COUNTRYSIDE SURVEY 1990

MAPPING THE LAND COVER OF GREAT BRITAIN USING LANDSAT IMAGERY: A DEMONSTRATOR PROJECT IN REMOTE SENSING

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SUMMARY

1. The Land Cover Map of Great Britain is the first such map since the 1960s, the first to be readily accessible to end users since the 1930s and the first ever in digital form. It was launched by the NERC and BNSC in July 1993.

2. The land cover mapping was undertaken as a BNSC demonstrator project, with the DoE contributing as a user under the Countryside 1990 (CS1990) project.

3. The land cover was mapped using a supervised maximum likelihood classification of Landsat Thematic Mapper data.

4. The resulting database records 25 cover types, consisting of sea and inland water, beaches and bare ground, developed and arable land and 17 semi-natural vegetation types comprising 3 woodland classes, 4 dwarf shrub communities, bracken, 3 wetland classes and 6 grassland types.

5. The maps take the form of grid-cell data, each cell representing a 25 m square on the ground. A minimum accurately mappable area of 1 ha gives land cover patterns at a field by field scale. In addition, features with strong spectral signatures (eg water bodies and woodlands) may show patterns down to a minimum mappable unit of 0.125 ha.

6. By combining summer and winter data, classification accuracy was substantially improved over the levels normally associated with single-date analyses: in particular, the summer-winter data separated semi-natural vegetation, with its permanent cover, from arable areas which were seasonally bare, which in turn were distinguished from built-up areas which were permanently bare. Furthermore, the winter data distinguished between deciduous and evergreen vegetation.

7. Comparisons with independent ground reference data showed correspondences which varied between 67% and 90% depending on the level of detail at which comparisons are made.

8. The maps have been integrated with data from CS1990's sample-based, field survey, which recorded detailed information on land cover, land use, linear and point features and species composition. This will allow site-specific estimates, based on the details recorded by field-survey, to be refined using maps of the generalised cover patterns in that region.

9. The cover maps and sample field data have been built into a PC-based information system, at 1 km resolution, for landscape planning and management.

10. Current applications of the cover map are outlined in the report. Examples include studies of species diversity, biogeography and environmental chemistry, with relevance to biological conservation, land use planning, and landscape management.

11. The growing interest in the use of the land cover map is illustrated by lists of organisations who attended the launch, and by examples of new potential applications currently under investigation by user-organisations.

INTRODUCTION

This is the Final Report of a project to compile a national, digital, land cover map from satellite images. The Institute of Terrestrial Ecology (ITE) 'Land Cover Map of Great Britain' was launched on 12 July 1993 by Natural Environment Research Council (NERC) and the British National Space Centre (BNSC) in a presentation to 200 guests, introduced by the Space Minister, Rt Hon Patrick McLoughlin.

This report outlines the methods used to produce the Land Cover Map of Great Britain, the results obtained, and the applications of the data.

The Land Cover Map of Great Britain is an integral part of the Countryside Survey 1990 (CS1990), sponsored by the Department of the Environment (DoE). In addition, CS1990 provides field-recorded information on land use and the ecology of Great Britain in 1990. CS1990 aimed to quantify past changes, and is a baseline against which to measure changes in the future.

The integration of the Land Cover Map with the other elements of CS1990 is the subject of separate reports to the DoE (Barr *et al.* 1993; Fuller *et al.* 1993), though summary details are given here. The CS1990 project has spawned a DoE-funded 'Comparison of Land Cover Definitions' (Wyatt *et al.* 1993) which also is briefly summarised in this report.

This report reviews applications, current and planned. It also records the range of potential users, as evident from organisations represented at the Launch or who have subsequently made enquiries.

The report concludes with a forward look to the future for land cover mapping of Britain from space.

BACKGROUND

There has been no complete map of the land cover of Great Britain since the early 1960s (Coleman, 1961; Coleman & Maggs 1965) and no published map since that made in the 1930s (Stamp 1962). None of the cover maps, until now, have been available in digital form. Thus the process of land use planning in Britain has been based, at best, on piecemeal surveys, which are often incomplete and may be incompatible.

