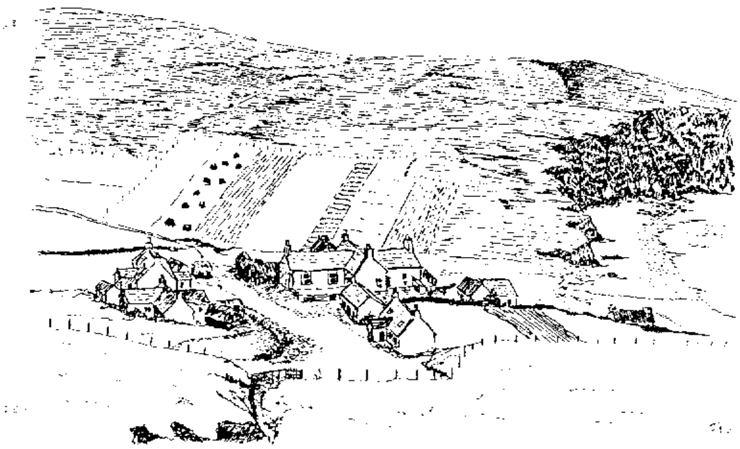


31(1) The varied landscapes in this class tend to have more recently added development projects such as croft house replacements, fish farming, and even windmills. The traditional patterns are therefore disturbed, showing that diversity of landscape features is not the only criterion that should be applied in landscape evaluation.

31(2) The traditional land patterns and practice have small fields and crofts, and a diversity of crops and semi-natural vegetation. Such landscapes not only hold a strong visual appeal, but also a wide range of botanical and zoological diversity.

31(3) The more exposed outer coasts have widespread dereliction, both in grazing and cultivation, because of the more difficult environment. The vegetation is thus returning to a less complicated pattern, with species such as *Molinia* expanding, and also the loss of the local small-scale field patterns.





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Bob Bunce

10 REFERENCES

ARMITAGE, P.D., MOSS, D., WRIGHT, J.F. & FURZE, M.T. 1983. The performance of a new biological water quality score system based on macro invertebrates of over a wide range of unpolluted running water sites. Wat. Res. 15, 679-689.

ASSELIN, A. 1988 Changes in grassland use consequences on landscape patterns and spider distribution In: Connectivity in Landscape Ecology proceedings of the 2nd International Seminar of the International Association for Landscape Ecology Ed K.F. Schreiber p 85-88 Paderborn: Schonigh.

AVERY, M. (In prep) The use of the ITE land classification in the estimation of Moorland Bird Populations.
BALL, D.F. & BARR, C.J. 1986 The distribution of sites of the Monitoring of Landscape Change Project in relation to classes in the ITE Land Stratification. Institute of Terrestrial Ecology Project 987 HTS/NERC F6/ 92/BB.

BARR, C.J., BENEFIELD, C.B., BUNCE, R.G.H., RIDSDALE, H.A. & WHITTAKER, M. 1986. Landscape changes in Britain, Abbots Ripton: Institute of Terrestrial Ecology.

BAUDRY, J. & BUNCE, R.G.H. Editors. Land Abandonment and its role in conservation. (Options Mediterraneennes. Serie A. Seminaires Mediterraneennes no 15) Zaragoza: Centre International de Hautes Etudes Agronomiques Mediterraneennes.

BENEFIELD, C.B. & BUNCE, R.G.H. *1982 A preliminary visual presentation of land classes in Britain.* (Merlewood Research and Development paper no 91) Grange-over-Sands: Institute of Terrestrial Ecology.
BEST, R.H. 1976 The extent and growth of urban land. The Planner, 62 8-11

BIGNALL, E. 1978 The fixed angle photography method used on Loch Lomond NNR NCC South West Region (Scotland) Research and Technical Note No I

BUNCE, R.G.H., BARR, C.J., MITCHELL, C.P. & PEARCE, M.L. 1983 Estimates of present forest cover in Great Britain. In: Energy from biomass. Ed A. Strub, P.Chartier and G. Schleser. 2nd E C Conference, Berlin. London:Applied Science.

BUNCE, R.G.H. & SMITH, R.S. 1978 An ecological survey of Cumbria. Kendal: Cumbria CC and Lake District Special Planning Board

BUNCE, R.G.H. *1989 Ed Heather in England and Wales. (ITE Research Publication no 3.) London:* HMSO

BUNCE, R.G.H. & HEAL, O.W. 1984 Landscape evaluation and the impact of changing land-use on the rural environment: the problem and an approach. In: Planning and Ecology. Ed R.D. Roberts, T.M. Roberts London: Chapman & Hall.

BUNCE, R.G.H. 1978 Land classification for ecological survey. In: The assessment of ecological and recreational resources at the regional and national scales Ed G.C. Barrow, 11-14 Recreation Ecology Research Group

BUNCE, R.G.H., BARR, C.J. & WHITTAKER, H.A. 1981 The land classes of Great Britain: preliminary descriptions for users of the Merlewood method of land classification. (Merlewood Research and Development paper no 86) Grange-over-Sands: Institute of Terrestrial Ecology

BUNCE, R.G.H., BARR, C.J. & WHITTAKER, H.A. *1983 A stratification system for ecological sampling. In:* Ecological mapping from ground, air and space Ed R.M. Fuller, 39-46 (ITE symposium no 10) Cambridge: Institute of Terrestrial Ecology

BUNCE, R.G.H. & JENKINS, N.R. 1989 Land potential for habitat reconstruction in Britain. In: Biological habitat reconstruction Ed G.P. Buckley 81-91 London: Belhaven

