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THE SURVEY AND CLASSIFICATION OF UPLAND AREAS FOR LAND MANAGEMENT STUDIES - A REVIEW

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1. Introduction

There is a range of ecological options for the use of any area. A tract of upland might, for example, be used most wisely as grazing land under existing or newly-domesticated herbivores (staff of the Rowett Research Institute and the former Nature Conservancy have demonstrated that Scottish Red deer are not to be despised as meat producers on coarse West Highland ranges); as land most likely to be productive under trees; as land whose productivity of grasses palatable to stock can be improved; as land remarkable for its biological features and accordingly meriting conservation for wild life or public enjoyment; as land likely to erode and deteriorate still further if changed in any way; or as land so run down by mismanagement as to need a century or so under natural woodland or herbage for its soils to recover; or some combination of these and other uses might be feasible. Such options can be stated by ecologists. (ITE Report 1974).

The obvious limitation on the possible uses of land by the physical and biological characteristics of the land itself creates the need to differentiate and classify segments of the land surface with reference to such characteristics, so that land use planning and management can proceed on a basis of ecological understanding as well as taking into account technological, economic, and social issues. It is also desirable that we should be able to predict the nature and extent of the effects of different land use policies on soils, vegetation, and wildlife. Trees, agricultural crops, water, and wildlife are renewable resources that derive from the land, and they interact. The productivity of any of these resources, the nature of the interactions, as well as the aesthetic and recreational potential of land, varies in space and time, depending on both the characteristics of the land itself and on man's influence.

There are many possible approaches to land classification, these are discussed in Section 2 as classifications of land per se and as classifications for specific purposes. Most of the latter require detailed information (e.g. on soils) which is not available for most upland areas of England and Wales. Where the interest is in classification for agriculture or forestry, an alternative approach is to identify the current forms of land use. For most upland areas, such information is more readily obtained than is information on the soils. Munro (1974) considered that inadequate attention had been paid to surveying the potential of the hills and uplands of the United Kingdom. The last published survey of the hill grasslands of England and Wales was carried out by Stapledon and Davies (1940), while Scotland has never been adequately covered. In 1965, the Second Land Utilisation Survey (Kings College London) mapped some aspects of natural vegetation in the uplands of England and Wales. Publication of the Second Land Utilisation Survey maps has been only partially completed, and the results and implications for planning have been discussed by Coleman (1976). In that survey, land that is not improved farmland is mainly in the categories Woodland or Heath, Moorland, and Rough land.

The Second Land Utilisation Survey also made a survey of vegetation in 29 classes, each of which is a vegetation community and may be related to land use potential. The object was to produce a Wildscape Atlas of England and Wales; "Wildscape is mountain and moorland, heath and coast, bog and fen, ... In this country they (the areas) are more often semi-natural than natural, but nevertheless they are the closest to nature of all British landscapes" (Coleman, 1970). Unfortunately, financial constraints have prevented the publication of all but a sample page for Wensleydale.

Land use has often been described in terms of the appearance of its vegetative cover. Thus, the term 'grassland' has been used rather than 'enclosed and managed grazing land', and 'heathland' rather than 'land used as rough grazing' or 'to provide food for game'. In the widest sense, land use also includes the way in which the land is held and the size of units; the structures erected upon it (Coppock, 1970).

Land use data can only be evaluated, certainly as 'potential' or 'capability' measures, in respect of some defined purpose, and should be given with stated levels of accuracy. Accuracy can be thought of in two senses, the quality of the information recorded, i.e. whether it is a correct description of the land using activity, and correct location (Coppock, 1970). Data can be evaluated from what is known about the method by which they were collected; they can be analysed for internal consistency; they can be subjected to field checks.

Coppock (1970) stated that none of the British sources of land use data is wholly satisfactory, and there are notable gaps in the availability of information. Most detailed data relate only to the area under different uses, records of inputs and outputs are available only on a much broader scale and information on structures and tenure is quite inadequate and is often seriously out of date. With the exception of the two privately-organized land use surveys directed respectively by Sir Dudley Stamp and Miss A. Coleman, the sources are partial and rarely compatible. Probably the most accurate records are those of State forests kept by the Forestry Commission. Except in so far as information on woodlands is shown on Ordnance Survey maps and on those of the two land use surveys, all of which have been recorded over a period of years, data on private woodland are much less satisfactory. It is particularly true that uplands are very inadequately differentiated on land use surveys.

A National Land Use Classification was published in 1975 by H.M.S.O.

The classification consists of four tiers of land use names ranging from the Order at the top down through Group and Sub-Group to the Class at the bottom. The na4es in the Order tier are very general terms which are developed in greater detail at each successively lower level. For example, Agriculture and Fisheries form Order AG, non-cultivated places form Group 08 which is divided into Sub-Group A (grazing places) and Sub-Group B (forestry places). Grazing places are sub-divided into Class A (permanent pasture) and Class B (rough grazing), while there are six Classes for forestry. The classification does not appear to have been accompanied by a survey.

Current land use is influenced by external pressures as well as by the capability of the area. As Ball (1964) pointed out, the vast post-war change of land use from grass to arable on the chalk lands would hardly have been predicted from a land-use map, but might well be suggested by considerations of soil distribution. However, the land-use map existed and the soil map did not, and for the greater part of England and Wales still does not, exist.

Statham (1972) made a study of the North York Moors. In this area, the predominantly dry but exposed climatic conditions allow a greater flexibility for cropping and cultivation, including arable, than in other British uplands. For the purposes of his study, Statham divided land use activities into three main groups:

1. Primary: activities for which land is primarily managed.

2. Secondary: subsidiary activities in a multi-use system where land is managed primarily for another activity.

3. Tertiary: unlike primary and secondary activities, which are resource based, these activities are the social and cultural expressions of human exploitation of the resources reflected in the population distribution, i.e., e.g. settlement, services, employment.

A three-stage process was involved:

1. Classification of the study area into grades for each main sector of activities. For ease of comparison five main grades were used with a few sub-divisions.

2. Compilation of composite maps to examine the possible patterns of optimum uses under a range of weightings and to identify conflict and opportunity areas.

3. A more detailed analysis of the main conflict areas.

The adoption of criteria for classification and evaluation depended partly on the information available and partly on professional advice and judgement. Where possible, evaluations were made in an objective and quantified form, but it usually proved necessary to resort to subjective judgements. The process was, however, systematic throughout, and since only relative comparisons were being made, simple subjective assessments were thought to be sufficient.

Statham (1972) drew attention to the marked dichotomy in land management in uplands and lowlands. Lowland is typified by intensive husbandry with careful attention to soil maintenance and enhancement, whilst upland is characterised by extensive pasturalism without soil conservation. Although some might argue that soil maintenance in lowlands has not been as careful as it might have been, the contrast pointed out by Statham certainly exists.

Upland cultivation was once more extensive than it is today, and abandoned farmland is now widely distributed in the foothills of British uplands (Parry, 1976). Evidence for such abandonment is often reported incidentally in ecological and historical studies, but there has been no comprehensive survey of abandoned farmland in Britain. The distribution of former tillage now lying under rough pasture may well delimit hill land that would reward reclamation in the future, thus giving some idea of the potential for improvement. Parry (1976) outlined a method for the mapping of abandoned farmland, illustrated by reference to former cultivation in the Lammermuir Hills in south-east Scotland. About 21% of present moorland in those hills was once improved, but has since reverted, 9% being abandoned before 1860 and 12% during the last century. In another area, Nidderdale (west Yorkshire, between Malham and Ripon), Tinsley (1975) stated that the contraction in upland farms has continued into this century. Many deserted farmsteads near the limit of improved land testify to a formerly more intensive use of the moors.

In the past, land use patterns in uplands evolved not only in response to the limitations of the environment, but also to changes in social organisation and economic and other forces imposed from outside (see, for example, Chapman, 1976). The land use patterns which result from such an interplay of factors may lead to deterioration of some areas or the improvement of others at quite a high price (Pritchard, 1969). The impact of land use on the land and landscape is discussed in Section 6. The future of the uplands is inevitably connected with overall developments in the rest of the country and the resulting pressures. An effective use of upland resources requires a rational base for planning, resting on sound factual knowledge of the physical characteristics and ecology of these areas.

The present paper reviews methods for classifying land (as land per se and in terms of possible uses), for capturing and handling the necessary data, and for interpreting the largely ecological data against the background of controlling factors, chiefly economic and political. The methods to be used in a particular study will depend on the objectives and scope of that study. The aim of this review is to outline the advantages and disadvantages of the methods which have been used, and to suggest methods which might prove useful but which have received little attention, in the hope that it will help researchers to decide which methods are most suitable for their purpose. The level of detail needed will depend upon the purpose of the study. More detail is required for the management of resources than for general planning purposes.

2. Land classification

There are many alternative approaches to land classification, they have been discussed by, among others, Stewart (1968) and Vink (1975). Broadly, the approaches may be divided into those which classify the land *per se* and those which classify it with respect to its suitability for some defined purpose. The former concentrate on the physical characteristics of the land, and include the various geomorphological approaches, 'terrain analysis' - a term used when the characteristics of the land are studied for military or engineering purposes - and classifications based on geology or distributions of soil types. Existing classifications in terms of suitabilities for specified uses are mostly agricultural, notably the agricultural soil capability classifications of the United States Department of Agriculture (U.S.D.A.) and the Soil Survey of England and Wales, and the Agricultural Land Classification of the Ministry of Agriculture, Fisheries and Food (M.A.F.F.). Also included are classifications for forestry, recreation and wildlife.

Most of these classifications are of the 'traditional' type. More recent numerical approaches which may be useful are discussed later.

It is worth noting that land inventories have been developed for planning purposes in the U.S.A. and Canada. They do not usually contain sufficient information to be used for management of specific areas.

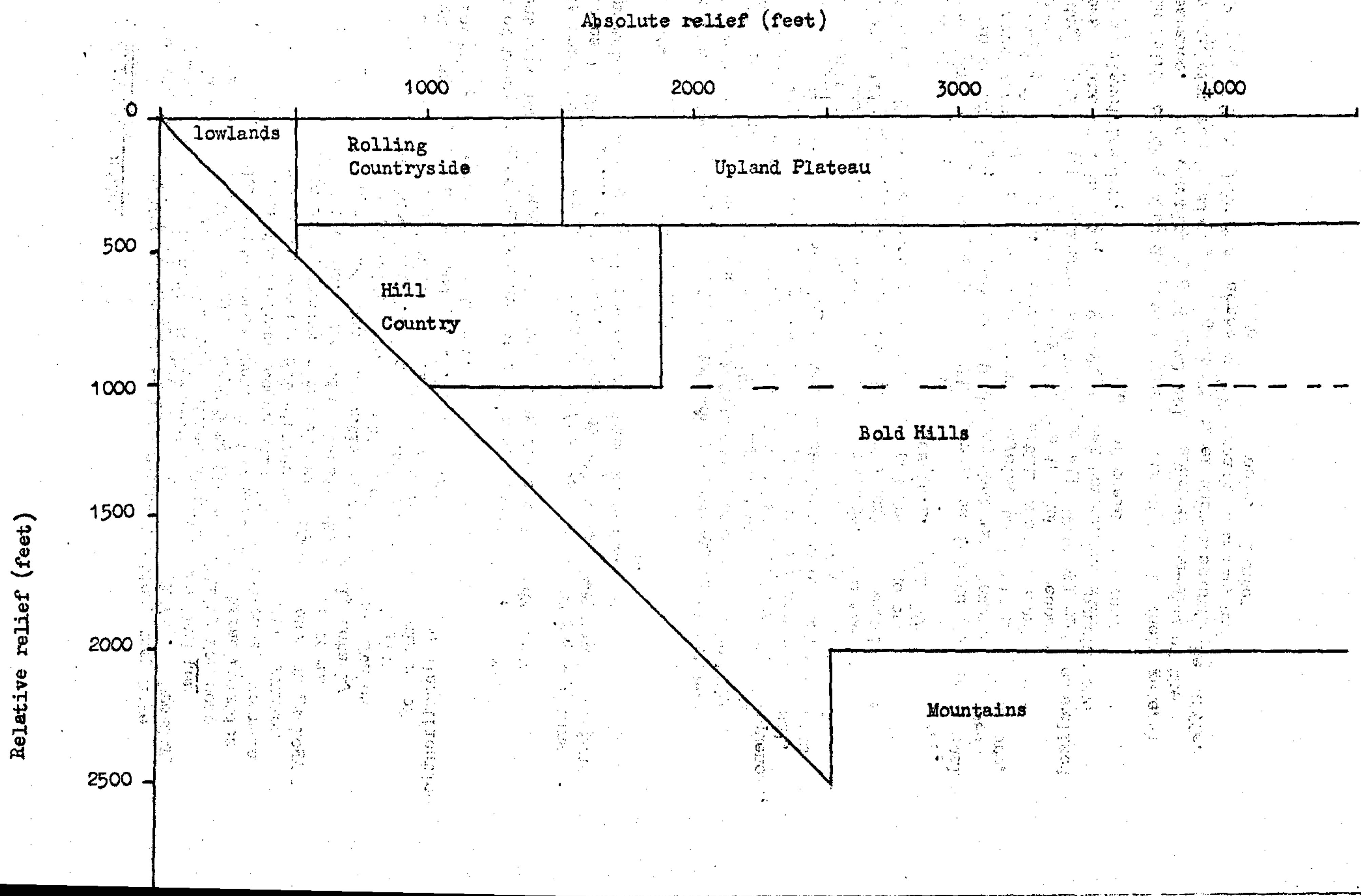
2.1 Classification of land *per se*

Most of the biophysical land classification schemes now in existence have their methodological bases in the attempts of early 20th century geographers, concerned with broad divisions of the earth's surface on a continental scale, to identify regions of physical similarity or uniqueness. Most are based on a genetic approach which seeks to underline the causal, developmental factors in arriving at the identification of distinct units of the earth's surface (Moss, 1975). Moss reviewed schemes that have been generally applied in various parts of the world. Many existing land classification systems have been developed for large continental land masses with large areas of uniform types (e.g. King, 1974).

Wright (1972) reviewed geomorphological approaches to land classification. He drew attention to the problem of deciding what is a taxonomic individual in landform studies. In quantitative analysis, the 'unit area' approach is commonly adopted, samples being taken within the framework of a uniform, arbitrarily-located, grid. Although there is much to recommend this approach, it has limitations for surveys of all but small tracts of country, because land character and regional boundaries will be generalized unless a fine grid is used. The problem of scale is a recurring one in land classification.

It is fairly evident that different upland areas differ in their general appearance. For example, the general relief characteristics of the Lake District and Snowdonia appear to be broadly similar, and they differ from, say, the Pennines and the North York Moors. Linton (1968)

Fig. 2.1.1 Classification of landforms based on absolute and relative relief



attempted a direct classification of Scottish 'landform landscapes' based on absolute and relative relief, i.e. the altitudinal difference between the highest and lowest points in a mapping unit. Six main categories were distinguished: (1) Lowland, generally below, but sometimes above, 500 feet. May be smooth and gently rolling or strongly accented; (2) Hill country, summit altitudes may range from as little as 600-800 feet up to 1600-1800 feet, but the relative relief is less than 1000 feet; (3) Bold hills, hill groups with steep slopes and stronger relative relief - usually in excess of 1200 feet - yet lacking the attributes of mountains; (4) Mountains, relative relief exceeding 2000 feet, isolated; (5) Plateau uplands, high areas of low relative relief - generally 300 feet or less; (6) Low uplands, areas below 1000 feet with low relative relief but which are morphologically upland.