Satellite images are particularly valuable for mapping large areas. The CORINE programme on environment has set out to map all of the European Community, but using visual interpretation and manual mapping methods to produce a generalised product with minimum mappable units of 25 ha (CEC, 1992; Wyatt & Fuller, 1992). Computer classifications of land cover have been made of the Netherlands (Thunnissen *et al.* in press), Finland (Kuittenen & Sucksdorff, 1987) and Sweden (Satellitbild, 1992).

ITE's experiments with Landsat Thematic Mapper (TM) images, especially studies in lowland Cambridgeshire and upland Snowdonia (Fuller et al. 1989 a & b, Jones & Wyatt, 1989; Fuller & Parsell, 1990), showed the data to be capable of providing information on major cover types and land uses, at field by field scale, for all of Britain. The use of composite summer/winter data proved particularly useful to improve the detail and accuracy available from satellite imagery (Fuller & Parsell 1990).

By 1990, it was apparent that ITE's use of TM, for land cover mapping in Britain, had evolved from the research and development stage to operational status. As a result, funds were sought for the production of the Land Cover Map of Great Britain and these have been provided equally by NERC and BNSC.

At that time, a field-based sample survey was being planned, sponsored by NERC and the DoE. In this study, ITE surveyed, in detail, a stratified random sample of 1 km, National Grid squares, recording land cover and use, information on linear and point features, and quantitative data on flora and aquatic invertebrates. The sampling strategy used 32 strata, namely the ITE 32 Land Classes (Bunce & Heal, 1984; Barr 1990; Bunce *et al.* 1992), which were classified by analysis of biogeographical data from published maps. The DoE wished to incorporate land cover data derived from remote sensing, and so represented a key end-user of the Land Cover Map. They funded the integration of the field survey and remotely sensed data in the Countryside Information System, a PC-based decision support system for landscape planners and managers. Thus Countryside Survey 1990 (CS1990) became the 'umbrella-project', for a wide range of individual surveys.

AIMS

The land cover project

1. To compile a digital map of land cover in Great Britain

2. To make quantitative assessments of accuracy

3. To integrate the map with other data in a GIS environment, including demonstrator output.

This report

To record details of:

1. image availability

2. land cover classes

3. methods used for classification

4. methods used for post-classification corrections

5. results in terms of maps and output data

6. accuracies measured against independent surveys

7. integration of the Land Cover Map of Great Britain with CS1990 field data

8. integration in the Countryside Information System (CIS)

