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Table 6. Tropical trees with timber potential vegetatively propagated in tropical glasshouses at the Bush Estate, near Edinburgh.

1. Moist forest		
	West Africa	*Ceiba pentandra* *Chlorophora excelsa* *Nauclea diderichii* *Terminalia ivorensis* *Terminalia superba* *Triplochiton scleroxylon*
	East and Central Africa	*Dalbergia melanoxylon* *Vateria seychellarum*
	Central and South America	*Albizzia carabeae* *Cedrela odorata* *Cordia alliodora* *Swietenia mahogani* *Tipuana tipu* *Toona ciliata*
	S. E. Asia and Australasia	*Agathis australis* *Agathis damara* *Agathis macrophylla* *Agathis obtusa* *Agathis robusta* *Agathis vitiensis* *Araucaria hunsteinii* *Gmelina arborea* *Shorea albida* *Shorea almon* *Shorea contorta* *Shorea macrophylla*
2. Savannah and dry forest		*Acacia senegal* *Afzelia africana* *Azadiracta indica* *Khaya senegalensis* *Prosopis juliflora*

years ago. *T. scleroxylon* is only one of a wide variety of tropical trees from moist forests to semi-deserts (Leakey & Last 1980) that can be propagated vegetatively (Tables 6 and 7). The possibilities of similarly domesticating other trees for the production of timber, fuel and a whole range of valuable minor products seem virtually limitless.

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Table 7. Tropical trees capable of providing 'amenity' or minor forest products vegetatively propagated in tropicalised glasshouses at the Bush Estate, near Edinburgh.

Fruit	*Casimiroa edulis* *Chrysophyllum cainito* *Citrus halimi* *Shorea macrophylla* *Tamarindus indica*
Pharmaceutical	*Teclea verdoorniana* *Oricia suaveolens*
Kapok	*Ceiba pentandra*
Multi-purpose (gum/fodder/tannins etc.)	*Acacia senegal* *Prosopis juliflora*
Amenity	*Delonix regia* *Caesalpina spinosa*

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AN INTEGRATED SYSTEM OF LAND CLASSIFICATION

Introduction and objectives

A system of land classification should provide a framework within which to identify all land uses, both actual and potential. However, most methods adopted by agencies such as the Ministry of Agriculture, Fisheries and Food (MAFF), the Department of Agriculture and Fisheries, Scotland (DAFS), and the Forestry Commission (FC) have usually had restricted objectives, in keeping with their statutory obligations. As a result, sets of independent and non-interactive descriptions, often based on a variety of irreconcilable subjective judgements, have been produced at one of 2 levels, either (i) broadsweep generalised assessments rarely supported by detailed ground surveys, or (ii) complete censuses which are time-consuming and expensive to make. However, it is possible to visualize a unified system of classification, with subjective judgements restricted to a minimum, which could provide a common framework for many users at one and the same time, not only for agriculture and forestry, but also for such purposes as the conservation of wildlife and water resources, and the provision of recreation.

Recent surveys, starting with a part of Cumbria (Bunce *et al.* 1975) and expanded to include the entire region (Bunce & Smith 1978), have encouraged the evolution of a classification based on the multivariate analysis (Hill *et al.* 1975) of 282 environmental attributes concerned with:

i. Climate—eg temperature taken from 1:1 000 000 climate maps.
ii. Physiography—eg altitude taken from 1:50 000 Ordnance Survey maps.
iii. Geology—eg bedrock taken from geological maps, and
iv. Human artefacts—eg road lengths taken from 1:50 000 Ordnance Survey maps.