These categories can be given subjective weighting in terms of 'scenic interest'. This approach was used in a study of countryside recreation in Lanarkshire (Duffield and Owen, 1970) and in a landscape analysis of Caernarvonshire (CCPD, undated), which is illustrated diagrammatically in Fig. 2.1.1. The class boundaries in the Figure should not be interpreted too rigidly.

The problem is to express such differences quantitatively. Techniques for morphometric analysis of landforms, with special reference to maps, are discussed in Slaymaker (1966). Of particular interest in that publication is a paper by Carson which examined the use of statistical techniques and the problems encountered by geomorphologists in trying to relate geomorphological features to a range of variables. However, none of the papers classified landforms. Various methods for examining landforms are discussed in King (1966), and Wright (1972).

Perhaps the most widely-known scheme is the land systems approach developed by the Division of Land Research and Regional Survey of the Australian Commonwealth Scientific and Industrial Research Organisation (C.S.I.R.O.). Somewhat later, the Oxford - MEXE (Military Engineering Experimental Establishment) group started with the need to store and collate information on terrain to guide the planning of engineering construction and military operations. These two groups and the National Institute for Road Research of C.S.I.R.O. in South Africa worked independently and yet evolved similar techniques.

The Oxford - MEXE group (Beckett and Webster 1965a, b, c) produced a system of terrain analysis which relies heavily upon air photo interpretation.

The categories used were: facet - the largest portion of terrain that can be conveniently treated as one block for purposes of moderately extensive land use or construction, facets may be delimited on air photographs at scales from 1:10 000 to 1:80 000 and should contain not more than one soil family or higher soil category (Brink et al, 1966); land elements, such as individual slope elements, make up the facets, and the facets in turn are grouped to make up land systems recognizable in cartographic form at scales from 1:250 000 to 1:1 000 000 (Webster and Beckett, 1970). Land systems are grouped into land regions, which are of the order of size that may be portrayed on maps of scale 1:1000 000 to 1:5 000 000.

A major problem in the classification of land form is the question of scale. Ball (pers. comm.) commented that using the units of Brink et al (1966), all of the western highland Britain is a land region, and land systems are probably distinguishable. However, there is a very great drop in area of the category at the facet level. Facets would be very small, although repeated across the landscape, and in most upland areas it would be difficult to see a facet as different from an element. Facets can be of dimensions of tens of metres or tens of kilometres. In practice, one can recognize units such as valley floors, concave valley sides, convex upper slopes, hill crests, but these often fall between the land system and facet as defined.

Speight (1968) attempted to set up a quantitative model of land form with special reference to erosional situations. Variables used to characterize land form elements were slope gradient, rate of change of slope gradient, contour curvature, and unit catchment area. For a test area of 3.7 sq km values of these variables were obtained from 1:2400 scale maps with contour interval 1.52 m. The investigation was confined to the mapping of formalized versions of a few commonly-accepted types of landform element that are distinguishable on the basis of form alone, in such a way that no point either failed to be assigned to an element or was assigned to more than one element, and that a reasonably comprehensive and consistent description of the total landscape was achieved. The study showed that, on a given set of definitions, mapping may proceed in a self-consistent way that allows of no ambiguity and permits the quantitative comparison of landscapes from place to place.

However, linear patterns appear to occur at a finer scale in the landscape than do areal patterns and may offer more chance of discrimination between land systems. Therefore, Speight also examined the following properties of land systems: ridginess, ridge reticulation, and ridge vector magnitude and orientation. These properties were assessed in sample areas of 4×10^6 sq ft, and maps were prepared to display the patterns of variation. The problems caused by the differences in scale of these two approaches seem to need further investigation.

Greysukh (1967) described a computer-oriented technique for identifying 6 classes of landform by the distribution of slope vectors around a point. From each point of known X, Y, Z co-ordinates, lines were drawn connecting it to a ring of adjacent points. The pattern assumed by a diagram of slope versus azimuth was then taken as diagnostic. Experimental results were not given, but it seems clear that problems of scale also arise in this method.

These so-called 'parametric' descriptions, like the 'parametric' approach to agricultural land capability, seek to put quantitative values on classes which have been previously recognized in a non-quantitative or semi-quantitative way. Whether this is a useful approach, or whether the quantitative data would be more usefully handled by multivariate methods (see below) to give entirely new insights into the data, is a matter which merits further consideration.

Wright (1972) concluded that quantitative differentiation in terms of specific terrain properties is best suited to intensive surveys of small areas. In classifications of larger areas, the special-feature method needs reinforcing by some system of land units compounded from areal 'individuals' rather than simply point data, and built up on the ground rather than according to preconceived terrain types. This would enable regional contrasts to be distinguished with greater precision than would otherwise be possible.

2.1.1 Relationships between soils and landform units.

Air photography has been found to be useful in examining relationships between soils and landform units, but there is more scope for work in this field. The value of air photography lies in the recurrence, usually in characteristic patterns, of the photographic images. Patterns of landform, drainage, vegetation, and soil surface characteristics are almost universal. Most air photo interpreters, whether soil scientists, geologists, or ecologists, make use of patterns and resolve them into the recurrent components. Then, in order to find out what the soil, rock, or vegetation is like, they inspect a few examples of each class of component on the ground. In this way, time can be saved because not all the land need be visited. As the area to be surveyed is increased (within certain limits), any given pattern is more likely to be repeated and hence a greater area can be mapped from air photography with limited field work than is possible using the same resources in normal field survey (Webster, 1969).

Landform or landscape units may have a predictable relationship with the associated soils (e.g. Huggett, 1975), although, perhaps, only at a fairly general level. Toleman (in M.A.F.F. 1974) noted that in N.W. Scotland it was found that landform units had regularly-occurring patterns of soil complexes, and such units could also be recognized for forest management purposes. Rudeforth and Webster (1973) and Rudeforth (1975) gave examples of air photo units recognized in Wales that are applicable to land classification.

The technique of using land facets as a predictive tool in soil mapping was tested by Areola (1974) on a number of sites in Montgomeryshire (now part of Powys) Wales. Soil properties were extrapolated from land facets (interpreted from aerial photographs), and statistical techniques (coefficient of variation, analysis of variance, discriminant analysis) were used in testing the variation of soil properties within and between facets. The results showed that the land facets possessed a considerable degree of homogeneity in important soil properties such as particle size distribution, colour, stone content, pH, and free iron oxide, although they were highly variable in the distribution of exchangeable cations and organic carbon. The similarity between analogous facets based on individual soil properties was not very great, especially with reference to ground drainage and parent material lithology. However, when all the properties were considered together, the similarity between analogous facets was greater than that based on the individual properties.

How far land units, whether derived from physical maps or air photographs, are useful in predicting the potential for specified land uses in British uplands is a matter requiring further investigation.

2.2 Classification of land for specific purposes

2.2.1 Agriculture

Vink (1960) examined various interpretative soil groupings, the main ones being soil quality classification and soil suitability classification. The former has no economic bias, whereas the latter always has. vVink noted that in making a classification, certain assumptions are made, even though they are often not fully recognized by the authors themselves, and he cited as an example the Capability Classification of the U.S.D.A. Soil Conservation Service.

Olson (1974) and Boyer (1974) reviewed respectively interpretative land classification systems in English-speaking and French-speaking countries, and it appears that the approaches are broadly similar. In English-speaking countries, the land capability classification of the U.S. Department of Agriculture has perhaps been the most widely used and adapted. The land use capability classification of the Soil Survey of England and Wales is basically an adaptation and revision of the U.S.D..A. classification, modified to fit conditions in Britain.

Albers et al (1975a) made a comparative study of some West European land classification systems. The Dutch and English systems are descriptive and are based on the exclusion of land from the better classes because of the presence of certain limiting factors. The French and German systems, and the system of Sys and Verheye (developed for arid and semi-arid regions) are 'parametric' (see section 4.3).

Albers et al criticized the Dutch system because the limiting factors (excess water, local trafficability, droughtiness, friability of the plow layer, slaking hazard, slope, and the possibilities for growing certain crops) are introduced into the classification in a way that is inexact and based mainly on cartographic and agricultural experience. Because of a lack of definitions, the system becomes regional and subjective. Some factors which are capable of precise definition (e.g. organic matter content, stoniness) are lacking. They criticized the English system (that of the Soil Survey, see below) because certain limiting factors (e.g. susceptibility to erosion) are vaguely defined; factors like organic matter and nature of parent material are lacking; the difference between north- and south- facing slopes has not been made; the criteria for artificial drainage are disputable. Neither the Dutch nor the English systems give an absolute production level for the different classes.

Albers et al (1975b) compared the above five systems for land suitability classification with the more detailed standards based upon discussions during the Expert Consultation on Land Evaluation for Rural Purposes held in Wageningen in October 1972 (Brinkman and Smyth, 1973). They concluded that; (a) four of the land suitability classification systems (the German system excluded) hardly pay any attention to the land utilisation type; (b) a considerable number of major land qualities and characteristics have not been considered in the French and Dutch systems and in the system of Sys and Verheye, probably because they were not considered important locally. The German and English systems consider many more, but not all, of the major land qualities and characteristics; (c) none of the five systems quantifies the influence of land characteristics or major land qualities on crop productivity or management requirements. They outlined the steps which need to be taken to arrive at a land suitability classification system applicable to arable farming in western Europe. In particular, there is a need to establish class-determining limits for the major land qualities influencing crop productivity and management practices.

The Soil Survey of England and Wales (hereafter referred to as the Soil Survey) classification (Bibby and Mackney, 1969) makes certain assumptions:

1. The classification is primarily for agricultural purposes.

2. Land is assessed on its capability under a moderately high level of management and not necessarily on its present use.

3. Land which suffers from limitations which can be removed or reduced at acceptable cost is graded on the severity of remaining limitations.

4. The capability classification may be changed by major reclamation projects which permanently alter the previous limitations to use. Minor changes, e.g. mole drainage liable to regress in time, will not change the classification.

5. Within capability classes, soils may differ in management and fertilizer requirements and detailed cropping, and are only grouped because they have similar degrees of limitations affecting adaptability. The classification, however, is not necessarily a grouping of soils according to the most profitable use to be made of the land.

6. Within specific sub-classes are soils which suffer from the same degree and kind of limitation but which may differ in management requirements; for example, in sub-class 3w the wetness may result from slow infiltration or from the effects of rising ground water - each of these conditions will require separate treatment.

7. The system is based not on chemical but on physical limitations, for in general these are more permanent and difficult to rectify; severly limiting chemical properties, however, can be recognised as a soil limitation.

8. Distance to markets, types of roads, and farm structure, do not influence the grading, although these factors will affect decisions about land use.

9. The interpretations try to express current knowledge, and as new experience is acquired, a new interpretation will be necessary.

10. The system is not a soil suitability classification for specific crops or use, e.g. for potatoes or forestry. Interpretations of soil maps for such purposes may require different groupings of the mapping units to express the concept of land capability used in the system.

Factors important in assessing agricultural land capability are given in Table 2.2.1.1. Land is allocated to one of seven main classes according to the degree to which its use is limited by (i) wetness; (ii) soil properties - shallowness, stoniness, structure, texture, fertility; (iii) gradient; (iv) liability to erosion; (v) climate. Class 1 land has very minor or no physical limitations to use, while class 7 land has extremely severe limitations that cannot be rectified. The limitations imposed by gradient and climate are outlined in Tables 2.2.1.2 and 2.2.1.3. Some of the background to land capability classification is given in papers in M.A.F.F. (1974), and papers on soil type and land capability are given in Mackney (1974). Rudeforth and Bradley (1972) presented this classification in the form of a decision tree, which can be used to allocate any land unit to a class, although this was drawn up for Pembrokeshire and may need modification for use elsewhere.

Table 2.2.1.1

Factors important in agricultural land capability
(Rudeforth and Bradley, 1972; Rudeforth and Webster, 1973; Rudeforth, 1975)

Altitude	)	
Rainfall	)	
Potential transpiration	)	give Climatic Group
Temperature	)	

Slope gradient
Erosion risk
Topex
Liability to flooding

Soil drainage class
Soil depth for rooting
Soil stoniness
Soil texture
Soil moisture deficit
Soil pattern complexity

Also recorded:

Current land use
Major soil group
Soil structure
Geology
Slope shape

Table 2.2.1.2

Limitations on agricultural practices caused by gradient (Bibby and Mackney, 1969).

3°-7°	may cause problems with some gapping machines or mechanised weeders, precision seeders, and some root crop harvesters.	
7°-15°	restrict the use of a combine harvester	depending on the configuration of the ground
≥ 11°	two-way ploughing encounters difficulties	
≥ 15°	loading on trailers difficult these slopes tend to remain under grass for long periods	
≥ 20°	difficult to plough, lime, and fertilize	
≥ 25°	some soil movement occurs; formation of paths across slopes by animals begins; no mechanical operations possible without specialised machinery.	

Table 2.2.1.3

Climatic limitations on agricultural practices (Bibby and Mackney, 1969).

R = average rainfall (mm)

PT = average potential transpiration (mm)

T = long term average of mean daily maximum temperature

Three useful climatic groups have been defined:

I $R-PT < 100$ mm and $T > 15^{\circ}C$

limitations on crop growth slight or absent

II $R-PT < 300$ mm and $T > 14^{\circ}C$ (but excluding group I)

moderately unfavourable climate restricting choice of crops

III $R-PT > 300$ mm or $T < 14^{\circ}C$

moderately severe to extremely severe climate which restricts choice of crops

In general

(1) land over 2000 ft is generally above the tree line and provides rough grazing

(2) land between 1000 and 2000 ft with more than 60 in. annual rainfall provides rough grazing but pasture improvement is usually not feasible

(3) land between 600 and 1000 ft with more than 50 in. annual rainfall allows pasture improvement but is not suitable for arable crops

(4) land between 400 and 600 ft with more than 40 in. annual rainfall (45 in. in western Britain) is mainly suitable for grass and limited arable cropping.

More knowledge of the relationships between weather and crop growth is needed, but it is clear that differences in macroclimate influence land capability, and that this is reflected in the present land use pattern. Any useful categorisation of climate must correspond to the realities of existing land use, e.g. it must be able to differentiate between the dominantly pastural areas of western, and the dominantly arable areas of eastern, Britain; between the restricted choice of crops available in Caithness and the wider choice of eastern England.