BUNCE, R.G.H. & HOWARD, D.C. 1990 Species Dispersal in Agricultural Habitats London: Belhaven

BUNCE, R.G.H. 1977 The range of variation within the pinewoods. In: Native pinewoods of Scotland Ed R.G.H. Bunce & J.N.R. Jeffers 10-25 Cambridge: Institute of Terrestrial Ecology

BUREL, F. 1989 Landscape structure effects on Carabid beetles. Spatial patterns in Western France. Landscape Ecology 2 215-226

CHAPMAN, S.B. & ROSE, R.J. 1989 Vegetation change at Coombe Rigg Moss NNR Annual Report Institute of Terrestrial Ecology 1986/7

COPPOCK, J.T. & GEBBETT, L.F. 1978 Land Use and Town and Country Planning, Reviews of UK Statistical Sources, Vol 8 Oxford: Pergamon

CRESSWELL, P., HARRIS, S., BUNCE, R.G.H. & JEFFERIES, D.J. 1989 The Badger in Britain: present status and future population changes. J.Linnean Soc. 38 91-101

EASTERBEE, N., HEPBURN, L.U. & JEFFERIES, D.J. 1991 Survey of the status and distribution of the wildcat in Scotland 1983-1987 Edinburgh: Nature Conservance Council for Scotland

EDWARDS, D. & TRANTER, R.B. 1990 Existing and potential countryside recreation and tourism activities and their ecological consequences: a preliminary assessment based on the ITE land classification system. Reading Centre for Agricultural Strategy University of Reading

FULLER, R.M. 1987 The changing extent and conservation interest of lowland grasslands in England and Wales: a review of grassland surveys 1930-84 Biological Conservation 40 281-300

FURSE, M.T., WRIGHT, J.F., GUNN, R.J.M., CLARKE, R.T., JOHNSON, H.A., BLACKBURN, J.I., ARMITAGE, P.D. & MOSS, D. 1990. The impact of land use change on aquatic communities - an exploratory study. Report to the Deparmtent of the Environment.

GRANT, S.A., TORVELL, L., ARMSTRONG, R.H. & BEATTIE, M.M. 1987 *The manipulation of mat grass* by grazing management In: Agriculture in the Hills and Uplands. Ed M. Bell & R.G.H. Bunce p 62-65 Grange-over-Sands: Institute of Terrestrial Ecology

GREIG-SMITH, P. 1957 Quantitive Plant Ecology London: Butterworths

GRIFFITHS, G.H. & WOODING, M.G. 1988 Pattern analysis and the ecological interpretation of satellite imagery Proceedings IGARSS Symposium Edinburgh p 917-921

GRIME, J.P., HODGSON, J.G. & HUNT, R. 1988. Comparative Plant Ecology: a functional approach to common British species London: Unwin Hyman

HARRISON, A.R., DUNN, R. & WHITE, J.C. 1989 A statistical and geographical examination of the Monitoring of Landscape Change data. Vol 1 Main Report Final Report to the Department of the Environment Research Project. PECD/7/7/47

HARVEY, D.R., BARR, C.J., BELL, M., BUNCE, R.G.H., EDWARDS, D., ERRINGTON, A.J., JOLLANS, J.L., MCCLINTOCK, J.H., THOMPSON, A.M.M. & TRANTER, R.B. 1986 Countryside implications for England and Wales of possible change in the Common Agricultural Policy. Executive Summary (Report to the Department of the Environment and the Development Commission) Reading Centre for Agricultural Strategy University of Reading

HEIL, G.W. 1984 Nutrients and species composition of heathland. PhD thesis. University of Utrecht

HILL, D.A. & ROBERTSON, P.A. 1988. The pheasant: ecology, management and conservation. Oxford: Blackwell Scientific Publications.

HILL, M.O. & JONES, E.W. 1978 Vegetation changes resulting from afforestation of rough grazing in Caeo Forest, South Wales. Journal of Ecology 66 433-456

HILL, M.O. 1979 DECORANA a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Itahca, New York: Correll University

HILL, M.O. & RADFORD, G. 1986 Register of permanent vegetation plots. Abbots Ripton: Institute of Terrestrial Ecology

HILL, M.O. 1986 Ground flora succession in commercial forests. In: Trees and wildlife in the Scottish uplands; Huntingdon: ITE symposium no 17 71-78

HILL, M.O. 1989 Computerised matching of releves and association tables, with an application to the British National Vegetation Classification Vegetatio 83 187-194

HILL, M.O. 1982 Management of natural and man-made habitats: effects of grazing in Snowdonia. Annual Report: Insitute of Terrestrial Ecology 1982

HILL, M.O. 1979. TWINSPAN - a FORTRAN programme for arranging multivariate data in an ordered two way table by classification of the individuals and attributes. Ithaca N.Y. Section of Ecology and Systematics, Cornell University.

HOPKINS, A. & WAINWRIGHT, J. 1989 Changes in botanical composition and agricultural management of enclosed grasslands in upland area of England and Wales, 1970-86, and some conservation implications. Biological Conservation 47 219-235

HOPKINS, A., WAINWRIGHT, J., MURRAY, P.J., BOWLING, P.J. & WEBB, M. 1988. 1986 survey of upland grassland in England and Wales: changes in age structure and botanical composition since 1970-72 in relation to grassland management and physical features. Grass and Forage Sci. 43 185-198

HARMS, W.B. & KNAAPEN, J.P. 1988 Landscape- ecological mapping of the Randstad area, the Netherlands, In: Connectivity In Landscape Ecology Proceedings of the 2nd International Seminar of the International Association for Landscape Ecology Ed K.F. Schreiber p 81-88 Paderborn: Schonigh.