9. applications, past, present and future

10. areas for future developments of remote sensing for land cover mapping

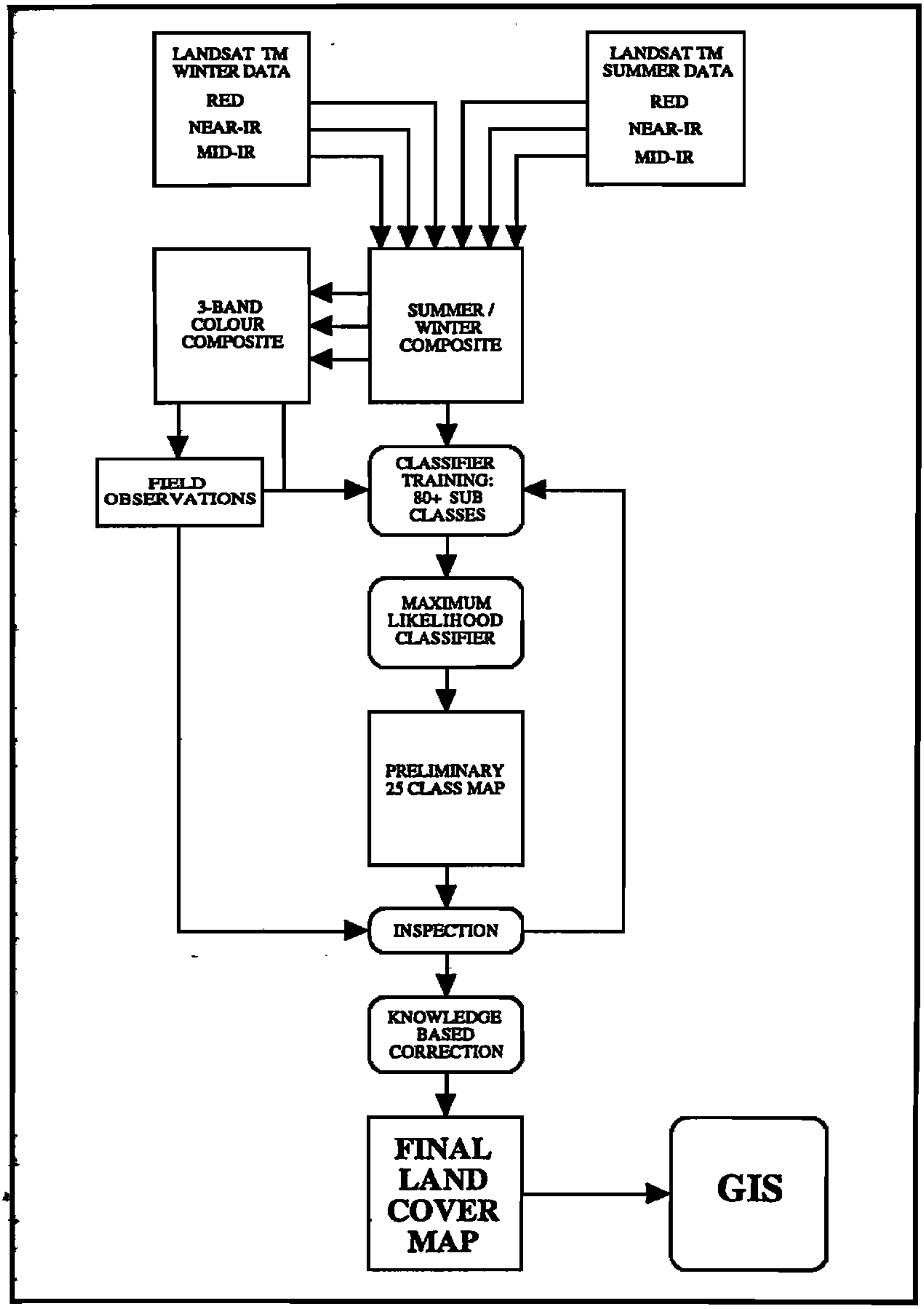

Figure 1. Diagram summarising methods used to produce the Land Cover Map of Great Britian.

MAP PRODUCTION

The mapping process involved geometric correction of summer and winter scenes, co-registration of summer-winter pairs of scenes, field reconnaissance of sample areas, a maximum likelihood classification based on field reconnaissance, followed by validation; thereafter, the data were integrated into full cover-maps and geographical information systems (GIS). These stages are summarised in Figure 1.

Landsat TM image acquisition

Landsat's Thematic Mapper (TM) sensor records reflectance from 30 m ground cells, in seven wavebands of the visible and infrared range of the electromagnetic spectrum. The sensor scans from side to side as the satellite advances, so that continuous 185 km swaths of the land surface are recorded. Images are supplied to users as 185 km lengths of the swath, or 'scenes' of digital data. The study was based on Landsat TM data because, unlike the alternatives, the sensor includes a detector which is sensitive to middle infrared (IR) wavelengths (1550-1750 nm), important in separating a wide range of vegetation cover-types (Townshend *et al.* 1983).

Eight Landsat paths cover Britain. The orbits overlap very substantially in these northern latitudes, by about 45% in southern England, and exceeding 50% from mid-Scotland northwards. This means that it is possible to achieve full cover using alternate paths of data in northern Scotland but, in England and Wales, it is necessary to use every path. Note, however, that paths may vary slightly so the choice of alternate scenes must be made on individual merit. The baseline date for the mapping was 1990 but, to accommodate any image shortages, for example due to a high incidence of cloud-cover (Legg, 1991), an extended period of ± 2 years was allowed.