In the M.A.F.F. Agricultural Land Classification, land is allocated to one of five main grades according to the degree to which its use is limited by climate, relief, and soil. Maps of England and Wales have been published at a scale of 1:63 360. The emphasis is on flexibility for crop production, and Gilg (1975a) pointed out that the surveying method adopted in the production of the maps tends to underrate the extent of good land; if land is grade 1 for potatoes but grade 3 for all other crops, it is mapped as grade 3. Furthermore, the width of the five grades is not consistent. Gilg also pointed out that the scale of mapping was the same as the final publication scale, and the minimum unit evaluated was 200 acres (80.94 ha). Hence, the maps are not suitable for detailed work.

Jeffers (1976a) commented that although this classification is thought to be based on physical criteria alone, the various physical factors do not act independently. The evaluation may thus be regarded as an intuitive multiple regression technique, with crop yields (amounts, reliability, ease of achievement) compounded together as the dependent variable, and the physical criteria as the 'independent' variables. In practice, however, the process must inevitably have rested on the identification of certain combinations which possess the minimum balanced requirements for a certain type of agricultural use, the equivalent of a crude bio-assay.

For the purpose of looking at upland areas in detail, both the Soil Survey and the M.A.F.F. classifications are of limited value. Most uplands fall into the three poorest classes of the former and the two poorest grades of the latter. For efficient use of upland areas, a more detailed classification seems to be required.

M.A.F.F., prompted by the fact that the Ministry's existing Agricultural Land classification of England and Wales maps, while useful for general planning, have inadequate detail for studies on a more local scale, plus the fact that the existing classification gives no indication of the improvement potential of unimproved land (Grade 5) are developing a more detailed method of classification for the areas currently in Grades 4 and 5. Pilot surveys have been undertaken (e.g. the parish of Bainbridge for the North Riding Pennine Study), but so far, no details of the classification have been published.

Newbould (1974, 1975) reviewed the current state of techniques for the improvement of hill pastures for agriculture. He noted that the most important single factor which influences animal output from the hills is nutrition, and the key to an improved nutrition cycle for the grazing animal lies in pasture improvement. Hill soils are generally acid, short of phosphorus, and have poor physical structure. The nature of the soils has been much influenced by the climate, which is, in general, cold, windy, and wet. The climate, the nature of the soil, and the effects of man's activities have resulted in a wide spectrum of hill-plant communities. Indigenous hill pastures produce small (by lowland standards) yields of dry matter, mostly of low digestibility, although some pasture types yield dry matter of quite high nutritive value, the highest values occurring for only a short time, e.g. late May to early June. Moreover, traditional systems of hill farming result in marked under-utilization of the herbage, with an ever-increasing dilution of pasture quality season by season. Clearly, areas most suited for improvement could be selected more efficiently if improved soil and vegetation information was available. Newbould suggested that the sort of information required might be obtained if the principles of the M.A.F.F. hills and uplands system were linked with information from regional climatic maps, and that on access, possible fence lines, and water supply.

Bendelow and Hartnup (at press) discussed the assessment of climatic limitations in relation to the land use capability classification of the Soil Survey. As the chief agricultural use of uplands is for grazing, climatic classification could be useful and realistic, since the growth of grass shows a good relationship to temperature and moisture balance.

2.2.2 Forestry

The production of wood (cellulose) is perhaps less dependent on soil fertility than is the production of proteins and carbohydrates in food crops and livestock. The chief demand in commercial forestry is for quantity of timber, and hence for large volume-producing trees which give the best yields and financial returns. Classification of land for forestry inevitably includes a consideration of yield. Various workers have attempted to express in equations the relationships between site factors and forest height-age relationships (site index), this is sometimes known as the factorial approach. The philosophy of classification for forestry in Canada was discussed by Rowe (1962).

In Britain, Statham (1972) in his study of the North York Moors, devised a classification which was based on ecological and known economic constraints of a widely-occurring and restrictive nature. Several assumptions were made: (1) Relative priorities of food and timber production in the foreseeable future rule out extensive afforestation of grades 1-3 agricultural land; (2) existing investment in agriculture (buildings, stock, fences, walls) lowers potential for forestry development even where the biological potential is high; (3) a corollary of (2) is that land at present managed for forestry generally has a higher potential for forestry than non-forested land, except in areas of very fertile soils, where clearance to agriculture would be more profitable; (4) the existence of common land is a short-term but not a long-term constraint; (5) as with agriculture, socio-economic factors such as land prices, location, access, distance to markets, ownership factors, are not taken into account; (6) amenity, recreational, and conservation factors are not considered; (7) the present balance of subsidies etc. between forestry and agriculture is assumed, but not necessarily the actual rates. The grading system evolved by Statham was as follows:

Grade 1: land with variable but generally poor soils with low economic constraint to forestry development (these areas include most of the existing forests).

Grade 2: land with poor to very poor soils with low to moderate economic constraints to forestry development. Subclass 2a Common land (coincides with unenclosed moorlands).

Grade 3: land with poor soils and moderate to severe economic constraints to forestry development. (These areas are the poorer agricultural land).

Grade 4: land with moderate or good soils but severe economic constraints to forestry development except for sporting amenity.

Grade 5: land with severe ecological constraints to the successful growth of trees.

The mixing of ecological and economic criteria in this classification is questionable. Economic considerations can change very rapidly in present-day Britain, and it seems better to produce an ecological classification upon which real or hypothetical economic considerations can be superimposed.

Consideration of yield classes and regional differences has probably been the main reason why a classification of land for forestry capability has not yet been published in Britain. In Canada, where the ecological situation with regard to forestry is rather different, all mineral and organic soils can be put into one of seven classes based on an inherent ability to grow commercial timber. Associated with each capability class is a productivity range based on the mean annual increment of the best species or group of species adapted to the site at or near rotation age. As in the agricultural land capability classification, the classes represent increasingly severe restrictions on use, and the subclasses indicate the nature of the restricting factor(s) (McCormack, 1971).

However, Kumar (1977) questioned whether the Canada Land Inventory (CLI) is really applicable to Canadian forests. The wood productivity scale is based on the mean annual increment of the best species for 'normal stands' or 'fully stocked stands' under ' good management', but the CLI does not define these terms. Kumar questioned the use of the term 'normal stands', he noted that there is no criterion to define a 'fully stocked stand', and that what constitutes 'good management' in Canada is an elusive factor. If management objectives differ from province to province and forest to forest, forest productivity will also vary. Furthermore, the concept of forest capability ratings reinforces the false assumption that the present-day, first-class forests of Canada can be replaced. Degeneration of ecosystems and costs of regeneration seem to have been ignored.

In Britain, difficulties have been experienced when attempts have been made to evolve a general site capability classification for forestry. These are due to the fact that: (1) the site factors which directly influence production of the major commercial species are not well understood; (2) the effects of changing alterable site limitations (by drainage, cultivation, fertilisation) are difficult to quantify; (3) a tree crop has a greater effect on the site itself than have agricultural crops; (4) the extensive use of non-indiginous species has increased the extent of unknown relationships between species, yield, and site factors which would be naturally wide due to Britain's climatic, physiographic, and lithological variation; (5) much of the earlier work on site classification was based on vegetation description, and although the natural vegetation of the site, as modified by anthropogenic factors, did reflect site limitations, only empirical correlation could be made when making decisions on the selection of species for planting. The Forestry Commission has generally taken the view that it would pursue regional classification which improved the efficiency of forest managers in the exercise of their functions (Toleman, in M.A.F.F. 1974).

Examples of regional classifications are given by Toleman and Pyatt (1974) and by Pyatt et al (1969). Busby (1974) gave forest site yield guides to upland Britain on a regional basis. In assessing the economics of forestry in a given situation, in particular when comparing the economics of different forms of land use, it is necessary to consider not only estimated yields, but also the costs of establishing the forest. For current Forestry Commission planting, something like three-quarters of the total area will require some kind of fertiliser. This is mostly phosphorus, although on the poorer peats a phosphorus and potassium mixture is applied at planting or a few years later. At present, nitrogen fertilising is confined to check crops in the pre-thicket stage and to some slow-growing semi-mature crops on very poor mineral soils. Nitrogen is often applied in combination with phosphorus in these situations (Toleman and Pyatt, 1974; Everard, 1974; Binns, 1975). Also, some form of site preparation may be necessary (Edlin, 1964; Taylor, 1970).

It is worth noting that some site factors which are limiting for agriculture are not limiting to forestry, e.g. (Toleman, in M.A.F.F. 1974).

1) slopes up to 35° are acceptable

2) stoniness or boulder content or bouldery surfaces have little effect on forest utilisation unless very high frequency is encountered

3) organic and organo-mineral soils do not represent as severe limitations for forestry as for intensive agricultural use.

In contrast, some limitations such as wetness associated with clay textures and low or zero potential water deficit can be a serious limitation in forestry or on stability grounds, and can affect production much more seriously than in agriculture. Also, shallow soil over limestone is a serious limitation for many conifer tree species but can be utilised quite productively by intelligent agricultural practice. Climatic and topographic factors probably play a greater part in classification for forestry. Paterson (1956) produced an index for estimating the potential productivity of tree stem wood using only climatic factors (see section 4.3).

In a classification of upland areas, classification of land for forestry capability might be based simply on whether or not trees will grow at a given minimum yield class. The economics of forestry in that area could then be considered separately, especially in the light of changing economic circumstances and Government priorities.

Such a classification has been produced for us by R. Toleman and D. G. Pyatt (Forestry Commission), and is given in Tables 2.2.2.1 and 2.2.2.2.

Table 2.2.2.1 General classification of land for Forestry Capability.

NORTHERN PENNINES AND SCOTTISH BORDER

(R. TOLEMAN)

Elevation	Topex	Brown earth 1	Podzol Ironpan soils Peaty ironpan soil 2	Gleys Peaty/non peaty 3	Flushed and Molinia bogs 4	Hill peat Unflushed bogs 5
< 230 m (750')	> 30	NS SS SP CP LP JL EL DF Other conif. O Bi Ald Other B.L. (90%)	NS SS SP CP LP JL Some other conif. O Bi Ald few other B.L. (90%) EL (>50%)	NS SS SP CP LP JL EL Several other conif. O Bi Ald Several other B.L. (90%)	SS LP (90%) NS Bi Ald (>50%) SP (<50%)	LP (90%) SS (>50%) NS Bi Ald (<50%)
	< 30	SS SP LP JL Other B.L. (90%) NS CP EL O Bi (>50%) Ald (<50%)	SS LP (90%) NS SP JL Bi (>50%) CP Ald (<50%)	SS LP Few other conif (90%) NS SP JL Bi Ald (>50%) EL O (<50%)	SS LP (90%) NS SP Bi Ald (<50%)	LP (90%) SS (>50%)
230 m to 400 m (750'-1300')	> 30	NS SS SP LP (90%) JL Bi Ald (>50%) EL O (<50%)	SS SP LP (90%) NS (>50%) JL Bi Ald (<50%)	SS LP (90%) NS SP Bi Ald (>50%) JL (<50%)	SS LP (90%) NS SP Bi Ald (<50%)	LP (90%) SS (>50%)
	< 30	SS LP (90%) NS SP JL Bi (<50%)	SS LP (90%) SP (<50%)	SS LP (90%) JL (<50%)	SS LP (90%)	LP (90%) SS (>50%)
> 400 m (1300')	> 30	SS LP (>50%) SP Bi (<50%)	SS LP (>50%) SP (<50%)	SS LP (>50%)	SS LP (>50%)	SS LP (<50%)
	30	SS LP (>50%) SP (<50%)	SS LP (>50%)	SS LP (>50%)	SS LP (>50%)	SS LP (<50%)

Feasibility of producing crops:-

> 10 m ht
> GYC 5

- in each site type

STRONG PROBABILITY (90%)
PROBABLE (>50%)
POSSIBLE (<50%)

Fertilization is normally carried out in site groups 4 and 5 which ensures that both LP and SS achieve>GYC5

"Other Broad leaves" means BL species not named in that box.

Similarly with conifers.

NS Norway spruce
SS Sitka spruce
SP Scots pine
CP Corsican pine
LP Lodgepole pine
JL Japanese larch
EL European larch
DF Douglas fir
O Oak
Bi Birch
Ald Alder
B.L. Broad-leaved species
GYC Growth yield class

Table 2.2.2.2 General classification of land for Forestry Capability.

NORTH AND MID-WALES
(D. G. Pyatt)

Elevation	Topex	Brown earths 1	Ironpan soils and integrades 2	Gleys including peaty gleys 3	Flushed and Molinia peats 4	Calluna, Sphagnum and Eriophorum peats 5
200-400 m 650-1300'	> 30	SS NS JL EL SP CP LP O Bi Ald (90%) Many other conif. several other B.L. (>50%)	SS NS JL SP CP LP Bi Ald (90%) Several other conif. (>50%) O a few other B.L. EL (<50%)	SS NS JL EL SP CP LP O Bi Ald (90%) Several other conif. (>50%) Several other B.L. (<50%)	SS NS JL SP LP Ald Bi (90%) Several other conif. (>50%) O Several other B.L. (<50%)CP EL	LP (90%) JL SP SS (>50%) NS EL a few other conif. Bi Ald (<50%)
	< 30	SS JL SP LP (90%) NS EL CP Bi (>50%) O Ald a few other B.L. (<50%)	SS LP (90%) JL SP (>50%) NS CP a few other conif. Bi. Ald (<50%)	SS LP (90%) NS JL SP a few other conif. Bi Ald (>50%) EL O (<50%)	SS LP (90%) NS JL SP a few Other conif. (>50%) Bi Ald (<50%)	LP (90%) SS (>50%)
400 to 600 m 1300-1900'	> 30	SS NS JL EL SP LP (90%) Bi (>50%) CP O Ald a few other B.L. (<50%)	SS LP (90%) SP JL (>50%) NS EL CP a few other conif. Bi Ald (<50%)	SS LP (90%) NS JL SP Bi Ald (>50%) EL a few other conif. O (<50%)	SS LP (90%) NS JL SP a few other conif. Bi Ald (<50%)	LP (90%) SS (>50%)
	< 30	SS JL LP (>50%) NS EL SP Bi (<50%)	SS LP (>50%) JL SP (<50%)	SS LP (>50%) NS JL (<50%)	SS LP (>50%)	LP (>50%) SS (<50%)
> 600 m 1900'	> 30	SS JL SP LP Bi (<50%)	SS SP LP (<50%)	SS LP (<50%)	SS LP (<50%)	LP (<50%)
	< 30	SS (<50%)	SS (<50%)			

Feasibility of producing crops:-

>10 m ht
>GYC 5

- in each site type

STRONG PROBABILITY (90%)
PROBABLE (>50%)
POSSIBLE (<50%)

Fertilization is normally carried out in site groups 4 and 5 which ensures that both LP and SS achieve GYC5

"Other Broad leaves" means BL species not named in that box.

Similarly with conifers.