HUNTINGS SURVEYS & CONSULTANTS LTD 1986 Monitoring landscape change Borehamwood: Hunting

INSTITUTE OF TERRESTRIAL ECOLOGY 1990 ITE Land Classification and its application to survey: an internal appraisal. Grange-over-Sands: Institute of Terrestrial ecology, Merlewood Research Station.

KISH, J. 1965 Survey sampling. Chichester: Wiley

LAVERS, C.J., HAINES-YOUNG, R.H. & AVERY, M.I. In press: The use of landscape models for assessment of bird populations in the Flow Country, Scotland. In: Landscape Ecology and Spatial Information

MACDONALD, D.W., BUNCE, R.G.H. & BACON, P.J. 1981 Fox populations, habitat characterisation and rabies control J. Biogeogr. 8 145-151

MARGULES, C.R. & USHER, M.B. 1984 Conservation evaluation in practice 1. sites of different habitats in North East Yorkshire Journal Environmental Management. 18 153-168
MARRS, R.H. In press. The effects of herbicide drift. British Crop Protection Council Weeds.

MARRS, R.H., RAWES, M., ROBINSON, J.S. & POPPITT, S.D. 1986 Long-term studies of vegetation change at Moor House NNR: guide to recording methods and the database. (Merlewood Research & Development paper no 109) Grange-over-Sands: Institute of Terrestrial Ecology

MCARTHUR, R.H. & WILSON, E.O. 1967 *The theory of island biogeography Princeton: Princeton* University Press

MCCARTNEY, H.A. 1990 Dispersal mechanisms through the air In: R.G.H. Bunce & D.C. Howard Dispersal in agricultural habitats p 133-158 London: Belhaven

MILES, J. 1988 Vegetation and soil change in the uplands In: Ecological change in the uplands Ed M.B. Usher & D.B.A. Thompson p 570-71 Special Publication no 7 of the British Ecological Society Oxford: Blackwell

MILES, J. 1985 The pedogenic effects of different species and vegetation types and the implications of succession. Journal of Soil Science 36 571-584

MILLER, G.R., MILES, J., HEAL, O.W. 1984 Moorland Management: a study of Exmoor Institute of Terrestrial Ecology

MITCHELL, C.P., BRANDON, O.H., BUNCE R.G.H., BARR, C.J., TRANTER, R.B., DOWNING, P., PEARCE, M.L. & WHITTAKER, H.A. 1983 Land availability for production of wood energy in Britain In: Energy from biomass Ed A. Strub, P. Chartier & G. Schlesser 159-163 (2nd E C Conference Berlin 1982) London: Applied Sciences

NRSC 1990 Satellite imagery and upland bird habitat. Fact sheet. Farnborough National Remote Sensing Centre

PARRY, M.L. 1977 Mapping moorland change - a framework for land use decisions in the Peak District. Bakewell: Peak Park Joint Planning Board

PETERKEN, G.F. & JONES, E.W. 1989 Forty years of change in Lady Park Wood: the young grwoth stands. Journal of Ecology 77 401-429

PIELOU, E.C. In Press. The different significance of biological diversity. Paper presented at the International Symposium on Biological Diversity, Madrid

POTTER, C.A. & GASSON, R. 1988 Conservation through land diversion: results from a survey. Journal of Agricultural Economics 39 (3) 340-351

POTTS, G.R. 1986 The partridge - pesticides, predation and conservation. London: Collins

QUEEN, R. *1990 Environmental information and personal choice in* land use changes in marginal areas. PhD thesis, University of Lancaster

SHANNON, C.E. & WEAVER, W. 1963 The mathematical theory of communication. Illinois: University of Illinois Press

SHARPE, D.M. & FIELDS, D.E. 1982 Integrating the effect of climate and seed fall velocity in seed dispersal by wind: a model and application Ecological Modelling 17 297-310

SHARROCKS, J.T.R. 1976 Atlas of Breeding Birds In Britain and Ireland Berkhamsted: Poyser

SHOARD, M. 1980 The theft of the countryside. Hounslow: Smith

SHREIBER, K.F. 1988 Connectivity in Landscape Ecology. Proceedings of the 2nd International Seminar of the International Association of Landscape Ecology Paderborn: Schoningh

SIMPSON, C.G. 1964 Species diversity in North America recent mammals. Systematic Zoology 13 57-73

SMITH, R.S. 1988 Farming and conservation of traditional hay meadows in the Pennine Dales Environmentally Sensitive Area. In: Ecological Change in Uplands. Ed M.B. Usher & D.B.A. Thompson - p 183-201. Special Publication no 7 of the British Society Oxford: Blackwell

SPEDDING, C. 1988 Land use change in Britain. In: Changing Land Use and Recreation Ed H. Talbot-Ponsonby CRRAG

SYKES, J.M., HORRILL, A.D. & MOUNTFORD, M.D. 1983 Use of visual cover assessment as quantitive estimates of some British woodland taxa. Journal of Ecology 71 437-450

TRANTER R.B., JONES P.J. & MILLER F.A. 1988 Some socio-economic characteristics of farmers and their farm businesses in GB by ecological zone as categorised by the ITE land classification system. Report to ITE for the Ecological Consequences of Land Use Change Project Reading: Centre for Agricultural Strategy University of Reading

TRANTER, R.B., JONES, P.J. & MILLER, F.A. 1988. The potential for alternative crops for Great Britain with likely social, economic and ecological consequences Reading: Centre for Agricultural Policy, University of Reading

THOMAS, A.S. 1963 Further changes in vegetation since the advent of myxomatosis. Journal of Ecology 51 141-186

USHER, M.B. 1986 Wildlife conservation and evaluation. London: Chapman & Hall.