Definition of summer and winter images

This study used summer and winter data, in composite, to help separate the various target classes (Fuller *et al.* 1989a). Arable areas which alternate between full plant cover and bare ground within a year were distinguished from semi-natural vegetation which retained full cover though perhaps predominantly plant litter in winter; deciduous trees differed from evergreens, and deciduous rough grasslands were distinct from permanently green agricultural swards; urban areas and bare ground were characterised by their bare appearance in both summer and winter. (Fuller & Parsell, 1990).

'Summer' was considered to cover that period when plants are in full growth and includes mid-May to late July. Winter covered the time from mid-October (in practice the date of the first frosts) to around mid-March. Other months represented transition periods which were best avoided. In practice, the useful periods shifted with altitude; they also varied from north to south, and east and west in Britain and they were inevitably dependent on the year in question. The final choice was also compromised by image availability. Therefore it was essential to take summer/winter pairs on their own merit, based on local knowledge of vegetation, cropping and climate.

Image search and data handling

In all, 46 different scenes were required for full GB cover. Summer-winter composite images were used whenever possible. Where this proved impossible, single date cover was used: 88% of GB was classified from combined summer-winter images, 12% from single-date, mostly summer, data. The only missing data were for Tiree, part of Coll and the southern tip of Shetland which did not fall within suitable scenes of GB Landsat cover.

Analyses were made on International Imaging Systems (I^2S) Model 75 and IVAS image processors. A major challenge was the large quantity of data to be processed - a summer-winter composite scene requires about 0.2 gigabytes of storage. To ensure the smoothest possible flow, 1.4 gigabytes of computer disk storage was dedicated to the project, allowing each summer and winter pair, for each scene, to be registered, amalgamated, and classified with the minimum of disk management.

Geometric correction and image co-registration

Landsat TM summer data were geometrically registered to British National Grid (BNG) using control points which were selected on 1:50 000 Ordnance Survey maps and identified interactively on an input image. The relationship between image coordinates and BNG was calculated using a polynomial model. The image was then transformed to fit this model (Schowengerdt 1983), to produce an output image of the chosen 25 m pixel size, with a BNG map projection. The winter data were then resampled to fit control points identified on the summer scene.

Geometric correction was, on average, to sub-pixel level. Co-registration of Landsat raster maps with 143 vector field-maps of CS 1990 squares showed average displacement to be 0.8 pixels (20 m), that 75 out of 143 squares needed no shift to achieve correspondence, that 43 squares needed a one pixel shift, 15 squares needed 2 pixels movement and only 10 squares needed more than 2 pixels movement.

The summer/winter composite images were made by co-registering scenes or part scenes to give a single output image. This image contained six bands of data, three each from the original summer and winter scenes, namely Landsat TM bands 3, 4 and 5 - ie red, near and middle IR radiance data (Fuller *et al.* 1989b, Fuller & Parsell 1990). These bands were chosen as representing wavelengths with characteristic responses from vegetation (red for chlorophyll absorption and IR for mesophyll reflections). They are also less affected by haze-problems than is the blue-green part of the spectrum.

Selection of target land cover types

An appropriate classification of cover types was the key to a consistent, accurate and useful cover map. By reference to other surveys (Fuller, Jones & Groom, 1990) it was possible to draw on a wide range of experience in vegetation mapping, and to devise a classification suitable for applied uses. The study was strongly influenced by the pilot exercises in Cambridgeshire and Snowdonia, with evolution based on experiences in the current survey, and incorporating a consultative exercise involving other surveyors and end-users (Fuller, Jones & Groom, 1990).

The final list of cover types is given in Table 1. The nomenclature may convey different meanings to different users, so a description is given in Appendix 1. Consultation showed that some users would have liked more detail, while others felt the list was over-ambitious. Comments on specific classes were often contradictory. The distinctions between uplands and lowlands were thought by some to be artificial, based on subdividing a continuum, though the two extremes have very different ecological characteristics. Some people noted that widespread classes (eg the agricultural grasslands) deserved further subdivision, but comments of others rightly noted the difficulty in relating reflectance differences in grasslands to real agricultural meaning: management practices can easily obscure the nature of the sward. Some remarked on the rarity of particular classes and questioned their inclusion.