Table 2.2.2.3

Site factors important for forestry (Toleman, in M.A.F.F. 1974)

In decreasing order of importance:

Soil type
Altitude
Accumulated temperature (Birse and Dry, 1970)
Exposure (Birse and Robertson, 1970)
Rainfall and potential water deficit (Birse and Dry, 1970)
Topex
Aspect
Accumulated frost (Birse and Robertson, 1970)
Slope gradient
Soil depth
Lthology

Other factors are:

Topographic class and slope type
Vegetation (presence or absence of Calluna vulgaris, Trichophorum caespitosum, Eriophorum vaginatum, Molinia caerulea, scrub shrubs, Pteridium aquilinum).
Boulder factor
Terrain form and roughness

2.2.3 Recreation

Uplands support a range of recreational activities which make different demands on the land. Walking, rock climbing, pony trekking and angling require no special facilities other than those provided by the landscape. Such activities make relatively intensive use of only a small proportion of the total area. In the case of walking, this has resulted in the erosion of many upland footpaths. Cross-country skiing is an activity which is growing in popularity. It requires no special facilities apart from snow and suitable terrain, and it remains to be seen what impact it will have on the land. Shooting of grouse and pheasants places a different type of demand on the land in that it requires that the land be managed in a particular way. On the other hand, deer shooting does not require such special management. In general, such recreational activities also include aesthetic pleasure derived from the scenery.
Robinson et al (1976) examined methods for evaluating the visual quality of landscapes. Two methods were recommended, and it was recognized that all such methods involve subjectivity.

The basis of the classification for recreation used in the Canada Land Inventory (McCormack, 1971) is the quantity of recreation land use which may be generated and sustained per unit area of land per year under perfect market conditions. A high land class unit therefore has a high index of attraction in terms of popular preferences and a use tolerance which permits intensive use without unduly degrading the resource. This ranking does not take into account present use or accessibility. Intensive and dispersed activities are recognised. Intensive activities are those in which relatively large numbers of people can be accommodated per unit area, while dispersed activities are those which normally require a relatively large area per person. Recreation subclasses indicate the kinds of features which provide opportunity for recreation, and are thus positive aspects of land and do not indicate use limitations.

This concept could be applied in Britain; clearly the carrying capacity of the land is an important factor in assessing suitability for recreation. Barkham (1973) examined the concept of carrying capacity, and noted the difference between ecological carrying capacity, i.e. the maximum land use pressure that an area will tolerate without ecological degradation, and recreational capacity, which depends upon subjective factors. Attempts to evaluate land capability for recreation in Britain have usually involved subjective assessments of one sort or another (e.g. Statham, 1972; Duffield and Owen, 1970). Ovington _et al_ (1974) discussed problems arising from the upsurge of tourism in National Parks in general, and for the Ayers Rock-Mt Olga National Park in Australia. They advanced the concept of tourist carrying capacity as a basis for landscape planning and resource management. Sinden (1975) discussed an extension to this concept.

The Federal (Republic of Germany) Institute of Vegetation Science, Nature Conservation, and Landscape Management has evolved a method for determining potential recreation areas. Water bodies, woodland, arable/grassland ratio, relief strength, and climate have been assessed in the manner of an economic value analysis. The days of sunshine are graded highest, next come the water bodies, the relief strength, the woodland, the snow cover, the decreasing level of rainfall, and the arable/grassland ratio. From this a colour map of the Natural Attractiveness has been prepared (Olschowy, 1975). This method seems very subjective.

Various attempts have been made in Britain to classify land for recreational purposes (e.g. Duffield and Owen, 1970). These attempts usually involve some sort of subjective grading system, often based on 'landscape quality' (e.g. see Jacobs, 1974; Lane et al 1975). Duffield and Owen (1970) used Linton's classification of landforms to which were assigned arbitrary scores for 'scenic attractiveness'.

Field studies in the Lomond Hills area of Central Fife in Scotland (Gilg, 1974) have demonstrated that Linton's method of assessing scenery as a natural resource has potential as a basis for constructing a more rigorous model, but one which could still be simple enough to be easily applied by local authority and other planners. These studies demonstrated that Linton's method is clearly workable and worthy of extension. The method can be adapted to a variety of scales and a rigid sampling frame. However, the scale of values and the extension of the method to environments outside Scotland are important considerations to be tested. Gilg (1975b), as the result of a colour slide experiment, suggested a modified scoring system for the different landforms and a revised ranking of land use. Gilg (1976) investigated sources of possible variation in deriving the scores of the Linton method, and concluded that the possibility of errors occurring through two particular factors must be remedied before the method could be used as a fully operational tool for planning purposes. The two factors are (a) the difficulties of interpretation between two or more types of land use/land form when they both occur in the same square, and (b) the need to produce a specific matrix of values for identifying land form quantitatively, similar to that used in Lanarkshire (Duffield and Owen, 1970).

The classification of land for recreational uses is so complex that it requires a separate study.

2.2.4 Water resources

As from April 1 1975, the management of water resources in England and Wales has been in the hands of a number of regional Water Authorities. The main upland areas come under the North-West, Northumbrian and Yorkshire, Water Authorities and the Welsh National Water Development Authority. The North-West Water Authority, when consulted informally about the classification of land for water resources, stated that the management of water resources was being concentrated more in the transfer of water from rivers rather than the establishment of reservoirs in catchments. Hence it appears to be unnecessary to classify land for this purpose.

The major impact of the Water Authority on the uplands is likely to be in its management of existing upland catchments. The Water Authorities are large landowners. The N.W.W.A., for example, manages 40 sq. km. (10 000 acres) of water and about 600 sq. km. (150 000 acres) of land, much of it in National Parks (N.W.W.A. first annual report, 1974-1975). Access to some of these areas has to be restricted, but in others recreational use is possible.

2.2.5 Mineral potential

Possible categories are:

1. Area being actively mined, or with permission for mining

2. Land with probable mining potential as deduced from prospecting results and geological evidence

3. Land with possibility of mining potential, as deduced from geological evidence

4. Area in which, on geological evidence, presence of mineral deposits might be suspected

5. Area for which no geological or other information is available

6. Non-mining land

2.2.6 Wildlife

The Canada Land Inventory (McCormack, 1971) provides for the classification of land in terms of its suitability for ungulates and also for wildfowl, but it is not clear if this has been much used in practice.

Hawes and Hudson (1976) stated that the limitations of the Canada Land Inventory stem from its subjectivity, lack of reference to present land use, and lack of consideration of habitat manipulation costs in assigning capability ratings. Furthermore, habitat descriptions are not of sufficient detail to allow the rating of land units for wildlife species other than those considered in the original survey. Hawes and Hudson attempted to overcome these limitations with a more holistic, habitat-based classification. The classification is based on elements stable for long term planning, for example, land forms with associated soil and climax vegetation (the method was used in southern British Columbia). Land use is considered as well as costs of habitat manipulation, and basic habitat information is provided so that all species with known habitat requirements can be evaluated. This approach permits continued refinement on the basis of site-specific studies. Limitations result from the lack of local knowledge about species habitat requirements, and the use of climax vegetation, which may not exist. Migration also presents a problem in all land classifications for wildlife. Where migration is significant the most critical portion of a species' range can be evaluated.

The Nature Conservancy Council has recently published its review of sites considered important in nature conservation (Ratcliffe, 1977). In selecting these sites, three stages were involved: (1) Recording the intrinsic site features; (2) Assessing comparative site quality; (3) Choosing a national series of key sites. Criteria involved in (2) were size, diversity, 'naturalness', variety, fragility, 'typicalness', recorded history, position in an ecological/geographical unit, 'potential value', 'intrinsic appeal'. The selection of sites in (3) was influenced by the need adequately to represent the natural range of variation in climatic, physiographic, edaphic, and anthropogenic features. The sites were graded 1 (National Nature Reserves or sites of equivalent status) to 4 (Sites of Special Scientific Interest of low regional importance). Full details are given in Ratcliffe (1977).

2.3 Numerical methods of classification

In studies for land classification and potential, data may be obtained with increasing effort (and therefore cost) from existing maps, from air photographs, or from field survey. The maps may be available for the whole of Britain (Ordnance Survey) or they may be specialist sources, only partially available or interpretable for land classification at a particular scale (e.g. geological or soil maps). It is necessary to consider what data and data-handling techniques are available which can produce classes that can be interpreted in terms of potential for particular purposes.

Any classification of any population of objects is an intellectual exercise whereby the data can be grouped in one of a number of different ways, depending on the objectives of the classifier. Classification may be defined as the arrangement of entities in groups or classes according to their common properties (Wright, 1972). Broadly speaking, the purpose of most classifications is to enable the classifier either to make inductive generalisations about the data or to make predictions. No single classification of a group of objects can serve all possible purposes, and the objects may need to be classified in a variety of ways according to the needs of the classifier.

It is important to distinguish between classification, based on discontinuities in the object-space and 'dissection'. Dissection (Kendal and Stuart, 1968, p 314) is the process of dividing the individuals of a unimodal data set into a given number of groups. It is important not to confuse this process with classification, there is no implication that the resulting groups represent in any sense a 'natural' division of the data, they are merely a matter of convenience and the only real criterion is their utility.

Howard (at press) has reviewed numerical classification and cluster analysis techniques and their application in ecology. Perhaps the first important consideration in numerical classification is the nature of the data (attributes). In general, attribute data are of six basic types (Clifford and Stephenson, 1975): (1) Binary (2) Disordered multistate; (3) Ordered multistate; (4) Ranked; (5) Meristic; (6) Continuous; although other types do occur. These categories are not completely separate, for example an attribute scored as binary in terms of single sample sites may be better expressed in meristic form if the sites are subsequently considered as clusters.

Differences of opinion exist on the value of binary (presence or absence) data in ecological work, but the consensus of opinion seems to be that other data are preferable, and the results of using data with numerical values are more informative than those using binary data. Among the shortcomings of binary data is the problem of consequential attributes, i.e. the presence of one feature may lead to secondary, or further, attributes. Continuous quantitative data present fewer problems and are amenable to a wider range of analyses. It is usually unsatisfactory to convert either meristic or continuous data to binary form (Clifford and Stephenson, 1975). Jeffers (pers. comm.) considers that a mixture of binary and continuous data is not usually useful.

Sneath and Sokal (1973) pointed out that the proper selection of characters is clearly a critical point in numerical taxonomy. There are certain kinds of characters whose nature clearly disqualifies them from use in numerical classification: (1) Meaningless characters; (2) Logically correlated characters; (3) Partial logical correlations; (4) Empirical correlations. Such characters are redundant.

A range of techniques is available to enable the classifier to examine various aspects of a multivariate data set. However, it is important that the models and principles on which the mathematics are based should be well-founded and the conclusions reached tested against further experience. In the majority of cases, there are no absolute criteria against which to test the structure of a classification, and so it is important to be clear about the steps taken in its derivation (Clifford and Stephenson, 1975). Multivariate methods may be used to explore relationships among data, and to generate hypotheses, but they do lay traps for the unwary. As Anderberg (1973) noted "Most persons using cluster analysis probably employ it in such an exploratory fashion, but sometimes with an excess willingness to accept the gospel as pronounced by the computer. The tendency to ascribe truth to numbers produced mechanically is well known in the field of factor analysis and no less prevalent in cluster analysis". Again, Anderberg, "Cluster analysis methods involve a mixture of imposing a structure on the data and revealing that structure which actually exists in the data. The notion of finding natural groups tends to imply that the algorithm should passively conform like a wet teeshirt. Unfortunately, practical procedures involve fixed sequences of operations which systematically ignore some aspects of structure while intensively dwelling on others".

Jeffers (1970) stated that although special methods of classification have been developed in the field of numerical taxonomy, these methods are not generally appropriate to the situation in which the individual sites or sampling points to be classified are numerous. It is unlikely, therefore that such techniques as the minimum spanning tree or cluster analysis will have any immediate application to land use surveys, although methods such as association and information analysis are perhaps relevant.

He has subsequently (pers. comm.) modified this view, and his reasoning is as follows. If in, say, land classification, a large number of attributes and/or variables is recorded, it is unwise to attempt a direct classification(e.g. by any of a range of clustering techniques) without preliminary investigation of the existence of discontinuities in multivariate space, and of the variation introduced by the method of sampling employed. Some method must also be found to test the significance of any method of clustering that is ultimately adopted.

Jeffers suggests that a more useful approach is first to <u>categorize</u> the data, i.e. to make a preliminary examination of the nature of the variation expressed in the attributes and variables. The purposes of this categorization are (a) to determine the dimensionality of the data; (b) to explore interrelationships between the dimensions; and (c) to eliminate variables which contribute little or nothing to the study. An example of this strategy is given in Fourt et al (1971) on growth of Corsican pine in relation to site factors. The data consisted of 50 variables in four groups, (1) tree crop 6 variables; (2) climate and physiography 15 variables; (3) soil physical properties 13 variables; and (4) soil and foliage chemical properties 16 variables. A principal component analysis (PCA) of the data in each group gave the following components (1) tree growth - two components (accounting for 90.4% of the original variability); (2) climate and physiography-four components (90.4%); (3) soil physical properties-five components (86.7%); (4) soils and foliage chemical properties-six components (82.7%). The original 50 variables were reduced to 17 components, the correlations between the component values were calculated, and the significance of the correlation coefficients was tested for linear interrelationships between the components of the four groups (the components of any individual group being, of course, orthogonal). These relationships were shown diagramatically and interpreted. Non-linear and interactive relationships can also be tested in this way.

Having categorized the data, classification may be appropriate, either by cluster analysis based on the component values, or by alternative methods suggested by the structure of the data. For example: (a) There may be some a priori reason for recognising groups of individuals, discriminant analysis could then be used to assign the remaining individuals to those groups; (b) There may be some a priori reason for recognising sets of variables, and canonical correlation could be used to examine the relationships between these sets. In complex cases alternative methods of analysis and classification would need to be tested and compared.

On the question of objectivity, it is evident that true objectivity is rarely, if ever, attained. The writer of the algorithm decides what steps will be carried out and in what order, and the user may have to specify distance criteria. These methods are objective only insofar as the set procedures are applied uniformly and without bias to all data sets. Indeed, Wright (1972) stated that classification is, ultimately, a subjective process. It is governed by the information that is gathered by the classifier and how it is organized by him, and this depends upon his background and beliefs and his conception of what is relevant in attaining particular objectives.

Several workers have used numerical methods in soil and land classifications (e.g. Sarkar et al, 1966; Grigal and Arneman, 1969; Arkley, 1970; Cipra et al, 1970; Cuanalo and Webster, 1970; Rudeforth and Bradley, 1972; Courtney and Webster, 1973; Crommelin and de Gruijter, 1973; Webster and Burrough, 1974; de Gruijther and Bie, 1975; Webster and Butler, 1976). Most methods so far used produce groups or clusters without reference to class limits thought to be of significance to land use (Webster and Burrough, 1974). Rudeforth (1975) outlined a system for designating classes from soil and site data, assessing mean values and variability of properties within classes, and which leads to a new approach to the recognition of potential crop land. This method will be considered in more detail in section 4.2.

Turner (1974) gave examples of the application of three types of cluster analysis which, he thought, might be useful in natural resources research.