VAN DORP D. & VAN GROENENDAEL 1991 Dispersal of seeds, a key factor in the regeneration of species rich grasslands. In: Proceedings of the European IALE Seminar on Practical Landscape Ecology p 99-105 Roskilde: Roskilde University Centre

VERKAAR, H.J. Corridors as a tool for plant species conservation? In: Bunce, R.G.H. & HOWARD, D.C. Species dispersal in Agricultural Habitat London: Belhaven

WARNOCK, S. & BELL, M. 1987 Likely farmer response in the hills and uplands: results of a survey based on the ITE sample framework In: Farm extensification: implications of EC regulations 1760-87 Ed N.R. Jenkins & M. Bell (Merlewood R&D paper no 112) Grange-over-Sands Institute of Terrestrial Ecology

WATSON, A. 1988 Land use, reduction of heather, and natural tree regeneration on open land. Annual Report Institute of Terrestrial Ecology 1988/9

WATSON, A., MOSS, R., ROTHERY, P., PARR, R. & WATSON, A. 1984 Demographic causes and predictive models of population fluctuations in red grouse J Animal Ecology 13 639-662

WATT, A.S. 1955 *Bracken versus Heather. Journal of* Ecology 43 490-506

WEBB, N.R. 1986 Heathlands. London: Collins

WELLS, T.C.E, COX, R. & FROST, A. 1989 The establishment and management of wildflower meadows (Focus on Nature Conservation No 21) Peterborough: Nature Conservancy Council

WELLS, T.C.E., BELL, S. & FROST, A. 1981 Creating attractive grassland using native plant species Shrewsbury: Nature Conservancy Council

WILLIAMS, M.L., ATKINS, D.H.F., BOWER, J.S., CAMPBELL, G.W., IRWIN, J.G. & SIMPSON, D. 1989 A preliminary assessment of the air pollution of the UK. Stevenage: Warren Spring Laboratory

WRATTEN, S.D. & THOMAS, C.F.G. 1990. Farm-scale spatial dynamics of predators and parasitoids in agricultural landscapes In: Bunce & Howard, Species dispersal in agricultural habitats, p 219-237 London: Belhaven

WRIGHT, J.F., ARMITAGE, P.D., FURSE, M.T. & MOSS, D. 1989 Prediction of invertebrate communities using stream measurement Regulated Rivers: Research and Management Vol 4 147-155

APPENDIX I

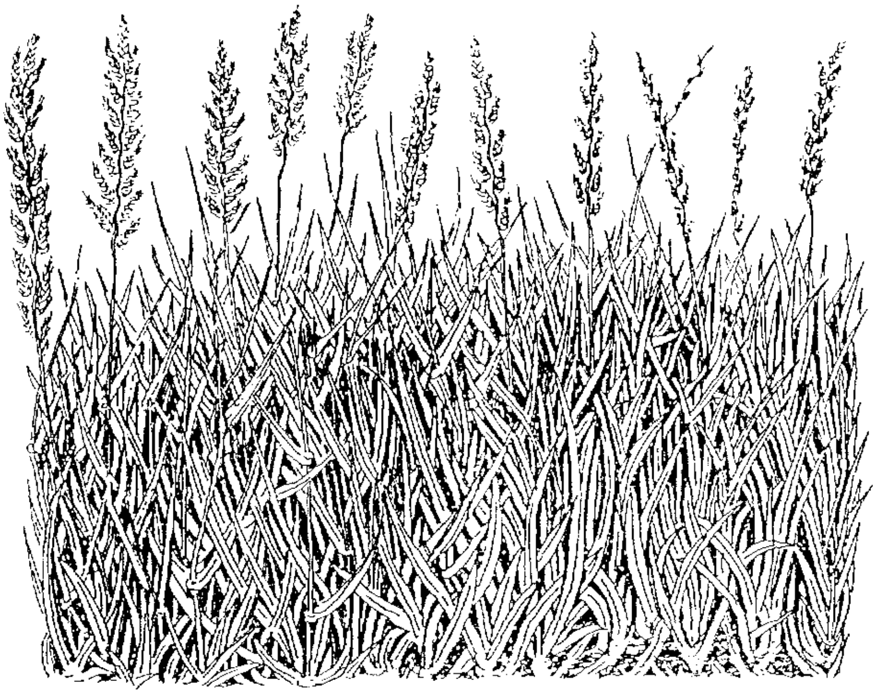
DESCRIPTION OF THE AGRICULTURAL INTENSITY CATEGORY

LEYS

L1 Very intensive Ley: highly productive grass species, either Italian or perennial rye grass, managed as a short duration ley on a 1 to 3 year rotation. Heavy fertiliser and slurry applications are normally integrated with a rigorous herbicide regime. Zero grazing is usual with several cuts for silage each season. Few or no broadleaved plants occur in such grassland monocultures managed for high yield through minimum diversity and maximum production.