In surveys of Cumbria, data were recorded for every 1 km square of the National Grid, which provides a useful, and readily available, reference system. The square usually, and desirably, contained a fairly restricted range of environments and was of a size that could be readily encompassed if, and when, field surveys were required. Because it would be impossible to survey every one of the 230 000 squares, measuring 1 km^2, into which Britain can be divided, it was decided to focus on a 1 km square at each 15 × 15 km intersection, giving a total sample of 1 228 squares; a further 4 826 squares have been abstracted more recently. Multivariate analysis of the 282 attributes classified the squares into 32 land classes (Figure 13) which were produced as a result of a series of successive dichotomous divisions for which key indicator attributes were identified. Knowledge of these key attributes enables 'unknown' 1 km squares to be assigned rapidly to their appropriate land classes.

How can these land classes, based on physical attributes alone, be interpreted? Can they be associated with areas with different assemblages of natural or semi-natural plants, with different soils or combinations of soil types, with different mosaics of agricultural crops, forests and woodlands? In order to verify the ecological worth of the land classes, surveys were made of 8 replicate, randomly-chosen squares of each of the 32 land classes. Records were made of:

i. the occurrence of species of higher plants and a restricted list of bryophytes in (a) each of 5 random quadrats, each 200 m^2 and (b) linear 'quadrats' 10 m × 1 m alongside streams, roads and hedges;
ii. soil profiles exposed after digging a pit, up to 75 cm deep, in the centre of each of the quadrats used for listing plants; and
iii. land uses (using 65 categories), the composition of forests and woodlands, and the occurrence of different breeds of farm animals.

By associating actual land uses with the different land classes, it has been possible to predict, with high degrees of accuracy, land uses in unsurveyed areas of Britain. The same has been done for soil types, but many other aspects of importance to physical planning, eg landscape types and possible forestry impacts, remain to be investigated.

RESULTS

Land class descriptions

Although there are frequent outliers, most of the 32 land classes have well-defined patterns of distribution within Britain indicating the existence of continuous environmental gradients (Figure 13). For example, the distribution of land class 4, fenland, is much as expected, virtually confined to East Anglia, but that of some of the others was not foreseen, eg land class 7, which extends from the coastal regions of west England into west Wales and south-west Scotland. Two examples of land classes may be shown with reference to Scotland, where land classes 24 and 25 have contrasting distributions. Land class 24, typical of north and western Scotland (Plates 9 & 10), includes high altitude sites with comparatively heavy rainfall (Figure 14, and contrasts with land class 25, tending to be distributed in the Scottish borders and near the east coast of Scotland and northern England (Plates 11 & 12), which is located at lower altitudes with much less rain (Figure 15), both classes having similar light regimes. From assessments of the soil pits in replicate quadrats and of the surveys made of land use and vegetation, land class 24 is dominated by rankers and peats; its predominant land uses are hill grazings and grouse moors, with its natural vegetation having appreciable amounts of purple moor-grass and heather. In contrast, the soils in land class 25 include a range of brown earths, with barley and leys being the major land uses, and perennial rye-grass being the dominant plant species in natural assemblages.

These thumb-nail sketches show that the land classes, which can be made from existing maps, provide arrays of habitats which are ecologically meaningful, and bring together locations with similar types of soil and land use. For the future, it is intended to explore the relationships of land classes with visual features of the landscape, and with aspects of recreation, amenity and conservation. As these series of linkages are extended, the inter-relations between different land uses should be clarified, a task that has proved virtually impossible until now, in the absence of a framework upon which all land uses can be inserted with equal facility. For the present, natural vegetation in Britain has been classified into 75 types (a key will shortly be published) which provide a supporting system for land use and land type classifications.