They were: (1) A method of Loevinger et al (1953), based on maximizing the covariance ratio; (2) the procedure of Rubin and Friedman (1967) in which some scalar property of the pooled within-groups or between-groups sum of squares and products matrix is optimized; (3) the iterative condensation on centroids procedure of Tryon and Bailey (1970). Williams and Yamada (1976) described a clustering technique for land management models based on minimizing the average intercluster similarity while maximizing the average intracluster similarity (Ward, 1963). However, different clustering methods have different properties (Howard, at press) and care is necessary in relating the method most appropriate to the data and objectives.

The method of Ward (1963) was also used by Anderson (1975) to classify the 374 ADAS (MAFF) districts covering England and Wales in 1970. Eleven variables were obtained from a summary of the agricultural census data. Ward's algorithm gave a dendrogram from which ten groups were selected. These groups were then submitted to an iterative optimizing algorithm which took each entity in turn, computed its similarity with every group, and then assigned it to the group with which it had greatest similarity, regardless of the group to which it was initially allocated. This process re-allocates misclassified entities. The relationships among the ten groups were examined by multidimensional scaling, an ordination technique which, in this case, gave two dimensions which retained 90% of the rank information in the original similarity matrix. The two-dimensional ordination chart separated four groups characterized by livestock enterprises from five groups associated with general cropping and horticultural enterprises, with one group of mixed character between. Anderson also examined the groups by discriminant analysis, and found that, by the chi-square test, 22 of the 374 districts were not members of the group to which they were most similar. The results gave interesting insights into the data, and posed a number of questions.

Bunce et al (1975) noted the presence or absence of 152 attributes (a large proportion of them artifacts) in each of the 1 km squares of the 1:63 360 Ordnance Survey Tourist map of the Lake District. The data from every fifth square were used as a sample for reciprocal averaging ordination (Hill, 1973) and indicator species analysis (Hill et al, 1975). As a result of this procedure the 1 km squares could be allocated to one of eight groups. The meaning of these groups is not clear. There are certain theoretical problems posed by this approach. For example, altitude (a continuous variable) has been divided into arbitrary classes, each of which is present or absent. Marriott (1974) drew attention to the dangers inherent in converting continuous data to binary form. Furthermore, this process results in a loss of information which it is difficult to justify without more detailed examination of the data.

Another problem is that no evidence is presented to show whether or not the method used suits the data. Most clustering methods seek a particular type of structure in the data, and may break down or give misleading results if a different type of structure is present (Howard, at press). Unfortunately, Bunce et al (1975) did not publish their ordination diagrams. If there are distinct groups, they should be apparent in the results of the ordination. If there are no such groups, ordination may still throw some light on the relationships between the individuals. Furthermore, ordination may show that a clustering method has been used for data to which it is not suited. It is interesting to note that Gauch and Wentworth (1976) found that although reciprocal averaging ordination gave good results with vegetational data, results with environmental data were usually poor.

Where there is a large number of objects to be classified, the collection of continuous data is time-consuming and tedious. Jeffers (pers. comm.) has suggested two ways of dealing with this situation: (1) to use a large number of binary attributes with appropriate methods of analysis; (2) to measure continuous variables on a sample of the objects and to find by PCA the reduced number of variables which can be used on the full set of objects.

There is clearly much scope for the thoughtful application of numerical classification techniques to land classification problems, some approaches are given in Jeffers (1976b, 1977). We are currently investigating some other possibilities.

3. Methods for data capture

In the survey and classification of upland areas, data may be obtained with increasing effort (and hence cost) from: (1) maps; (2) air photographs; (3) field sampling. Clearly, much time and labour can be saved if the required information can be obtained from maps and air photographs, rather than field sampling.

3.1 Use of maps

When maps are used as sources of data, it is necessary to be aware of the limitations of the maps. If measurements, such as slope gradients, are made from maps it is wise to check on the specification for the particular scale of maps being used, as levels of accuracy vary with scale, but not uniformly so, and some features are often emphasised at the expense of others (Harley, 1975).

Macdougall (1975) discussed sources and magnitude of error in factor maps, and in the overlay process and suggested how map overlays may be made more accurate. He noted that maps used to assemble an overlay are almost always those which identify 'uniform' regions. Such maps have two kinds of accuracy standards: (a) the allowable error in the positioning of boundary lines (horizontal accuracy); (b) the degree of uniformity or purity of the regions. The horizontal error of a boundary line has two parts: error in the original source map and notes, and error introduced in the preparation of the final map. Modern methods and equipment can reduce the second of these to well within 0.1 mm. In comparison, the source material is likely to contain farmore error, and this is likely to be highest where boundaries occur in zones of transition (e.g. soil slope, vegetation maps) rather than along distinct edges between regions. The error resulting from inaccurate boundary lines is usually apparent to the user, but error resulting from non-uniformity of regions is not so obvious and is potentially more significant.

Pedologists appear to be most sensitive to the concept of 'purity' or 'uniformity' of regions. Bie et al (1973) suggested that purities are in the order of 55% and 75% for soil maps of normal complexity at scales of 1:50 000 to 1:63 360 and 1:25 000 respectively. Other possible sources of error are concerned with geometrical differences among maps and changes of scale.

It must also be noted that a soil mapping unit is a single expression of a multivariate system with a vector of means and a variance-covariance matrix. If a property is deduced from a soil map for any particular point, it is unlikely that any estimate of the likely accuracy of such a sample could be obtained. In the traditional approach to soil mapping, soils are identified in pits and the boundaries of mapping units are drawn by interpolation from auger borings using known relationships with landscape facets, geology, and vegetation. The mapping units are defined and described in terms of the soil series they contain. In most cases, one series dominates the mapping unit which then bears that series name; more complex units carry the names of co-dominant series. In either case, the units contain lesser areas of other profile classes. The profile classes - soil series, variants, and phases - included in the mapping unit may be listed, and their frequency of occurrence assessed (e.g. Clayden and Evans, 1974). Various authors have discussed the concept of 'purity' of soil mapping units (e.g. Bascomb and Jarvis, 1976; Beckett and Bie, 1975, 1976) as well as soil map accuracy (Legros, 1973).

A soil classsification unit and a mapping unit are not necessarily identical. The basic soil classification unit employed in Britain is the Soil Series, defined by reference profiles of specific morphology formed on a particular parent material. The mapping unit should ideally consist only of soils which have a very tightly restricted and defined range of variation in all properties from the specification of the reference profiles. Inevitably, this restricted definition cannot be rigidly adhered to in practice. The scale of mapping and the nature of the country impose what variation must be accepted (Ball, 1964).

It is also worth noting that a soil series can contain soil phases reflecting differendes in stoniness, slope, depth, and land use which may not be shown separately on the maps. Beckett and co-workers (e.g. Beckett, 1967, 1968; Beckett et al, 1967; Webster and Beckett, 1968; Bie et al, 1973) have examined the questions of the quality of maps of land resources and of cost-effectiveness in land resource surveys.

A different field soil survey approach was used by Rudeforth (1974) who described the soil at regular 1 km intervals (systematic sampling) in small pits, at exposed sections, and from auger borings. Most boundaries between mapping units were drawn from aerial photographs and landscape observations made while walking to sample points, supplemented in cases of doubt by further auger borings. Some boundaries found in the field were extrapolated using published geological maps. Variability of the smaller map units was studied from additional random pits (cf Rudeforth, 1969). This type of sampling requires fewer pits per unit area than the traditional method (see below). Jansen and Arnold (1976) described a method for defining ranges of soil properties based on grid cell sampling.

Soil maps have been little used in land use planning in Britain (see papers in Davidson, 1976). In the USA, generalized soil maps have been used for broad planning of resources for some time (e.g. Nichols and Bartelli, 1974; Shields, 1976). Recently, computers have been used to store, retrieve, and manipulate large amounts of natural resources (including soils) data. The main use has been computer generation of interpretative maps. A growing use is automatic comparison of soil resource data with other resource-oriented data. In some applications, it is necessary to generalize detailed soil maps by selecting the dominant soil within a cell. Nichols (1975) studied the agreement between detailed soil maps and those generalized using various cell sizes. On a soil survey map with a medium amount of cartographic detail, the average agreement was 70.5%, 64.4%, and 48.4% for unit cell sizes of 8.64 ha, 16.20 ha, and 64.80 ha. On soil maps with low, medium, and high amounts of cartographic detail the average agreement was 71.6%, 64.4%, and 41.3% respectively, for a standard unit cell size of 16.20 ha. A t-test was used to test the agreement between the acreage of soil mapping units obtained from map information, assembly, and display system (MIADS) versus the acreage measured by dot counting. No significant differences were found between sample means of the two methods.

3.2 Use of air photographs and remote sensing

A map is a plane representation of a portion of the earth's surface which, instead of being plane, is a rough and irregular portion of the surface of a sphere. Although an aerial photograph pictures a portion of the earth's surface on a plane surface, it is not a map but a perspective view on which images are displaced from their map position by the curvature of the earth, lens distortion, relief displacement, and tilt displacement. Nevertheless, when provided with sufficient supplementary information and the proper equipment, the photogrammetrist can construct an accurate map. In interpreting air photographs, it is essential to obtain adequate ground control (Spurr, 1960). Because of the distortions in air photographs, any measurements which need to be made are probably best made from maps, using the air photographs to provide additional information (cf. Edwards, 1975; Higginson, 1975).

Curtis (1974) discussed the remote sensing techniques available for environmental monitoring and described examples of remote sensing studies using infra-red line-scan, in particular with regard to shelter-belt studies in rural areas, and multi-band photography, in respect of its potential application to land use, soil, and vegetation studies, in Britain. Vink (1968, 1970) also discussed the use of air photographs.

Evans (1974, 1975) discussed the best time of the year for taking air photographs for soil surveys.

On a scale of 1:10 000, colour photography has been used in the planning of the Pwllpeiran Scheme, and also by the Nature Conservancy in surveys of Dartmoor (Ward et al, 1972) and parts of Snowdonia (Mew and Ball, 1972). Colour photography, although expensive, results in net saving because of the limited ground-work involved. It is possibly the most accurate and objective method of recording long-term vegetation changes, (Munro, 1974).

Goodspeed (1968) examined the possibilities for manipulating data from air photographs, both from the point of view of sampling and of frequency decomposition. He concluded that direct application of the techniques may well be profitable in evaluation of land characteristics. Air photographs and satellite data are particularly useful in studies of vegetation, e.g. for forest inventories or land use (Steiner, 1968; Martin-Kaye, 1974; Curtis, 1974; Hubbard and Grimes, 1974; Bush and Collins, 1974; Dodge and Bryant, 1976; Tarnocai and Kristoff, 1976; Howard, 1976). The question is, how far are they useful for determining the characteristics of soils?

Blanchard et al (1974) considered the possibilities for measuring soil moisture remotely. They concluded that reflectance methods are further developed than are temperature methods, but both require more testing. Eagleman (1974) noted that analysis of the L-band radiometer data from Skylab show that they are highly correlated with the moisture content of surface soil layers (see also Newton et al, 1974). Stockhoff and Frost (1974) concluded that it is practicable to determine the moisture content of surface soil by airborne polarimetric measurements, and Milfred and Kiefer (1976) used repetitive aerial photography with colour and colour infrared film to study changes in surface soil moisture patterns. Carroll (1973 a, b) reviewed the application of remote sensing techniques to soil survey, and commented on the need for research on well-defined laboratory models as well as empirical field studies before remote sensing can be used to monitor soil conditions.

As it is clearly impossible to recognize soil profiles on air photographs, the former have had to be inferred by examination of the geology, geomorphology, vegetation, and tone or colour of the surface soil. Air photographs help in providing soil boundaries prior to soil classification in the field (Howard, 1970; Westin and Frazee, 1976). Carroll et al (1977) described the use of air photo-interpretation for soil mapping. Tonal differences provided by the vegetation, particularly with spring photography, have been found useful at higher elevations in the United Kingdom. For example, in Galloway and Exmoor (Curtis, 1966) and in west Wales, Juncus is associated with (low) humic or peaty gleys, Pteridium with acid brown earths, Eriophorum with peat and Molinia with peaty gley podsols. In west Wales it was also possible to recognise Erica Calluna heath, Vaccinium myrtillus, Scirpus caespitosa - Eriophorum, Nardus, and Sphagnum types (Howard, 1970; see also Nature Conservancy air photo survey of the Isle of Rhum; Carroll et al, 1977; Curtis and Mayer, 1974).

Odenyo and Rust (1975) used density slicing techniques on air photographs to evaluate the accuracy of existing soil maps. This method sliced film optical density into eight levels, each of which could be displayed as a distinct colour on a colour monitor. They found that the interpretation of a given pattern of colours could not be carried across the boundaries of the cultivation units, each of which had to be interpreted separately or grouped with another cultivation unit with a similar cultural practice. Cultural practices (e.g. crop residues left lying on the soil surface) are apt to cause differences in optical reflectively that are not related to intrinsic soil characteristics. However, in certain circumstances, the density slicing technique may prove useful.

Belcher (1948) noted that the first, and perhaps most important, step in inferring soil conditions from air photographs is to identify the landform, the importance of which lies in its relation to the mantle of soils which has been produced. It is possible to assign definite characteristics of shape to landforms composed of different rocks, drifts, alluvium, etc., and further refinement is possible using colour, erosion, and surface drainage. Crampton (1975) used air photographs to recognize landscape units (i.e. vegetation-landform patterns) which could be grouped into regions related to climate in the Mackenzie River valley.

Some factors affecting land use (e.g. poor drainage, rock outcrops, extensive erosion) are directly determinable or can be inferred from air photography. However, from the point of view of land capability classification, the value of air photography may lie in photomorphic mapping, which depicts land types, or land systems, using the pattern produced on air photographs by the total interrelated physical and cultural features of the landscape. The concept depends on the recognition that definite relationships exist between components visible on the ground - such as landform, drainage, vegetation, and field and settlement patterns - and others which can be inferred or interpreted from associated features. These components appear on air photographs in the form of characteristic patterns consisting, more specifically, of tone, texture, and lineaments which can be interpreted as a composite image representing a specific land type. This concept is examined in section 2.1.

The photomorphic method is easily adapted to statistical analysis through the correlation of the image components with ground sampling and census data, and the comparison of the individual components of similar photographic patterns (McPhail and Lee, 1972). Beckett (1974) discussed methods for the statistical assessment of resource survey information obtained by remote sensing. The growing techniques of automatic pattern recognition from remote sensing imagery, using densitometer and computer analysis (Rosenfeld, 1968) also have potential applications for photomorphic surveying.

3.3 Sampling methods

The main object of a sampling procedure is to secure a sample which, subject to limitations of size, will reproduce the characteristics of the population as closely as possible. It is important for sampling methods to avoid error due to bias, which is the aggregate of errors tending in the same direction. Bias, if present, forms a constant component of error which does not decrease as the number in the sample increases. Whether or not a sample will give results which are sufficiently representative of the whole population depends on the magnitude of the random sampling error. The average magnitude of this error depends on the sample size, the variability of the material, the sampling procedure used, and the way in which the results are calculated. The relative accuracy of two samples of different size, or obtained by different methods, or both, may be defined as the reciprocal of the sampling variances of the estimates provided by them. The relative precision of two different methods of sampling based on the same type of sampling unit may be defined as the reciprocal of the ratio of the sampling variances of the estimates given by the two methods using the same number of units. The relative efficiency of two different methods of sampling based on the same type of sampling unit may be defined as the reciprocal of the ratio of the numbers of units required to attain a given accuracy with the two methods. In certain circumstances, the relative efficiency is equal to the relative precision (Yates, 1949).