The classification is hierarchical in form, enabling users to aggregate to very simple levels. Rarer classes can be merged into related, more common, ones. Those who would make their own definitions of, for example, upland and lowland cover types, may amalgamate equivalent classes and redivide using external data, perhaps a digital contour map. The target classes were achieved by defining a large number of spectrally unique subclasses (see later) details of which are also available.

The Land Cover Definitions (LCD) project (Wyatt *et al.* 1993) was sponsored by the DoE to intercompare the wide range of surveys which have incorporated land cover and land use. It recommended a standard 'baseline classification' of the British landscape into 59 types of cover and use. It then compared other surveys. Where a particular survey merged together several baseline classes, the LCD project showed the constituent baseline types. Where a survey subdivided further than the baseline, appropriate simplifications were recommended. Results showed that some of the 25 'target' cover types of the Land Cover Map were subdivided further than equivalent baseline classes. A recommended aggregation of Land Cover Map classes gave 17 'key classes' which were comparable with most field and aerial surveys (Table 1). As 25-class data exist, the information is retained and indeed used by many applications projects. However, validation, integration with CS1990 field data and some GIS analyses demand operations at the 17-class level.

Field reconnaissance

The procedure of classification was based on extrapolation from samples of each class using a Bayesian maximum likelihood classification (Schowengerdt 1983) implemented in a particularly fast form using the I^2S hardware facilities (Settle & Briggs 1987). The samples or so-called 'training areas' were based on knowledge derived from field-reconnaissance survey. Reconnaissance routes were planned to encompass as much as possible of the diversity of the landscapes to be covered. The route was photographed and printed at around 1:60 000 scale. Photographs were annotated whilst following the route in a vehicle, but with frequent stops to examine species details and any other factors which might affect the exact classification of an area. Typically, field reconnaissance identified the cover in abont 1200 land/water parcels per Landsat summer-winter scene. A sample of the reconnaissance information was then used for definition of subclasses and training areas.

Table 1. The land cover classification to the original 25 'target' cover types and showing LCD-recommended aggregations (and nomenclature) for 17 'key' cover-types for provision of summary data and to 9 selected 'major' cover-types for pairwise boundary analyses (see later sections).

target cover (25 class)	key cover (17 class)	major cover (9 classes)
Continuous urban	Urban development	Urban/suburban
Suburban/rural development	Suburban/rural development	
Sea/estuary	Sea/estuary	
Inland water	Inland water	
Beach and coastal bare	Beach/Mudflat/Cliffs	
Saltmarsh/Intertidal vegetation	Saltmarsh	
Inland bare ground	Inland bare ground	
Tilled land	Tilled (arable crops)	Tilled land
Mown/grazed turf	Pasture/Meadow/Amenity grass	Pasture/Meadow/Amenity grass
Meadow/verge/semi-natural		
Bracken	Bracken	Bracken
Ruderal weed	Marsh/Rough grass	Rough grasslands
Felled forest		
Rough/marsh grass		
Grass heath	Rough pasture/Dune grass/ Grass moor	
Moorland grass		
Lowland bog	Bogs (herbaceous)	Bogs (herbaceous)
Upland bog		
Open shrub heath	Grass/shrub heath	Shrub heath
Open shrub moor		
Dense shrub heath	Shrub heath	
Dense shrub moor		
Scrub/orchard	Deciduous/Mixed wood	Deciduous/mixed wood
Deciduous woodland		
Coniferous woodland	Coniferous/Evergreen woodland	Coniferous woodland

Training the maximum likelihood classifier

Training the image classifier involved outlining groups of pixels representative of the particular classes or subclasses intended for classification. Transient features such as specific annual crops were not of immediate interest, so wheat and barley, for example, were treated as subclasses of arable land. Most classes required further subdivision into a number of subclasses, whenever distinct variants were seen (Kershaw & Fuller, 1992). There were frequent examples of single cover types showing several spectral variants: for example, in undulating terrain, most cover types showed strongly sunlit and shaded variants. Overall, 70-80 subclasses was a typical number for most scenes. The subclasses were later aggregated to give the target classes. As far as possible, there were 5 or more training areas per subclass, with a grand total of 100-200 pixels, but a minimum of 30 pixels in total was sometimes allowed where training areas were small or few in number (Kershaw & Fuller, 1992).