LAND CLASS 24

High altitude rugged mountains of north and western Scotland with moorland vegetation

Topography

Mean max altitude (m)		611
Mean min altitude (m)		267
Altitude class	0-76 m	1
(mean % area)	77-198 m	12
	199-488 m	56
	489-1189 m	31
Slope (°C)		18

Climate

Mean min temp January (°C)	0·1
Mean max temp July (°C)	18·0
Mean soil deficit (mm)	2·5
Mean annual rainfall (mm)	2290
Mean snowfall days	51·4
Duration bright sunshine (hrs)	4·1

Soils

Mean pH	4·5
Mean loss on ignition (%)	59·3
Percentage of total area	
Brown earths	5·0
Gleys	7·5
Gleyed brown earths	–
Brown podsolic soils	2·5
Rankers	37·5
Peaty podsols	17·5
Podsols	7·5
Peaty gleys	12·5
Peats	30·0

Land use

Percentage of total area	
Wheat	–
Barley	–
Other crops	–
Horticulture	–
Leys	–
Permanent grass	–
Rough pasture	2·9
Bracken	3·7
Rushes	1·6
Moorland	10·5
Peatland	45·5
Mountain grass	15·7
Woodland	8·6
Cliffs/sand/mud	9·9
Built-up	0·6

Native species

Percentage cover of major species	
Perennial rye-grass	–
Ling heather	12·5
Common bent	1·0
Purple moor-grass	38·8
Yorkshire fog	0·1
White clover	0·8
Cock's-foot	–
Mat-grass	6·9
Bracken	4·1
Crested dog's-tail	–
Italian rye-grass	–
Timothy	–
Deergrass	8·3
Sheep's fescue	1·9
Creeping bent	–

Figure 14 Description and occurrence of land class 24, high, steep-sided rugged mountains.

Plate 9 — Glen Cannich, Highland Region.
Photograph R. G. H. Bunce.

Plate 10 — The top of Glencoe, Highland Region.
Photograph R. G. H. Bunce.

Common caption: Land Class 24 — High altitude rugged mountains of north and western Scotland, with moorland vegetation.

Plate 11 — The Black Isle, Highland Region.
Photograph R. G. H. Bunce.

Plate 12 — Annan valley, Dumfries and Galloway Region.
Photograph R. G. H. Bunce.

Common caption: Land Class 25 — Low altitude land in eastern Scotland and northern England mainly under intensive cultivation.

LAND CLASS 25

Low altitude land in eastern Scotland and northern England, mainly under intensive cultivation

Topography

Mean max altitude (m)		144
Mean min altitude (m)		88
Altitude class	0-76 m	42
(mean % area)	77-198 m	30
	199-488 m	28
	489-1189 m	–
Slope (°)		3

Climate

Mean min temp January (°C)	0·3
Mean max temp July (°C)	18·3
Mean soil deficit (mm)	8·0
Mean annual rainfall (mm)	880
Mean snowfall days	40·4
Duration bright sunshine (hrs)	4·8

Soils

Mean pH	6·1
Mean loss on ignition (%)	6·5
Percentage of total area	
Brown earths	38·5
Gleys	33·3
Gleyed brown earths	20·5
Brown podsolic soils	2·6
Rankers	5·1
Peaty podsols	–
Podsols	–
Peaty gleys	–
Peats	–

Land use

Percentage of total area	
Wheat	0·3
Barley	31·3
Other crops	10·5
Horticulture	2·5
Leys	32·4
Permanent grass	5·5
Rough pasture	5·1
Bracken	–
Rushes	1·3
Moorland	–
Peatland	–
Mountain grass	–
Woodland	2·3
Cliffs/sand/mud	1·8
Built-up	6·4

Native species

Percentage cover of major species	
Perennial rye-grass	20·3
Ling heather	–
Common bent	6·0
Purple moor-grass	–
Yorkshire fog	3·1
White clover	4·6
Cock's-foot	1·0
Mat-grass	–
Bracken	–
Crested dog's tail	1·0
Italian rye-grass	2·0
Timothy	2·4
Deergrass	–
Sheep's fescue	–
Creeping bent	2·3