When planning a survey, the aim is to determine which method of sampling is likely to be most efficient and which size of sample is necessary to give the required accuracy. The smaller the size of sample needed to give the required accuracy, the less effort, time, and expense will be required. Furthermore, the smaller sample size is likely to allow the handling of more detailed information, and the use of more types of data analysis, than might be attempted with a larger sample size or a census of the whole population.

In examining upland areas, we may be looking for particular features or combinations of features, or we may be interested in the areas of land of a particular type or under a particular use. We may wish to computer map the results, or subject them to some sort of statistical analysis.

The surface of land may be regarded as a two-dimensional (areal) sampling plane. The sampling unit may be: (1) a point at which the presence or absence of some characteristic is recorded, or at which a value is read of some continuous pattern of variation; (2) a line (traverse) the length of which lying on a particular land use and related features is of interest; or (3) a small area (quadrat) in which the characteristics of interest are measured. Berry (1962) concluded that the simplest of these sampling units, i.e. points, have none of the problems of the others, and the data are simpler to handle.

Peltier (1962) discussed methods of area sampling for terrain analysis. The optimum type of sampling is best determined by the problem and by the kind of answer sought. If a frequency distribution or probability expression of total characteristics is sought, a sampling of single points or small areas appears best. Effort is decreased without a corresponding loss in accuracy by decreasing the area of the observation points and increasing their number. Detailed field observations on areas 50 feet square seem to be satisfactory for obtaining statistical data on topography, soils, vegetation, and parent rock material. In a situation requiring reliance upon secondary information, such as an explanation of the relationships of mean slope, relief, and drainage texture with lithology, quadrats of 1 sq. mile seem most satisfactory.

Secondary data recorded at scales smaller than 1:63 360 are generally poor and are not likely to reveal new relationships.

Point and transect samples led to similar general conclusions concerning frequency distribution. If direction, or the sequence of events involving movement, are important to the problem, then transect sampling appears best. This type of sample provides data for probability expressions of such things as the chances of finding an outcrop or drainageway, the chances of being able to see for 10 miles, or the chances that a motorized vehicle will get stuck. This type of sampling has proved most useful when combined with a form of gaming or simulated operational experiment.

A two-dimensional space may be sampled in a number of ways (Quenouille, 1949). We might use simple or stratified random sampling, or, because we are dealing with two dimensions, we might choose a simple (aligned) or unaligned grid pattern. Stratification, if intelligently used, nearly always results in a smaller variance for the estimated mean or total than is given by a comparable random sample (Cochran, 1963).
In a wide variety of cases, systematic unaligned sampling is found to be more accurate than stratified random sampling and simple grid sampling (Quenouille, 1949; Cochran, 1963). On the other hand, a simple grid may only be as accurate as simple random sampling, although central square grid sampling can be more accurate than stratified random sampling, and certainly better than simple random sampling (Yates, 1949; Cochran, 1963).

Systematic sampling is simple to draw and execute, and can be very convenient, especially when maps are being used. However, care is necessary in its use, as it is not suited to material with periodic features. It can be recommended when the autocorrelation function between any two points in the area is a concave upwards function of their distance apart, as seems to be the case in many natural populations (Cochran, 1963).

Berry (1962) compared stratified systematic unaligned sampling (four samples randomly oriented with respect to each other) and stratified random sampling with respect to their 'relative efficiency' (defined as the ratio of the variances, but this is not the definition of Yates (1949)) in estimating land use areas from maps. The 'relative efficiency' of systematic over stratified random was 5.65 for woodland, 3.4 for cropland, and 2.3 for pasture. These values imply that fewer observations are needed with a systematic unaligned sample than with a stratified random sample to obtain estimates with a given variance.

Osborne (1942) used the lengths of lines drawn on maps to obtain area estimates of (a) vegetation in southern California, and (b) forest type and condition in NW Washington. In (a) an area 30 miles wide was divided into strips one mile wide, and each strip was divided lengthwise into 30 parts. Twenty sets of lines one mile apart, one line per

strip per set were placed randomly giving 20 systematic samples. However, these samples were random in their totals and provided an estimate of the variance. For comparison, 20 completely random samples and 20 stratified random(or randomized block) samples were also taken. The area estimates by all three methods tended towards the same value, but the standard deviation of the systematic totals for cultivated land was only half as large as that of the randomized blocks, and only one-sixth as large as for completely random samples.

By calculating the average of the squares of the correlation coefficients of a measured line with all lines within the mile in which the first line occurred, together with the residual mean square from a polynomal fitted to one line from each mile, Osborne obtained estimates of the standard deviations for the systematic surveys. He concluded that (1) In his tests, stratified random surveys were only one-half to one-fourth as efficient as systematic surveys of the same intensity; (2) If data taken systematically are used with random sample formulae, biased estimates of the sampling errors of totals or means result; (3) random sample formulae, when applied to randomly selected observations of this kind, give dependable estimates of the sampling errors of totals; (4) from estimates of the correlation of lines, dependable estimates of the sampling errors of systematic samples may be obtained.

The difficulty with any form of systematic sampling is the estimation of the variance (Yates, 1953; Cochran, 1963). Chevrou (1976) examined the relationship between area and the length of the area boundary. He gave methods for using these to estimate the variance of the area estimate obtained by three methods: (a) transects, (b) systematic dot grid, (c) pseudo-systematic dot grid. Quenouille (1949) considered three methods of estimating the sampling errors of a systematic sample:

1) using sets of systematic samples randomly placed with respect to each other, i.e. the material to be sampled is broken up into a series of sub-areas or blocks and several systematic samples are taken in each block; the error variance is calculated from the variances of the systematic samples in each block.

2) using one set of systematic samples randomly placed, i.e. several systematic samples are taken and the area is then broken up into sub-areas or blocks; the error variance is calculated from the variances of the portions of the systematic samples in each block.

3) using one systematic sample, i.e. one systematic sample is taken which is broken into several systematic samples of wider spacing, e.g. four samples at four times the original spacing, the area is then divided into several sub-areas and the error variance is calculated from the variances of the portions of the sub-systematic samples in each block.

These three methods are increasingly accurate in their estimation of the mean, increasingly biased in their estimation of the sampling variance and decreasingly difficult in their practical application, so that the method of sampling may vary according to the population and according to the use to which the results are to be put.

Quenouille concluded with some observations on the problem of a trend in systematic sampling, and noted that Yates' method for overcoming this difficulty is likely to result in little loss of information (cf Bellhouse and Rao, 1975).

These considerations are relevant if estimates of percent of area occupied by particular land uses are of interest, or if it is desired to compare areas. When comparisons through time are of interest, and bias is relatively constant from one time period to the next, then accurate estimates of change can be obtained without satisfying the requirement of unbiased estimates (e.g. see Goodall, 1952).

The effect of bias may be less serious than has been supposed. The main problem seems to be the estimation of the sampling error. What is needed is empirical evidence against which to judge the sampling error of systematic sampling.

Bonnor (1975) drew a total of 14 areas, each belonging to one of four shape classes, and obtained 'true' area estimates by planimetry. Each of the 14 areas was also measured ten times with each of five dot grids of different densities. The area estimate from the sample dot count was compared with the 'true' count and the percentage error was calculated. The relationship between the percentage error and the number of dots in an area was examined graphically. From estimates of area size and shape made as a preliminary to the dot count, a dot grid could be selected such that a specified error will be attained.

In simple random sampling, if we wish to estimate the proportion or the percentage of units in the population which possess some characteristic or attribute, or fall into some defined class, we usually need to apply the binomial distribution, and although the hypergeometric distribution is the correct one for finite populations, the binomial is usually a satisfactory approximation (Cochran, 1963). If we let P = the proportion (or percentage) of units in the population with the characteristic in which we are interested, and p = the proportion (or percentage) in a sample size n, then the standard error of p is given by (for a percentage):

$$SE = \sqrt{\frac{P\,(100 - P)}{n}}$$

For normally distributed data, we would expect that the true percentage would be within 1.96 standard errors in 95 per cent of cases. The standard error falls very rapidly up to a sample size of about 100, and more slowly above that. The following table is from Robertson and Stoner (1970):

P%	n	SE
70	100	4.58
70	200	3.24
70	500	2.05
70	1,000	1.45
70	10,000	0.46

Similarly, the minimum proportion which can be detected is given for the 95 per cent probability level when p - (1.96 x SE) = 0. The following table (calculated by PJAH) gives minimum values of P with a 5 per cent and a 2.5 per cent chance that P will be meaningless (equivalent to 90 per cent and 95 per cent probability respectively, as this is a single-tail test):

5%	2.5%	n
2.63	3.7	100
1.33	1.88	200
0.54	0.766	500
0.27	0.38	1,000
0.03	0.04	10,000

This approach is not appropriate when interest lies in the total number of units in the population which are in a given class. In this event, it is more natural to ask: is the estimate likely to be correct to within, say, 7% of the true total? Thus we tend to think of the standard error expressed as a fraction or percentage of the true value. This quantity is usually called the coefficient of variation of the estimate. If the finite population correction is ignored, the coefficient is:

$$\text{coefficient of variation} = \sqrt{\frac{100 - P}{nP}}$$

For a fixed sample size, this coefficient decreases steadily as the true percentage in C increases. The coefficient is high when P is less than 5 per cent. Very large samples are needed for precise estimates of the total number possessing any attribute that is rare in the population. For P = 1 per cent we must have $\sqrt{n} = 99$ in order to reduce the coefficient of variation to 10 per cent, hence n = 9801. The Binomial distribution can be used to tabulate the frequency distribution of a, of p = a/n, or of the estimated total Np, when a is the number of units in the sample which fall into a class, N is the number of units in the population, n is the number in the sample. Simple random sampling, or any method of sampling that is adapted for general purposes, is an expensive method of estimating the total number of units of a scarce type. In this connection, it is useful to note Berry's results on the relative efficiencies of the different sampling methods mentioned above.

In general, with point sampling, the best results will be obtained if the objectives are fairly broad. In classification, this means reducing the number of classes as much as possible. The technique appears to be most useful in examining the larger classes (i.e. 30 per cent $<$ P $<$ 70 per cent).

It is clear that the number of samples does not depend on the area involved. Whether it is a whole region being considered, or a small area within a region, exactly the same number of samples will be required to make the same end statement with the same degree of error, provided that the distribution which we are studying is the same in each case. In upland areas, the distributions may differ at different scales. For example, a small valley may have areas of good soil in the valley bottom which form a large proportion of the valley, but may form only a small proportion of the upland area as a whole, with its generally poorer soils. With land variables, variation tends to increase as area increases, but not linearly.

4. Methods for handling the data

Apart from the traditional mapping approach, the type of data with which we are concerned may be handled in a variety of ways.

Tomlinson (1970) grouped methods for storing and manipulating geographical data (i.e. those which are specific to a location) into four categories:

1) Geographical indexing systems

This is the simplest type, it manipulates data lists on the basis of a location - specific index. An example of this is the U.S. Bureau of Census DIME system.

2) Simple grid manipulation

Single data sets whose location is known can be stored in arbitrary grid cells. The results can be displayed as line-printer character maps. Possibly the best-known of these is SYMAP V and its derivatives. Storage inside the computer is on the basis of one character per grid cell. Several types of data manipulation can be carried out on this grid cell storage matrix. Values provided at grid co-ordinate points can be spread homogeneously over areas (clusters of grid cells), previously described to the system. Isolines (contours) can be calculated for any intervals over the range of values of point data provided on the grid and can be internally superimposed on the grid. Spatial units can be defined by nearest-neighbour methods from point information (where each grid cell is assigned the value of the point data nearest to it) and boundaries are assumed along the line where the values change. SYMAP V has a wide range of statistical support options linked to the mapping system which permit calculations of means, standard deviations, histograms, and percentile groups of the data. Graphic display of the results of data storage and manipulation can be providing by simply printing out each cell as a symbol on a line printer. Lines can be approximated with printer characters and areas can be shaded with up to ten progressively darker shades.

Simple grid manipulation is particularly useful in upland land use and land capability studies because the maps can be generated quickly with even a small computer and limited printing facilities. A normal teletype printer gives some distortion because the distance between lines is not a whole multiple of the distance between characters on a line. One way of overcoming this is to have a re-geared line printer as at the Edinburgh Regional Computing Centre (Newcastle-upon-Tyne installation).

3) Map compilation systems

One of the easiest and most efficient manual ways to store and display geographical data is in map form. Computers can be used both to aid in the manipulation and compilation of maps themselves and to store, manipulate, and display geographical data derived from maps. One example of this is the Oxford System of Automated Cartography.

4) Graphic data handling syste s

Maps have two severe limit t ons n their use: (1) there is a physical limitation on the mount of data that can be stored and displayed on any map; (2) he map format demands visual and manual retrieval of any of its information . Measurements are laborious and quantitative comparisons are slow. Computers can be used to store the information found on existing maps and to receive additional information. The stored data can then be analysed in various ways. An example of this is the Canada Geographic Information System (cf. Switzer, 1975).

Automation in cartography is a rapidly-expanding field. Papers on various aspects may be found in Wilford-Brickwood et al, 1975.

4.1 Mapping of variables

Selective portrayal of chosen variables can complement maps which use orthodox units, e.g. those representing the sum of all morphometric profile features. In doing so, they are used to emphasise aspects which may be of special significance to a project (Stobbs, 1970).

An interesting variation on this is the technique of Rudeforth and Webster (1973) for indexing and display of soil survey data by means of feature cards and Boolean maps. Using such maps, it is possible to answer a wide range of questions such as: (1) what is the soil like at a given site? (2) where else can sites with this soil be found? (3) which sites have soils with given combinations of attributes? Comparison of the distribution patterns of different features and their combinations may reveal hitherto unsuspected relationships. Such maps can readily be prepared using electronic computers.

de Gruijter and Bie (1975) described a computer method for allocating cells to prespecified classes on the basis of values of each variable for the cells. Since these values remainunchanged, the user is free to employ any classification of his choice.

The sort of data used in such mapping can also be used to make comparisons, e.g. between the spatial distribution of land use and such characteristics as physiography, terrain type, drainage, soil depth, texture, type, and chemistry, climate, and any others which may be of interest. Any two geographical distributions can be compared, for example by preparing a contingency table and calculating the correlation coefficients, and chi-square provides a test of whether the association is significantly greater than could have arisen by chance.(Berry, 1962).

4.2 Capability mapping

Given a method for classifying land with respect to its ability to support an activity, or range of activities, in which we are interested, the possibility exists to generate computer maps for each type of use capability. The interpretation of these maps (see next section) can answer a number of questions concerning possible uses, conflicts of use, potential for change.