The classification process then extrapolated from these training data to identify all other pixels in the scene with the same spectral characteristics as the subclasses used in training. A maximum likelihood classifier (Schowengerdt 1983) allocated each pixel to its nearest subclass (in statistical terms) or rejected pixels, if dissimilar to all available subclasses. By defining a rejection threshold, it was possible to reject more or less of the scene. Training defined all but the very rarest of subclasses so the threshold was varied in order to classify about 98% of all land/water parcels (Kershaw & Fuller, 1992).

The process of training and classification was an iterative one, relying on preliminary classification, inspection of results, edition or addition of training subclasses, then reclassification, towards a final cover map.

Knowledge-based corrections

Some classes could not always be reliably separated purely on the basis of spectral differences. Contextual information, derived from within the data, helped correct any errors. The procedures worked on the basis that the large majority of pixels were correctly classified: errors were mostly 'noise' in the data. By filtering out the 'noise' a clean 'mask' could be made for correction purposes.

Coastal masking

Urban and suburban areas were often confused with beaches. Sea and inland water bodies were often identical in spectral signatures. Saltmarshes were sometimes confused with arable crops. By defining the coastline, it was possible to impose the rule that terrestrial habitats were only to be found inland of the line, maritime habitats to seawards. A coastal mask was made semi-automatically on the image processor. The cover map was generalised at a reduced, one-third scale, and cover types were aggregated into maritime and terrestrial types. A majority filter was used to remove small pockets of 'terrestrial habitat' at sea and *vice versa*. The mask was then enlarged x3 back to full size. Pockets of less than 6 ha were thus removed. By overlaying the mask onto the original map, it was possible to identify and automatically correct terrestrial-maritime confusions. Minor misregistrations around the coastline, and any larger pockets of error which remained, were later removed interactively.

Upland masking
The separation of upland and lowland cover-types was often made difficult by the similarities in dominant plant species contents, for example of heather on heaths and moors. Though strictly a continuum, the two extremes are very different in landscape terms and ecologically quite distinct, especially in their associated flora and fauna. The floral difference, combined with phenological, topographical and soil differences, allowed upland and lowland habitats to be separated with about 70% success. Small pockets of misclassified lowland habitat, in an extensive upland area and *vice versa* were filtered using procedures similar to those used for coastal masking.

Urban/suburban masking
The complex mosaics of vegetation and built-up land in urban areas sometimes suffered from minor misregistrations between summer and winter images, which gave pixels the same characteristic as arable land, namely a bare appearance on one date, vegetated on the other: where urban deciduous trees overhung tarmac and concrete, the same arose. These led to some patches of vegetation in urban areas being misclassified as arable land. An urban mask was used to correct urban 'arable' areas, under the mask, to suburban pixels. Other classes, such as deciduous and coniferous trees, water bodies or grasslands, were allowed to remain, being normal features of urban environments.

Cloud, shadow and snow masks
Cloud cover was a significant problem especially in more westerly scenes. Where cloud cover was extensive, it was possible interactively to cut out erroneous classifications arising through cloud on either the summer or the winter image and substitute with cover-data based on a classification of a single date image. Where cloud cover was more dissected, it was necessary to use automated procedures. Masks of cloud were built up by defining a brightness threshold above which the cover was taken to be cloud. To avoid problems with haze around cloud-fringes, the mask was grown by 6 to 10 pixels, depending on the extent of haze. To remove misclassification due to cloud shadow, two possible routes were used: a low brightness threshold sometimes successfully defined a shadow mask; if not, a displaced version of the cloud mask was added to the original (displacement was adjusted according to sun angle, cloud-height and terrain). The completed cloud-plus-shadow mask was then used to cut holes in the erroneous multi-temporal data and to select patches from a classification based upon the one good date. Snow masks were also needed in some winter scenes; again these were based on brightness thresholds and used to patch the snow cover.