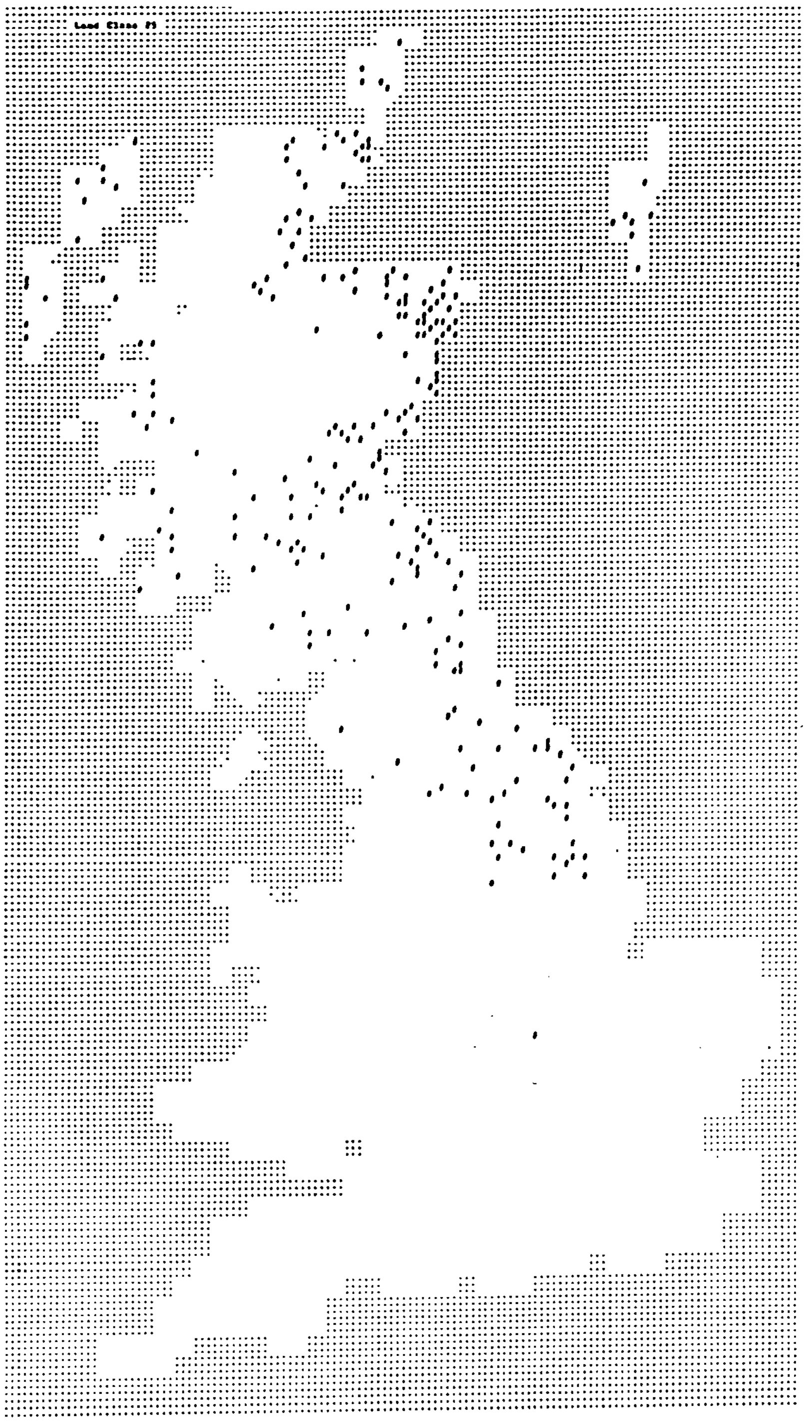

Figure 15 Description and occurrence of land class 25, northern lowlands with much less rain than land class 24 (see Figure 14).