Rudeforth (1975) outlined a system for designating classes from soil and site data, assessing mean values and variability of properties within classes, and which leads to a new approach to the recognition of potential crop land. In this method, a computer is used to assign land to classes in a pre-existing capability classification and to draw maps. Information collected at grid line intersects is particularly suitable for this purpose (c.f. Rudeforth and Webster, 1973). The method can be extended to identify land suitable for specific crops using the known range of values of soil and site properties from sampling locations where these crops occur. The method can also be used to examine the effects of changing the class limits, and to look for locations particularly susceptible to change.

4.3 Quantitative ('parametric') methods

Recent trends in the quantitative approach (sometimes referred to as 'parametric methods') to land evaluation were discussed in papers edited by Stewart (1968), and methods were summarised by Riquier (1974). The method consists of (1) evaluating separately the different properties of soils and giving them separate numerical valuations according to their importance within and between each other; (2) combining these numerical values according to a mathematical law taking into consideration the relationships and the interactions between the factors to produce a final index of performance; (3) this in turn is used to rank soils in order of agricultural value. In principle, the methods consist of examining plant production as a function of factors such as soil depth, texture, available water. The most simple (additive) method postulates that each factor operates independently, which does not seem to be the case in nature. The additive and subtractive method assumes that all the favourable factors add together while all the harmful ones subtract. In the multiplicative method, yield is limited by the lowest faccor, which seems to be more realistic and conforms to experimental data.

Various quantitative methods are being tested in different countries (Riquier, 1974). Perhaps the most widely applied is the Modified Storie Index:

$$\text{Land Productivity (Storie) Index} = A \times B \times C \times X \times Y$$

where A = % rating for the general character of the soil profile
B = % rating for the texture of the surface horizon
C = % rating for the slope of the land
X = % rating for site factors not included in A, B, C
Y = % rating for rainfall

The percentages are converted to decimal equivalents before multiplying together and the result is converted to a percentage (Olson, 1974). Riquier et al (1970) proposed a multiplication method using seven physical and chemical characteristics (or their substitutes) of the soil. The method is flexible but oversimplifies the influences of both climate and improved management practices on productivity. Other similar methods are given in Riquier (1974).

Albers et al (1975a), in comparing some West European land classification systems, considered a French system compiled by Begon and Remy (unpublished). This system, based on the scale of importance of the properties of soils for the required crops, is additive. A disadvantage with this system is that a limiting factor does not come forward enough if there are no other limiting factors. Albers et al criticised the scheme in detail. They also examined a German system used for taxation purposes. It looks at the natural yield capacity (based on soil condition, situation in the landscape, climatic factors). For arable farming and horticulture, and for pasture land, other factors are taken into consideration, such as the size of the farm, its composition (pasture/arable ratio, buildings, stock, stored forage and products), the internal and external traffic situation. This system was criticised for among other things, the assessment of texture, vague criteria for certain factors and no criteria for others, as well as for incorrectly purporting to give an absolute measure for production capacity. There is no information about the nature and severity of the limitation.

Specific information on soil requirements of crops is difficult to find and often vague, partly because crop specialists often tend to neglect studying the soils and soil scientists tend to neglect studying the crops. Soil information in crop handbooks is therefore often vague, and in books on soil science information on the requirements of specific crops is often completely lacking (Vink, 1975).

Leven et al (1974), in the USA, criticized various land classification systems and suggested the use of Land Response Units, i.e. units of land that exhibit strong homogeneity in land form, gross soil morphology, climate, native vegetation, vegetative production potential, and land use limitations. Land is rated on capability (based on soil moisture, temperature, and nutrient regimes) and sensitivity (based on erosion, runoff, and slope hazards). These ratings are then combined to give a single rating for the response unit. They stated that this system has been successfully used in land use planning and management projects in areas ranging in size, from 450 ha (1000 acres) to 303 520 ha (750 000 acres). The ratings were used to indicate the adaptability to the land of small revegetation projects, and for allocation of large portions of land for multiple use.

Wilkinson (in M.A.F.F. 1974) reviewed some independent approaches to quantifying soil survey interpretations in the appraisal of soil productivity, and described the approach used in Britain by M.A.F.F. The importance of understanding the various components of land and the relationship between potential and actual productivity was stressed. A brief description was given of a micro-plot technique to measure the relative potential productivity of soils and some results were presented.

Paterson (1956) developed an index for estimating the potential productivity of tree stem wood in cubic metres per hectare using only climatic factors. His formula was:

$$I = \frac{Tv \times P \times G \times E}{Ta \times 12 \times 100}$$

where Tv is the temperature of the warmest month (°C), Ta is the amplitude between the mean hottest and coldest months, P is the annual rainfall (mm), G is the length of the growing season (months), E is the percentage reduction for evapotranspiration. Paterson's index was modified by Weck (1957) and Becking (1962).

It must be accepted that in such quantitative methods, only the mathematical treatment of factors can be regarded as objective. The selection and compounding of these factors is prone to variable intensities of subjectivity according to the kind of procedure followed. "Realising the complexity of the problem, it is clear that man will always have the responsibility of selecting and assigning significant factors, but should then aim at limiting to an acceptable minimum the role played by subjectivity in these operations. This can only be done if the consideration of the significant factors retained reflects results of field trials and if these results have a statistical value" (Riquier, 1974).

4.4 Other computer-based methods

Numerical methods have so far been little used in the interpretation of land-use data. Beeston and Dale (1975) attempted to use 'multiple predictive analysis' (Macnaughton-Smith, 1965) in an examination of the efficacy of various land clearance methods for the control of woody weeds in southern Queensland. This technique is concerned with the analysis of three sets of variables (in this case, background, treatments, outcomes) recorded for a single set of individuals or sites. The background set of variables may be of any kind, and is used solely as a source of potential divisions into subgroups. The other two sets each contain a single multistate variable and it is the relationship between these two sets, and in particular the predictability of outcome class given treatment class, which is to be maximized. The results were not very impressive. Thirteen groups were accepted, but even at this level the contingency tables were very empty. The authors admitted that the results should not be taken too seriously until appropriate experiments have been carried out. They discussed ways in which the method might be improved. Fisher (1975) appeared to have more success when using this method to identify predictive plant species associated with particular terrace altitude classes in the New Forest.

Automatic contouring and trend-surface plotting aid in the interpretation and presentation of map-oriented information, but they do not necessarily present the most economical summary of the results. The technique of principal component analysis provies a relatively simple method of considering the various land use variables so as to obtain a parsimonious summary of the basic data collected in a survey. Having determined how many dimensions are necessary to account for some desired proportion of the variation revealed by the sample measurements, the analysis also provides the necessary linear functions of the basic land use variables for use in other techniques such as trend-surface analysis (Jeffers, 1970).

Canonical correlation is another little-used technique which is appropriate to surveys where the dependence of the variables of land use can be related to variables of the topography, physiography, and environment. This technique is best regarded as an exploratory tool which will give some idea of the complicated structure of a multivariate relationship. Natural variation is multivariate and consequently there are advantages to a model which analyses the variation of several dependent variables simultaneously. The linear combinations of both the environmental and land use variables may be related to their geographic position by automatic contouring or by trend-surface analysis. They may also be used as the basis for optimisation and simulation techniques (Jeffers, 1970).

McCarthy et al (1974) documented procedures developed for the evaluation of environmental consequences of spatially distributed activities in a region centred on Knoxville, Tennessee. An important aspect of their research is the ability to interrelate, and to show the cumulative effects of, different changes to the environment. The decision maker can begin to interact with the system and see the results of different management decisions. The primary object of their work is to (1) forecast and simulate future changes; (2) evaluate the consequences of alternative plans; (3) determine the optimal solution to given problems; (4) to provide the user with information and computational tools so that he can develop solutions subject to his own criteria.

The types of question which might be asked of the methods of McCarthy et al are, hypothetically:

1) Given predicted increases in employment and urbanisation, what will be the landscape pattern over the next 15 years?

2) Given the landscape pattern change, what would be the effect on privately-owned woodlots of increased forest harvesting by the TVA?

3) If TVA harvests a large number of woodlots and private landowners harvest their own land due to economic pressure, could this affect water quality of the streams in the area?

4) If water quality of streams in the area is affected, would biota of the reservoirs of the area be affected?

5) If reservoir quality is changed, how will various regional publics react through the political system.

Their land cover model recognises the following plant communities: (1) hardwoods; (2) pine-hardwoods; (3) pines; (4) cedar-hardwoods; and (5) old fields. The model simulates the natural successional changes by considering categories of land cover as states in finite Markov chains. As the simulation proceeds, the land allocation model overrides the natural change in some cells (i.e. mapping grid cells) with man-induced perturbations. This causes the land cover model to project changes into neighbouring cells where applicable, thus creating a new vegetative pattern in the natural system. These results can be illustrated by computer maps based on grid cells, or, more effectively, they may be superimposed on relief maps.

This is an interesting approach which seems to be worth following up. Markov models have not been used much in ecology, and their applicability needs to be explored. A Markov chain is a stochastic process in which transitions among various states occur with characteristic probabilities that depend only on the current state and not on any previous state. Only two basic conditions need to be satisfied for valid application of this process: (1) to predict the next state, one need know only the present state; (2) the transition probabilities between two specific states remain constant over time (i.e. it is a stationary process). A Markov chain is 'regular' if any state can be reached from any other state in a finite number of steps, and if it is not cyclic. The fundamental property of a regular Markov chain is that eventually it settles into a pattern in which the various states occur with characteristic frequencies that are independent of the initial state, this is the 'stationary distribution' of states.

Horn (1975) discussed various possible modifications to a basic Markov model which can be used in the study of forest succession. However, there are few studies in which the predictions have been tested against observations. Waggoner and Stephens (1970) calu cúlated the predicted probabilities of occurence after 40 years of species in 327 plots in mixed hardwood forests of Central Connecticut, and compared them with observed probabilities. Although oak persisted less than predicted, the persistence of maple, birch, and minor species; the transition from oak to maple and birch; the transition from birch to maple; and the transitions from other and minor species to maple and birch; could have been rather well predicted in 1937 from the matrix of probabilities for the first decade. A comparison of the steady states predicted from the observed probabilities of the first and fourth decades showed good agreement, apart from oak. If the changes in the forest fitted an ideal Markov chain, the two steady states would be the same. The data suggested that some transition probabilities for the forest can be treated as if they came from a stationary Markov chain.

5. Interpretation of the data : controlling factors

In studying upland areas, we can describe quantitatively the characteristics of individual areas, possibly using computer maps. These maps can be used in a variety of ways. For example, they can be used to find the areal distribution of particular use or capability classes in an area, and to show which areas or sampling locations have a high capability for more than one use. The potential uses may be mutually exclusive, in which case there will be a conflict of interests, or they will be compatible, in which case multi-purpose land use will be possible. Such maps would be useful as an aid to decision making. Different upland areas could be compared on the basis of various properties, e.g. the proportions of the different areas (a) under a given land use; (b) with a capability for a particular use; (c) with particular soil/climate/landform characteristics or combinations, or perhaps with regard to the distances of the sampling points from the nearest roads.
We can also use them to examine the possibilities for change, the likely direction of change, and its impact on the landscape. Let us consider as an example, agriculture and forestry. The land capability classification and maps will tell us what is possible. However, current land use may not achieve this potential because of the presence of controlling factors (constraints) such as: (1) land tenure system, (2) size of farm, (3) labour intensity, (4) capital intensity, (5) level of technical know-how, (6) farm power (source and accompanying implements), (7) demand for products, (8) economics, notably with regard to subsidies and taxation policies. It is evident that a change in one or more of the constraints will lead to a change in the relationship between current use and capability.

Having examined an area on a systematic basis (e.g. grid intersections) and having assigned a capability class to each location, we can determine the percentage of the area which is capable of a given use, and also the area which is currently under a particular use. This gives an indication of the scope for change. For example, if 75% of an area is suitable for forestry but only 5% is forested, there is scope for a 15-fold increase in forest, or extension by a given acreage. We can also say what species would grow at each sampling location, hence maps could be produced showing the appearance of the land at various levels of afforestation. A forestry expert could give estimates of establishment costs and likely yields.

Statham (1972), having assigned to each map square of the North York Moors its grading for capability with respect to a range of uses, attempted to evolve a pattern of 'optimum' uses by allocating to each square the activity with the highest grading for that square. Various weighting systems were used, for example: (a) all activities have equal weightings; (b) weightings for agriculture = 1, forestry = 1, recreation = 3, nature conservation = 3; (c) weightings for recreation = 1, nature conservation = 1, agriculture = 3, forestry = 3. Statham recognised conflict areas as land where the highest grading occurs in the same square for two or more incompatible activities in the equal weighting situation and opportunity areas as land which occurs in the highest grade category for a different use than that existing, even when that activity is weighted against. The main conflict area in his study was the area of open moorland, on which Statham concluded, afforestation should be encouraged and reclamation for agriculture discouraged, although a number of significant heather moors should be retained, mainly for amenity reasons.

Wannop (1972) described the use of Development Potential Analysis, which is, essentially a systematic and comprehensive development of traditional sieve map procedures, in generating alternative strategies in the Coventry - Solihull -Warwickshire Sub-regional study.

As Cunningham (1971) pointed out, decisions about the future land use pattern in the upland and hill areas of Britain are ultimately political decisions, since most forms of contemporary use - agriculture, forestry, tourism, wildlife conservation - depend on some form of Government assistance through grants, subsidies, or taxation policies. Economics dictate that agriculture and forestry should be more profitable, and hence a more rational approach to decisions about land use is required. Further investigation is needed in determining the constraints to various forms of land use and of integrating them in a systematic way so that better decisions can be made.

Some of the political constraints affecting land use are Special Development Orders and planning restrictions such as occur in National Parks, Areas of Outstanding Natural Beauty, Nature Reserves, Sites of Special Scientific Interest. Section 11 of the Countryside Act 1968 emphasizes the desirability of conserving the amenity and natural beauty of the countryside, and this could impose great restraints. Section 14 of the same act requires that advance notice be given for the convertion of moorland and heath into agricultural land.

The land capability is a function of its inherent properties (soil, climatic, etc.) whereas the constraints are separate from it and superimposed on it. The constraints, or controlling factors, are aspects of the organisation of human affairs and can change quite quickly, particularly in the case of economics (which also involves politics). The detailed study of these factors is clearly outside the realm of ecology, and outside experts will need to be consulted.

In this context, the Cornell farm classification (Olson 1974; Olson and Hardy, 1967; Conklin, 1969) is interesting. Farms were examined from a vehicle equipped as an office. Each farm was classified into one of three groups on economic performance data gathered over several years. Farms operating at the "high" level produced about four times more than those at the "low" level, while those operating at the "medium" level produced about twice as much as those at the "low" level. Multiplication of these factors by the number of farms in each class gave relative values of farm productivity within each area, and areas could be compared. Comparison of the ratio high/low productivity farms indicated the relative prosperity of farming in different areas.