L2 Intensive Ley: pastures dominated mainly by perennial rye grass or other productive forage grasses such as cocksfoot and timothy, but with a small number of arable weeds, such as plantains, dandelions, chickweeds, thistles and docks, beginning to colonise following the reseeding process. Perennial rye grass has become ubiquitous in longer leys and intensive permanent pastures nationwide because it is a grass which responds well to fertilisers, sets seed well and stands heavy grazing and regular cutting. Mainly used for silage with several cuts per year, but also occasionally for hay and paddock grazing.

L3 Semi-intensive Ley: considerable difficulty is encountered in separating the older leys from highly improved grasslands, mainly P2, and to a lesser extent P1, although the latter will generally have fewer broad-leaved species. The duration of this ley is taken as five years for this study. Apart from rye grass and other forage grasses, some secondary colonisers appear, eg. red clover, yorkshire fog, and meadow grass. Management includes fertiliser and slurry applications but not in such high quantities as those on L1 or L2. This category is mainly used for silage but is also cut for hay and/or grazed.



L1

L2

L3

PERMANENT PASTURES

P1 Intensive Permanent Pasture: a trend in lowland grassland management is to use fertiliser or slurry and herbicides to increase the production of old grasslands without reseeding. In terms of the common grass species this category is comparable with L1 and L2, and differs only with respect to reseeding which may occur on a longer rotation, eg. 10 years. Botanically it contains very few species but may have a more varied population of invertebrates. It is mainly used for silage with several cuts a year but hay is also common.

P2 Semi-intensive Permanent Pasture: although productive grass species still predominate, a wide range of broad-leaved species, mainly arable weeds but also some of the more persistent meadow species, are present, eg. daisies, speedwells, dandelions, creeping buttercup, common mouse-ear, and a number of secondary grassland colonisers, eg. soft brome and smooth meadow grass. Swards in this category may also have a substantial proportion of white clover as leguminous nitrogen fixation replaces inorganic dressings. This land is mainly used for hay but some silage is produced or it is utilised for grazing only. Management includes some fertiliser or slurry and farmyard manure dressings.

P3 Low-intensity Permanent Pasture: often termed unimproved grassland with little or no applications of farmyard manure. Usually grazed or cut or hay. Increasing number of sensitive broad-leaved species, eg. yarrow, meadow buttercup and self-heal and a more mixed assemblage of native grasses, eg. meadow fox-tail, crested dogs tail, sweet-vernal grass, and oat grass. The range of plants in such grasslands will vary with soils, drainage and management. Some swards may have a high proportion of the more traditional forage grasses such as crested dog's tail. There such grasses occur with less than 25% perennial rye grass it is assumed that they form part of an unimproved sward.

P1

P2

P3

Further divisions within P3

P3 Herb-rich Grassland: this scarce category includes grassland with a relatively high species richness. P3H includes calcareous grassland, with a possible density of up to 30 or 40 species within a m2, associated with limestone or chalk. Relatively herb-rich swards also occur on a range of neutral soils and other sites characterised by meadow species such as ragged robin, knapweed, bush vetch, hawk's beards, cuckoo flower and meadow vetchling. The management of such swards involves traditional systems of grazing, hay cutting and, in some areas, burning. Herb-rich swards have generally evolved over a long period of time without the imposition of inorganic fertilisers or pesticides.

P3A Abandoned/Unmanaged Grassland: this category is often found in areas which have seen a transition from mixed farming to arable farming and so occurs where the operation of agricultural machinery is impractical such as field corners and steep slopes. Neglected grassland is also common on vacant land on the urban fringe. Such areas of tussocky grass may harbour a bank or local flora if excluded from spraying regimes. Even a few species of grass allowed to grow unhindered may provide a valuable habitat for small mammals and phytophagous invertebrates.

P3M Maritime Grass: indicates unimproved grasslands in coastal situations which are often herb-rich with some maritime species different in composition according to the site which maybe cliff- top, sand dune or shingle ridge. These grasslands are usually grazed and rarely harvested for forage.

P3F Fen: eutrophic or mesotrophic, neutral or base-rich peatland dominated by sedges or rushes and characterised by tall herbs such as hairy willow herb, hempagrimony, meadow sweet and yellow flag. Traditional management may be for sedge cutting and grazing.

P3S Marsh and Wet Grassland: nutrient rich wetland on predominately mineral soil dominated by rushes or sedges. Usually grazed during the drier months in the year to avoid damage by poaching.

P3C Saltmarsh: areas or flat poorly drained coastal vegetaion wholly or partially inundated by most high tides. Distinctive plant communities occur at different levels above the tide marks. High saltmarsh often forms a sward dominated by red fescur and creeping bent. Usual management includes cattle or sheep grazing.

ROUGH GRAZING

Generally occurs in upland areas and typified by extensive sheep grazing and some beef cattle. There are also low densities of wild deer and ponies in some areas.

R1 Upland Grass: unimproved grassland on a mineral soil. A sward of native grasses with a high proportion of palatable grass species such as sheep's fescur and bent grasses typical of upland rough grazing.

R2 Moorland Grass: poor quality grassland in a moorland setting, usually dominated by unpalatable species typically purple moor grass and mat grass. Soils often have organic upper horizons.

R3 Moorland Shrub Heath: dominated by heather with other dwarf shrub species, often on peat. Typical of the drier moorlands of NE England where well-drained podzolic soils support a vigorous heather. Heather is also common on the wetter moorland in the west but typically with reduced dominance in association with blanket peat communities.

Further Divisions within Rough Grazing

R1B Bracken: areas dominated by bracken and pastures with a substantial cover of bracken.

R1R Wet Upland Grass: upland grass with a substantial proportion of rushes (>25%) in areas of poor drainage and/or heavy rainfall.