Land classes and land use

The proportions of Britain assigned to different land classes can be calculated readily by relating numbers of squares in each land class to the total number of squares in the grids covering Britain. When assessments are made of areas devoted to different land uses, various errors are incurred. First, the proportions of each land class devoted to different land uses are calculated from samples and not from total enumerations. The mean values should, therefore, be qualified by their confidence limits. Second, the land use categories used by ITE and the differing agencies are not completely coincident. For example, the MAFF distinction between temporary and permanent grass differs from that adopted by ITE. Despite these reservations, which need further examination, estimates of areas devoted to different land uses agree reasonably with independent assessments. Unpublished sources apportion 90·6% of Britain to rural and 9·4% to urban land uses: estimates derived from the present method of land classification are 92·4:7·6. Estimates of afforested areas and those devoted to grassland and arable crops are virtually coincident. In comparisons with crop data from the Annual Reviews of Agriculture 1977 and 1978—the years in which the field surveys were made—there was again a high degree of agreement (Table 8). Broadly, the degree of agreement was maximal for crops occupying large areas, eg wheat, barley, oats and potatoes.

Table 8. Comparison of estimates of areas of different crops (km^2) in GB derived from (i) MAFF/DAFS statistics for the years 1978 and 1979 (the years of the field survey) and (ii) a survey of cropping in replicate areas of the different ITE land classes.

	Annual Review of Agriculture km^2	Estimates based on ITE land classes km^2
Wheat	11700	10600
Barley	23100	21200
Oats	1820	1830
Mixed grain	189	328
Rye	100	51
Potatoes	2100	2010
Sugar beet	2050	1470
Oil seed	600	445
Vegetables	2160	2340
Orchards	530	597
Maize	170	269
Lucerne	170	196
Fodder crops	2080	1900

Correlation between the 2 sets of data is r = 0·999*** P = <0·001

Having reconciled land use estimates based on the land classification described in this article with those published elsewhere, a comparable examination has been made by Drs D. F. Ball and M. Hornung of the occurrence of different soil types. They made comparisons with soil maps of Britain and, with the exception of peaty podsols which are difficult to define, agreement was excellent, eg brown earths 30·6% to 33·5%, gleys 26·3% to 27·8%, and peats 11·6% as opposed to 10·8%.

The land classification project was initiated to meet problems posed locally in Cumbria. Now, having developed a national base, further regional interest can be investigated. For example, to aid the strategic consideration of land use in the region of Fife, a knowledge of land classes (derived from maps) and their associated (i) land uses and (ii) assemblages of plants enabled the estimates in Tables 9 and 10 to be prepared in a few days/weeks without field work. The tables show that:

a) Arable crops and leys are nearly equally common.
b) The proportion of Fife devoted to urban uses is twice as great as in Scotland generally (a figure in keeping with population distributions).
c) Pastures (leys and permanent) constitute 37·5% of the region (Scottish national average is 18·9%).
d) A quarter of the short-term leys in Scotland are found in Fife.
e) There is comparatively little woodland in the region, although it covers 100 km^2.
f) The region is primarily cultivated; it is also very uniform compared with other Scottish regions.

Excepting the urban areas and those devoted to arable crops, most of Fife is covered by vegetation which is grazed (22·7% ley; 14·8% permanent pasture; 6·8% rough pasture; and 7·9% moorland). Within the 'grazings', perennial rye-grass is the commonest species, followed by common bent and white clover, a distribution closer to the British average (perennial rye-grass, heather and common bent) than that of Scotland (heather, perennial rye-grass and purple moor-grass).

Comparisons such as these enable the resources at a regional level to be put readily into a national context. The system can be used in a similar way to examine potential impacts at a regional level—for example, a preliminary study in Fife suggested that only 14% of the land is likely to be planted with trees, whereas the figure is 32% for Scotland as a whole.

The evidence, so far, suggests that the array of objectively defined land classes provides a satisfactory series of strata upon which to structure surveys. Where it has been possible to compare the results of statistically designed partial surveys, based on land classes, with total enumerations, the degree of agreement has usually been highly satisfactory.