Vink (1960) gave an example of a quantitative approach used in the Netherlands, in which suitability was determined by the formula

$$Sa = \left((R.Y.).\,E_1 - R\,(F + C)\,E_2 \right)_{E.T.M.}$$

where Sa is suitability of soil type A, R = the acreage of each crop as percent of total farm acreage, Y = yield of each crop in kg/ha on soil type A, F = fertilizers used, C = other costs, E_1 and E_2 are economic parameters, E and T indicate the economic - technical situation for which the solution is valid, M = the management level for which the solution was calculated. The calculation was based on normalized monetary units and an example was given.

Table 5.1. Categories and groupings of the new international system of land suitability classification (Brinkman and Smyth, 1973).

Category	Order	Class	Subclass	Unit
No. of groupings	3	unlimited	unlimited	unlimited
Groupings	1 suitable	1.1	1.2w	1.2w (1)
		1.2	1.2t	1.2w (2)
		etc	1.2wt	1.2w (3)
			etc	etc
	2 conditionally	2.1	2.1At	
	suitable	2.2	2.1Bt	
		etc	etc	
	3 unsuitable	3.1		
		3.2		
		etc		

The new international system of land evaluation (Brinkman and Smyth, 1973; Vink, 1975) includes a new proposal for land classification based on the system of evaluation developed at the FAO Consultation (Wageningen, 1972). The essential aspects are shown in Table 5.1. The 'order' of the land suitability classification is of the highest significance. Here, the decision must be made whether a particular tract of land is suitable or not for a particular utilization type. Suitable land is defined as "land on which (sustained) use for the defined purpose in the defined manner is expected to yield benefits that will justify required recurrent inputs without unacceptable risk to land resources on the site or in adjacent areas". However, Vink (1975) noted that it is debateable, in some cases, whether or not sustained use is always a prerequisite. The crucial part of this new system lies in the fact that the land use on lands of Order 1 is "expected to yield benefits that will justify required recurrent inputs". Suitability is determined by the net result of outputs minus inputs on a recurrent, usually annual, basis.

Changes in the economic situation of upland farms from depression and declining real incomes in the sixties to comparative prosperity in recent years were discussed by Munro (1974). He noted that considerable emphasis has been placed on the economic condition of farming in the so-called marginal areas, because it has a marked bearing on farmer's attitudes to investment in land improvement and on the competitive position of agriculture as the main form of land use in the hills and uplands. Obviously, many of the smaller farms will require continued Government assistance to aid integration into viable units. Many of the larger family farms, especially those in Wales and the English border counties which have carried out land improvement since the war, are no longer marginal in the true economic sense. Munro considered that, unlike 10 years ago, no arguments can be put forward in favour of large-scale extensive ranching as a dominant form of land use. An example of the approach used by a commercial firm in planning the restructuring of farm units in Wales is given by Matthews Wrightson Land Ltd. (1975).

In considering British upland farms, the simple fact that in 1970/71, the hills of England, Scotland, and Wales, produced 7% of total British gross farm output conceals several vital aspects of the significance of the hills and uplands. The hills and uplands, though producing only about 10% of total livestock and livestock product gross output, are estimated to produce nearly 50% of the British sheep and wool output and between 20% and 25% of British gross cattle output. Clearly, agriculture in the hills and uplands provides a significant proportion of total grazing livestock output, in part as fat animals but mainly, and most importantly, as store stock for further fattening on the lowlands. They are the chief source of basic hardy breeding stock for lowland sheep farms and one important source for lowland beef breeding herds. This is particularly valuable when the lowland herds or flocks are decimated by disease, such as a major foot and mouth outbreak (NEDC, 1973).

Philip (1976) noted that it is difficult to choose between uses in areas where biological production and economic values are low, and information on the benefits to be obtained from different uses is sparse. Much of this type of land falls into ALC categories 4 and 5, and from the point of view of managers of upland areas, this classification is too broad. Also, much of the land has high amenity value, introducing the concept of intangible benefits. Furthermore, the land manager is forced to operate within a complex biological and a complex social system. Past systems of management are proving unsatisfactory. Decisions on related prroblems are being sought without considering their interactions. Taylor (1961) discussed the various pressures, including social considerations, which bear on land use decisions.

One way of examining the effects of the controlling factors and the consequences of policy decisions is by some form of computer simulation or model. This approach has not been used very widely. Voelker (1975), at Oak Ridge National Laboratory, reviewed the experience of a modelling team on constructing a large land-use model. This experience suggested that two types of problem block the evolution of model technology. Problems of the first type are technical and are related to lack of theory, model organization, and data availability. The second, and by far the most important, type of problem is related to the differing perceptions of model builders and model users, and the institutional setting that generates these perceptions. For example, the planners experienced difficulty in justifying the hiring and training of programmer's and data technicians in order to take over the modelling technology, and they were forced to spend a great deal of time in educating managers, sponsors, and users. In addition, the time-scale initially envisaged for the transfer of the model technology was too short. The planners' sensitive position in public issues made them hesitant to deviate from traditional techniques and accept new sophisticated procedures before feeling confident in simpler versions.

Modelling was thrust into the public consciousness by the achievements of the aerospace industry long before the science of land use was ready to support land-use modelling. Expectation arose, to a large extent, from the genuine need felt by planners for improved technology. However, once they were linked to a semi-public environment, models were restricted in their ability to evolve further. Even though it would have been useful, the models could not be treated as research vehicles; they were expected to produce accurate, specific, output geared to real situations. Because of the expectations placed on them, model builders were forced to be reticent about the negative aspects of their models. Decision-makers do not normally optimize all possibilities because of the limited capacity of the human mind. Furthermore, it is beyond the capabilities of both the model and the decision-maker to optimize all possibilities in an absolute sense. Hence, models should allow the decision-maker to consider more options in more detail than he would otherwise, without overwhelming his capacity to visualize relative trade-offs.

Voelker noted that by structuring a land-use model with independent sub-programs, problems stemming from a single large program could be overcome. Such sub-programs are more readily comprehensible, more flexible, and better adapted to their function because they operate with fewer individual constraints. Although this approach lengthens the time taken to run the model, and has a greater risk of user-induced error, the advantages for outweigh the disadvantages. Using an interactive approach, the user can guide the simulation through a variety of alternative paths; he can review intermediate results and change test conditions at intermediate decision points. Such sub-programs would be more convenient for routine problem solving.

A decision tool which has been used increasingly in recent years in the U.S.A. is linear programming. The U.S. Forest Service uses linear programming in both timber management and land use planning, and some large private companies have been using the method in planning and management. Linear programming involves the optimization of a linear objective function by allocating resources among activities subject to linear constraints. The decision on whether or not to use linear programming depends upon whether the problem can be represented in a form that meets the assumptions of linearity in its objective and constraint equations to a sufficient degree. One way of testing the appropriateness is through sensitivity analysis (Bell, 1977).

Goal programming is a variation of linear programming in which the mathematical model is so constructed that the single objective to be maximized or minimized is composed of several goals. Maximizing or minimizing the 'doctored' objective identifies the activities that result in the closest achievement of several goals instead of just one (Dane et al, 1977). One of the most promising applications of goal programming is to the management of forest resources (Field, 1973, 1977; Schuler et al, 1977). Goal programming enables resource specialists and decision makers to interrelate. The specialists provide the coefficients of the model, the decision makers list the activities to be considered and assign significance to the goals. Dane et al (1977) experimented with the use of goal programming to assist land use planning in the Mount Hood National Forest, Oregon. After several computer runs, the planners were able to discern: (a) How land allocations shifted with different combinations of goals, and what outputs were controlling those shifts; (b) What outputs or effects were most limiting, and thus most sensitive and in need of priority attention; (c) How sensitive goal priorities were and how they affected outputs; (d) What was being given up or traded to achieve a higher priority goal.

There is clearly scope for the thoughtful application of computer methods to the study of the complex interactions of factors influencing land use, and to examine the consequences of suggested courses of action. As always in this type of work, it is necessary to recognize and avoid pitfalls (Majone, 1977).

6. The impact of land use on the land and landscape

Clearly forestry has a marked visual impact on the landscape. What about farming? Cunningham (1971) did not believe that a case could be substantiated for forest production, as opposed to shelter belts, on the $4\frac{1}{2}$ million acres of enclosed upland permanent pastures, or indeed, on land which can be improved to be of similar productivity. He was of the opinion that systems should be sought which will economically exploit improved levels of animal output. One conception is a two-pasture system. This would comprise first, an area of better quality herbage such as Agrostis - Festuca, possibly upgraded with lime and slag, and clover, or a newly-established pasture using the technique appropriate to the conditions. Second, there would be an area of improved hill land. Grazing management would be based on intensive use of the improved pasture during two periods of the year - April to July and, after a rest, from October to November or December. Dry ewes and hoggs would run on the open hill throughout the year and the lactating ewes would be favoured in summer.

In order to increase his income a farmer might intensify. This would n eed the erection of permanent buildings, with some impact on the landscape. On the question of intensification, Munro (1974) noted that the Pwllpeiran scheme has shown the technical feasibility of introducing large-scale pasture improvement in areas with an annual rainfall in excess of 2500 mm (98.4 ins) up to altitudes of 700 m (2297 ft). According to Stapledon, only 1% of the land surface of Wales lies above this elevation and less than 5% of Great Britain. The economic viability of surface improvement in the hills will depend on its durability over a succession of hard winters, such as those experienced in 1947, 1963 and 1969, and also on the cost of providing access for the large quantities of lime and fertilizers which are required.

On upland farms and on the inbye portion of hill farms, intensification will mainly take the form of increased use of fertilizer nitrogen. Research will be needed on possible long-term effects on eutrophication (Munro, 1974). Munro considered that the financial benefits resulting from land reclamation will become apparent in the general maintenance of farms and buildings, and that where it is decided that in special areas no land improvement will be allowed, then it is the duty of the nation to see that adequate compensation is made, as in the German National Park system.

Surface treatment is gaining momentum in Wales as a result of promotion by the Advisory Service, and its visual impact can already be assessed. The replacement of areas of Molinia, Nardus, Festuca, and heather moor by dark-green ryegrass - clover pastures adds variety to the landscape and enhances its aesthetic appeal. Most of the steeper, rocky slopes and wetter bog communities remain virtually unchanged, as it is necessary to replace only 30-40% of the rough grazing on a hill to effect a substantial improvement in livestock nutrition (Munro, 1974).

Sheep farmers are conservative in their habits, and a sheep farmer is unlikely suddenly to sell all his stock and plant trees. Therefore a change from agriculture to forestry is likely to occur only with some change in the controlling factors. For example, if sheep farming in upland areas became uneconomical, there would be a drift of farmers from the land (as happened in parts of Wales). The farms might be taken over by a private enterprise for forestry, or by the Forestry Commission.

Land management, whether for agriculture, forestry, nature conservation, depends for its success on an understanding of ecological principles. In some cases, man is establishing more or less artificial ecosystems such as crops and plantations, while in other cases he is seeking to modify existing types of biological community. For such activities to succeed, it is essential that the processes involved be understood. The relative merits of the various forms of land use must be decided not only on economic and social grounds, but also on the basis of sound ecological information on the long-term effects of the various types of land use and management.

There is a tendency among land managers to assume that no changes occur except those which they themselves bring about. This is far from the case. Ecosystems which may appear stable, and which exhibit little sign of change in the short-term, may in fact show long-term trends of change. This is particularly so in the uplands, where the predominantly wet climate means that the soils are leached and thus tend towardsloss of nutrients and increase in acidity. Professor W. H. Pearsall pointed out that when sheep are cropped, minerals, notably nitrogen, sulphur, and phosphorus in proteins and calcium and phosphorus in bones, are removed from the ecosystem, and there is only a small replacement by rainfall. There is thus a constant drain on soil fertility. He used to maintain that the uplands should never have been deforested, as tree roots bring up nutrients from the weathering parent material or deep drift and return these to the soil surface in their litter, thus helping to counteract the leaching.

However, little is understood of the chemical and biochemical processes involved, the quantitative balance of inputs and losses, or the rates of change. Certain species may perform this function more efficiently than others, and some species are thought to have adverse effects (i.e. to accelerate acidity and leaching trends) and thus reduce the number of options open for the use of the land. However, the evidence is sparse and the effect of a given species may vary with conditions. Research is needed on this topic.

Tinsley (1975) noted that in Nidderdale the tenant farmers are limited in the numbers of sheep which they are allowed to keep as the interests of sheep and grouse conflict. The present productivity of the moors is carefully maintained, but the balance is precarious. There is a long tradition, going back to medieval times, of firing the moors. Tinsley concluded that the management practices of recent centuries have produced an inherently unstable environment. Burning, even when controlled, leads to an increase in the acidity of the surface peat and dries it out, making it easily eroded. Accidental fires occur with increasing frequency as recreational pressure increases. Should human pressure be reduced, it is debatable whether any natural tree regeneration could now occur.

Philip (1976) considered that over the last two hundred years or so, major changes in the use and methods of management of the extensive upland areas have been induced by relatively short-term and arbitrary financial advantages unrelated to the sustained production potential of the land. The diversity maintained by the older systems of upland farms and crofts has been destroyed, and the new designed only to maximize the short-term gains, or, in the case of the grouse moors, to satisfy a particular demand for sporting facilities. Exposure is a major factor limiting the productivity of the uplands, yet we have allowed the nibbling of the sheep and the burning of the heather to destroy tree cover, resulting in a loss of diversity and production (See also Simmons, 1966; Tivy, 1973).

Upland soils have been exposed to hundreds of years of exploitation, mostly by sheep grazing. As these soils represent an important resource, we should aim to manage them so as to increase their ability to produce products which we need. If we understood more about the processes involved, we could suggest ways of managing upland soils to improve their quality and productivity. For example, there is the possibility of using trees to improve upland grazings (e.g. Douglas and Hart, 1976). Apart from the use of trees for shelter, the leaf litter could change the conditions in the humus layers and thus influence the ground vegetation, which would also be influenced by the improved microclimate. At the same time, the trees could assist in removing surplus water, which might be cheaper than installing drainage systems. While it is clear that uncontrolled grazing may be harmful to forests, especially where there is regeneration, an integration of forestry and grazing may be practicable and may increase the return from uplands (e.g. Adams, 1976a, b).

The Forest Research Institute, Rotorua, New Zealand, became interested in the concept of combined forestry and grazing towards the beginning of the 1970's, when radiata pine profitability studies showed that an open-spaced, pruned crop offered the forest owner better financial prospects than the traditional forestry regimes. The application of this concept in New Zealand was discussed by Knowles (1975) with comments by Harper (1975). The New Zealand Forest Service and the Department of Lands and Survey are jointly developing a 6705 hectare integrated farm/forestry project (Strand, 1976).

One obstacle to this approach is the present division between farming and forestry, with the two land uses regarded as competitors. There may also be practical difficulties in managing estates with an integrated approach. Lindsay (1977) discussed problems encountered in Scottish estates during the period 1700-1850, and Adams (1975) reviewed world literature on the grazing of domestic livestock in forests. There seems to be a need for farmers, foresters, and scientists to explore the possibilities of a new approach in British uplands.

Ideally, classification of land for potential use should take into account the likely impact of different uses on the land and landscape. Unfortunately, at the present state of our knowledge, the impact will not always, perhaps only rarely, be predictable.

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