R1F Calcareous Flush: a localised narrow, areas of moving water characterised by water parsnip, self-heal and grass of parnassus.

R2F Non-Calcareous Flush: usually dominated by rushes and often with sphagnum.

R2L Lowland Heath: vegetation characteristic of low fertility, acidic soils dominated by small-leaved ericoid species forming dwarf shrub vegetation at low altitude (<210m). Dominant species bell heather, ling, cross leaved heath and dwarf gorses. Today these areas are rarely used for agricultural grazing except in the New Forest where cattle and horses graze in considerable numbers.

R3P Burnt: areas of land which have been burnt in the process of vegetation management, eg. burnt moorland associated with heather management on grouse moors.

R3V Moorland Shrub Heath: as R3 but bilberry is the dominant dwarf shrub. This damp moorland occurs on north-facing slopes and the cool moorland in NW England and Scotland in exposed situations often with birch woodland and scrub. Often in association with a deep layer of mosses and an appreciable amount of heather.

R3W Bog: an area of wet acid peat substrate rich in organic debris but low in mineral nutrients with a vegetation of ericaceous shrubs, sedges and mosses. Deer grass and cotton grass are often dominant.

R1

R2

R3

Paper: CSS 90/9

INSTITUTE OF TERRESTRIAL ECOLOGY
(NATURAL ENVIRONMENT RESEARCH COUNCIL)

Project T02051e1
DOE/NERC Contract PECD 7/2/40 (F3CR05/D6/05)

Reports arising from the project 'Ecological consequences of land use change' (ECOLUC)

Merlewood Research Station
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February 1991

List of reports arising from the DOE-sponsored project entitled 'Ecological consequences of land use change' (ECOLUC)

Bunce, R.G.H. & Howard, D.C. 1990
Geographical information systems for planning in ecology.
(Merlewood Research and Development Paper no. 114.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Bunce, R.G.H. & Howard, D.C. 1990.
Species dispersal in agricultural habitats.
London: Belhaven Press.

Cresswell, P., Harris, S. & Jefferies, D.J. 1990.
The history, distribution status and habitat requirements of the badger in Britain.
Peterborough: Nature Conservancy Council.

Edwards, D. 1988
Existing and potential recreation and tourist activities in the ITE squares. Draft final report.
Reading: University of Reading.

Edwards, D. & Tranter, R.B. 1990.
Existing and potential countryside recreation and tourism activities and their ecological consequences: a preliminary assessment based on the ITE land classification system.
Reading: Centre for Agricultural Strategy, University of Reading.

Griffiths, G.H. & Williams, C. 1990
The impact of land-use change on aquatic communities in mapping land cover change in water catchments from satellite imagery.
Farnborough: National Remote Sensing Centre.

Griffiths, G.H. & Wooding, M.G. 1989.
Use of satellite data for the preparation of land cover maps and statistics. Volume 1. Main report.
Farnborough: National Remote Sensing Centre.

Griffiths, G.H., Wooding, M.G. & Smith, J.M. 1990.
Ecological consequences of land use change. Volume II. Use of satellite data for the preparation of land cover maps and statistics. (Final report to the Department of the Environment.)
Farnborough: National Remote Sensing Centre.

Haines-Young, R.H. 1990.
A proto-type expert system for the landscape manager. (Report to the Institute of Terrestrial Ecology.)
Nottingham: University of Nottingham.

Haines-Young, R.H. 1990.
The use of remotely sensed data for the characterisation of linear landscape features. (Report to the Institute of Terrestrial Ecology.)
Nottingham: University of Nottingham.

Hallam, C.J. & Bunce, R.G.H. 1990.
Procedures for recording and analysing vegetation change - an example from Great Britain, 1978-1988. (Report to the Department of the Environment.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Hodgson, J.G. & Sutton, F. 1990.
Analysis of data from the ecological consequences of land use change project (ECOLUC).
Sheffield: Unit of Comparative Plant Ecology.

Howard, D.C. & Bunce, R.G.H. 1990.
The ecological consequences of land use change. GIS '90 symposium 'Making it work'. FRDA Report no. 107, 350-354.
Vancouver: Canada-British Columbia Forest Resource Development Agreement.

Hunting Technical Services Ltd. 1989.
Ecological consequences of land use change II: analysis of the monitoring landscape change project results. Final report.
Hemel Hempstead: Hunting Technical Services Ltd.

Institute of Terrestrial Ecology. 1990.
ITE land classification and its application to survey: an internal approach.
Grange-over-Sands: ITE.

Jeffers, J.N.R. 1990.
The ECOLUC knowledge-based system. (Report to the Institute of Terrestrial Ecology.)
Grange-over-Sands: J N R Jeffers.

Jenkins, N.R., Tranter, R.B. & Rehman, T. 1989.
The ecological consequences of a less-intensive agriculture: some results from the Reading Linear Programming Model of agriculture in England and Wales.
Reading: Centre for Agricultural Strategy.

Laurence Gould Consultants Ltd. 1989.
An estimate of future changes in land use. Link project for the changes in rural environment study.
Warwick: Laurence Gould Consultants Ltd.

Oxford University. 1990.
The ECOLUC knowledge based browsing system.
Oxford: University of Oxford.

Robertson, P.A., Woodburn, M.I.A., Tapper, S.C. & Stoate, C. 1989.
Estimating game densities in Britain from land-use maps.
Fordingbridge: the Game Conservancy.