Further developments

Reference has been made to soil types and the growth of plants, but the variety of associated interests would seem to be extremely wide. So far, the exploitation of the land classification described in this report is in its early stages of development. It has been used to help the objective enumeration of vegetation on land adjacent to railways, and to arrange collections of seed from naturally regenerated birches subject to different selection pressures, in this instance equated with land classes. Perhaps more excitingly, it is being used in an assessment of the potential production of biomass as a

Table 9. Areas devoted to different land uses in the region of Fife compared with those in Scotland and GB

	Total GB		Total Scotland		Area in Scotland as % of GB	Fife		Area in Fife as % of	
	km²	%	km²	%		km²	%	Scotland	GB
Ley	34 800	15	7 300	9	21	300	23	4·3	0·9
Permanent pasture	29 000	13	7 300	9	25	200	15	2·8	0·7
Rough pasture	22 300	10	10 000	13	45	100	7	0·9	0·4
Moorland	35 100	15	26 100	34	75	100	8	0·4	0·3
Arable	43 200	19	7 600	10	18	300	24	4·3	0·8
Urban	30 000	13	5 100	7	17	200	13	3·6	0·6
Water and rock	12 900	6	5 400	7	42	50	3	0·9	0·4
Woodland	22 100	10	8 400	11	38	100	7	1·2	0·4

Table 10. Areas of different native species occurring in the combined ley, permanent pasture, rough pasture and moorland categories of Fife, Scotland, and Great Britain (list restricted to the 20 commonest species in GB)

	% of total GB area	Total predicted km²	% of total Scotland area	Total predicted km²	% of total Fife area
Perennial rye-grass	9·8	22 500	8·9	5 330	21·5
Heather	6·1	13 900	16·8	10 100	2·3
Common bent	3·3	7 600	3·5	2 110	6·7
Purple moor-grass	2·4	5 400	6·8	4 090	1·5
Yorkshire fog	2·0	4 650	1·3	1 020	2·4
White clover	1·8	4 170	2·2	1 340	5·5
Cock's-foot	1·3	3 070	0·7	582	1·1
Mat-grass	1·3	2 900	3·1	1 870	0·4
Bracken	1·3	2 880	1·2	981	0·3
Crested dog's-tail	1·2	2 780	0·8	664	1·6
Italian rye-grass	1·2	2 700	0·7	563	1·4
Timothy	1·1	2 480	0·8	653	1·5
Deergrass	1·0	2 390	3·3	1 960	0·3
Sheep's fescue	1·0	2 380	1·2	960	0·4
Creeping bent	1·0	2 360	0·4	355	1·3
Wavy hair-grass	0·9	2 060	2·1	1 270	0·8
Sweet vernal-grass	0·7	1 600	0·8	658	0·6
Meadow-grass	0·7	1 500	0·5	382	0·4
Red fescue	0·6	1 440	0·6	463	0·8
Bilberry	0·6	1 330	1·1	912	0

renewable source of energy. In this project, agriculturists, foresters and ecologists, acquainted with the production of natural vegetation, were asked to assign production estimates for their differing 'crops' to the different land classes. From these estimates, it was a single step to calculate a figure for biomass potential which, in the instance, suggests that natural vegetation might be locally important as a renewable source of energy. This calculation included the concept of 'optimisation', the area in which land classification has its greatest potential. In Cumbria, attempts are being made to devise optimal patterns of land use for that region, in response to a series of politically decided objectives.

If it were decided to increase the area afforested, what would be the implications of this decision on other land uses and on the landscape? The use of linear programming and other mathematical models will facilitate investigations into these impacts, and is an area of research for future study. At present, in Britain as elsewhere, most discussion is concentrated on the implementation of regional changes without adequate monitoring of the effects of these changes. The present land classification enables changes to be monitored speedily, cheaply and effectively: there is thus no reason why direct and indirect effects should not be monitored at regular intervals in order to identify impacts that were not expected.

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