Tranter, R.B., Jones, P.J. & Miller, F.A. 1988.
Some socio-economic characteristics of farmers and their farm businesses in GB by ecological zone as categorised by the ITE land classification system.
Reading: Centre for Agricultural Strategy, University of Reading.

Tranter, R.B., Tayler, R.S. & Jones, P.J. 1989.
The potential for alternative crops for GB agriculture with likely social, economic and ecological consequences.
Reading: Centre for Agricultural Strategy, University of Reading.

Wallace, H.L. & Prosser, M.V. 1990.
Standardisation of recording of vegetation change. (Report to the Institute of Terrestrial Ecology.)
Bangor: Ecological Surveys.

Whitfield, W.A.D. 1987.
Validation and appraisal of soil and agroclimatic information for ITE sample areas.
Silsoe: Soil Survey and Land Research Centre.

Woiwod, I. 1990.
The relationship between moth diversity and ITE land classes.
Harpenden: Dept of Entomology, Rothamsted Experimental Station.

Wye College. 1990.
Ecological consequences of land use change - identification of 'set-aside priority areas'. Application to the ITE sample squares.
Ashford: Wye College.

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Publications arising from studies using the ITE land classification

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List of publications arising from studies using the ITE land classification

Aberdeen Centre for Land Use. 1989.
Environmental issues and agricultural land use options in Devon.
Aberdeen: Aberdeen Centre for Land Use.

Barr, C.J., Benefield, C.B., Bunce, R.G.H., Ridsdale, H.A. & Whittaker, M. 1986.
Landscape changes in Britain.
Abbots Ripton: Institute of Terrestrial Ecology.

Bell, B.G., Murray, T.D., Howard, D.C. & Bunce, R.G.H. 1989.
The environmental constraints on the UK resource for wind energy.
(NERC contract report to the Energy Technology Support Unit.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Benefield, C.B. & Bunce, R.G.H. 1982.
A preliminary visual presentation of land classes in Britain.
(Merlewood Research and Development paper no. 91.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Bignall, E.M., Curtis, D.J. & Mathews, J. 1988.
Islay: land types, bird habitats and nature conservation. Part I. Land types and birds on Islay.
Peterborough: Nature Conservancy Council.

Blazye, C.J. 1987.
The ITE land classification as ancillary data to image classification.
In: *Proceedings of the 13th Annual Conference of the Remote Sensing Society.*
Nottingham: University of Nottingham.

Blazye, C.J. 1990.
Land cover survey for landscape and land use monitoring: an examination of the ITE approach. (PhD thesis.)
Nottingham: University of Nottingham.

Bull, K.R. & Hall, J.R. 1989.
Classification and comparison of river and lake catchments. (NERC contract report to the Department of Environment.)
Abbots Ripton: Institute of Terrestrial Ecology.

Bunce, R.G.H. 1986.
The Cumbrian environment - an overview. In: *Pollution in Cumbria*, edited by P. Ineson, 38-41.
Grange-over-Sands: Institute of Terrestrial Ecology.

Bunce, R.G.H., ed. 1989.
Heather in England and Wales (ITE research publication no. 3.)
London: HMSO.

Bunce, R.G.H. & Barr, C.J. 1987.
The extent of land under different management regimes in the uplands and the potential for change. In: *Ecological change in the uplands*, edited by M.B. Usher & D.B.A. Thompson, 415-426. (British Ecological Society special publication no. 7.)
Oxford: Blackwell Scientific.

Bunce, R.G.H. & Heal, O.W. 1984.
Landscape evaluation and the impact of changing land use on the rural environment: the problem and an approach. In: *Planning and ecology*, edited by R.D. Roberts & T.M. Roberts.
London: Chapman and Hall.

Bunce, R.G.H. & Smith, R.S. 1978.
An ecological survey of Cumbria.
Kendal: Cumbria County Council & Lake District Special Planning Board.

Bunce, R.G.H., Barr, C.J. & Whittaker, H.A. 1981.
The land classes of Great Britain: preliminary descriptions for users of the Merlewood method of land classification. (Merlewood Research and Development paper no. 86.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Bunce, R.G.H., Barr, C.J., Whittaker, H.A., Mitchell, C.P. & Pearce, M.L. 1983.
Estimates of present forest cover in Great Britain. In: *Energy from biomass*, edited by A. Strub, P. Chartier & G. Schleser, 186-189.
London: Applied Science.

Bunce, R.G.H., Morrell, S.K. & Stel, H.E. 1975.
The application of multivariate analysis to regional survey.
Journal of Environmental Management, 3, 151-165.

Burt, J. 1985.
An assessment of stratified sampling for use in strategic urban planning: a study of land use in Greater London. (MSc thesis.)
London: Centre for Environmental Technology, Imperial College.

Charter, E. 1984.
A survey, classification and evaluation of small open water in Cumbria. (MSc thesis.)
London: University of London.

Cooper, A. 1986.
The Northern Ireland land classification. (Report to the Countryside and Wildlife Branch of the Department of the Environment for Northern Ireland.)
Coleraine: University of Ulster.

Cresswell, P., Harris, S., Bunce, R.G.H. & Jefferies, D.J. 1989.
The badger in Britain: present status and future population changes.
Journal of the Linnean Society, 38, 91-101.

Dartington Institute. 1987.
The potential for forestry in the Culm Measures farms of south-west England.
Dartington: Dartington Institute.

Dartington Institute. 1989.
Forestry on British farmland: an economic comparison. (Report to the Ministry of Agriculture, Fisheries and Food.)
Dartington: Dartington Institute.

Derwent, R.G., Pollard, G.J. & Metcalfe, S.E. 1988.
On the nitrogen budget for the United Kingdom and north-west Europe.
Quarterly Journal of the Royal Meteorological Society, 114, 1127-1152.

Edwards, S.J., Thomson, A.E., Hughes, M.G.B. & Porteous, A.E. 1982.
An ecological classification of the Strathclyde Region. (Contract report.)
Balloch: Nature Conservancy Council.

Elena Rossello, R., Carreteo, P. & Sanchez-Pollomares, O. 1985.
Classificacion terretorial del Pirineo y prepireno Navarros.
(Communicaciones I.N.I.A. Ser. Recurros Naturales no. 39.)
Madrid: I.N.I.A.

Elena Rossello, R., Tella, G., Allue, J.L. & Sanchez-Pollomares, O. 1990.
Classificacion biogeoclimatatica terretorial de Espana: definicion de ecoregiones.
Revue Ecologia.

Fowler, D. 1988.
Nitric oxide and nitrogen dioxide concentrations in rural areas of Europe. In: *Pollution climates in Europe and the interception by the terrestrial ecosystem,* 11-23. (Air pollution research reports no. 6.)
Luxembourg: Commission of European Communities.

Fuller, R.M. 1987.
The changing extent and conservation interest of lowland grasslands in England and Wales: a review of grassland surveys 1930-84.
Biological Conservation, **40,** 281-300.

Furze, M.T. 1991.
The relationship between freshwater macro-invertebrate assemblages and the ITE land classification. (NERC contract report to the Department of the Environment.)
Wareham: Institute of Freshwater Ecology.

Green, B.H. & Burnham, C.P. 1989.
Environmental opportunities offered by surplus agricultural production. In: *Biological habitat reconstruction,* edited by G.P. Buckley, 92-101.
London: Belhaven.

Griffiths, G.H., Wooding, M.G., Jewell, N. & Batts, H.A. 1988.
Use of satellite data for the preparation of land cover maps and statistics. (Report to the Department of the Environment).
Farnborough: National Remote Sensing Centre.

Hallam, C.J. & Bunce, R.G.H. 1991.
Procedures for recording and analysing vegetation change - an example from GB 1978-88. (Internal report to the Department of the Environment.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Harvey, D.R., Barr, C.J., Bell, M., Bunce, R.G.H., Edwards, D., Errington, A.J., Jollans, J.L., McClintock, J.H., Thompson, A.M.M. & Tranter, R.B. 1986.

Countryside implications for England and Wales of possible changes in the CAP.
Reading: Centre for Agricultural Strategy.

Highland Regional Council. 1984.
Highland Region/ITE land classification system. (Planning Department information paper no. 5.)
Inverness: Highland Regional Council.

Hopkins, A., Wainwright, J., Murray, P.J., Bowling, P.J. & Webb, M. 1988.
1986 survey of upland grassland in England and Wales: changes in age structure and botanical compositon since 1970-82 in relation to grassland management and physical features.
Grass and Forage Science, **43**, 185-198.

Horrill, A.D. 1989.
The distribution and fate of radionuclides from Chernobyl in vegetation in Britain.
Annual Report of the Institute of Terrestrial Ecology 1986-87, 57-58.

Horrill, A.D., Lowe, V.P.W. & Howson, G.H. 1988.
Chernobyl fallout in Great Britain. (NERC contract report to the Department of Environment.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Jenkins, N.R. 1991.
Ecological implications of lowering the intensity of agriculture.
Agriculture and the Environment Special Topic.

Land Use Research Group. 1990.
The ITE land classification and its application to survey: an internal appraisal. (Internal report.)
Grange-over-Sands: Institute of Terrestrial Ecology.

Macdonald, D.W., Bunce, R.G.H. & Bacon, P.J. 1981.
Fox populations, habitat characterisation and rabies control.
Journal of Biogeography, **8**, 145-151.

Mitchell, C.P., Tranter, R.B., Downing, P., Brandon, O., Pearce, M.L., Bunce, R.G.H. & Barr, C.J. 1987.
Growing wood for energy in Great Britain. (Report to the Energy Technology Support Unit.)
Harwell: Energy Technology Support Unit.

O'Connor, R.J. 1985.
Long-term monitoring of British bird populations: Proceedings of Symposium on birds as environmental indicators, Kusamo, Finland. *Ornis fennica,* **62**, 73-79.

Queen, R. 1991.
Environmental information and personal choice in land use changes in marginal areas. (PhD thesis.)
Lancaster: University of Lancaster.

Spedding, C. 1988.
Land use change in Britain. In: *Changing land use and recreation,* edited by H. Talbot-Ponsonby. London: Countryside Recreation Research Advisory Group.

Tomlinson, R. 1981.
A rapid sampling technique suitable for expedition use with reference to the vegetation of the Faroe Islands.
Biological Conservation, **20**, 69-81.

Tranter, R.B., Jones, P.J. & Miller, F.A. 1989.
Some socio-economic characteristics of farmers and their farm businesses in GB by ecological zones as characterized by the ITE land classification system.
Reading: Centre for Agricultural Strategy.

Warnock, S. & Bell, M. 1987.
Likely farmer response in the hills and uplands: results of a survey based on the ITE sample framework. In: *Farm extensification: implications of EC Regulation 1760/87,* edited by N.R. Jenkins & M. Bell. (Merlewood Research and Development paper no. 112.)
Grange-over-Sands: Institute of Terrestrial Ecology.