Local interactive corrections
In some areas, rare cover types (eg peat cuttings), perhaps too small to train as subclasses, were misclassified. It was possible to take out a 'tile' of the cover map, renumber the cover value in a locality to the correct value, and place the corrected 'tile' back into the cover map. This procedure was used to a very limited extent (<<1% of a scene), because more widespread instances would have been tackled by modifying the training procedure.

Post-classification filtering

To simplify the data, various filtering procedures were considered. It was concluded that the majority of pixels showed real complexity in the landscape rather than 'noise'. Therefore, the only filtering used on the corrected class maps consisted of a 3 x 3 kernel filter to remove isolated pixels, working at the subclass level. In other words, singleton pixels, unique in subclass-type, at the centre of a 3 x 3 grid of pixels were reset to the majority cover type of the 3 x 3 grid.

Building mosaic of full GB land cover

The mosaic of full GB land cover was built via an intermediate stage, with the data stored as 100 km squares. These were made as 'jigsaws' from the appropriate sections of each scene. As classification of each scene was completed, the sections were 'cut out' and stored in their 100 km tile. Joins were made within the overlap between scenes, using a sinuous outline, along uniform features, common in classification on both scenes, and maximising the use of the better of two scenes, where quality-differences existed. Building the mosaic simply involved butt-joining the tiles to give maps and data covering all of Great Britain.

MAPS AND DATA OUTPUTS

The digital Land Cover Map

The resulting maps of land cover show units down to a size of 2 pixels (0.125 ha). However, it must be stressed that not all features of this size would be mapped accurately. According to Townshend's calculations (1983) the minimum accurately mappable unit would be of the order of 3 to 5 ha. In practice, checks reveal that most features of 1 ha show clearly, giving a map which shows patterns at a field by field scale. Superimposed on this 'minimum accurately mappable area' is a finer detailed pattern of those smaller features with strong enough spectral signatures to discriminate them from the background cover: for example, roads, farms, shelter belts, water bodies, grass tracks and larger field headlands are evident throughout the cover maps. The Land Cover Map forms a datafile of *c.* 1 gigabyte.

Hard copy map production

Figure 2 shows the full map of Great Britain though much detail is lost in the reproduction at this small size. Figure 3 gives a key to the Land Cover Map. Figures 4-8 give examples of output showing parts of London, the Norfolk Broads, the North York Moors and Ardnamurchan, Scotland. These examples cover approximately 600 km^2 out of nearly a quarter million squares in Britain: at the scale of these examples, the full land cover map would be nearly 14 m x 8 m.

The output from the thermal wax printer, and indeed all hard copy output including filmwriter negatives are inferior to the image produced on the screen and therefore can only give the reader an impression of the overall detail. However, the quality of the classification is immediately apparent from examination of these plots.

In London (Figure 4) it is possible to see the urban centre giving way to suburban areas and the grass areas of the London Parks such as Hyde Park with the Serpentine; note the fine detail, for example, the 'herring-bone' of suburban streets or the bridges across the Thames.

The Broads map (Figure 5) clearly shows the semi-natural vegetation of river valleys; for example the River Bure valley from Wroxham is lined by wet 'carr' woodlands with extensive reed beds; the River Ant also has extensive reed beds which give way to grasslands where the Ant and Bure meet; by the time the River Thurne meets these Rivers, grasslands are punctuated by extensive areas of drained land used for arable farming. The surrounding landscape is also predominantly arable.

The North York Moors map (Figure 6) shows the heather moorlands, with the regularly pattern of burnt moor comprising mixed grass and regenerating heather, managed, by burning, for grouse. Note the steep valley sides with bracken, dropping down to the valley floor of pastures and meadows.

Figure 2 (*Overleaf*). The Land Cover Map of Great Britain - an overview

Figure 3. A key to the Land Cover Map of Great Britain

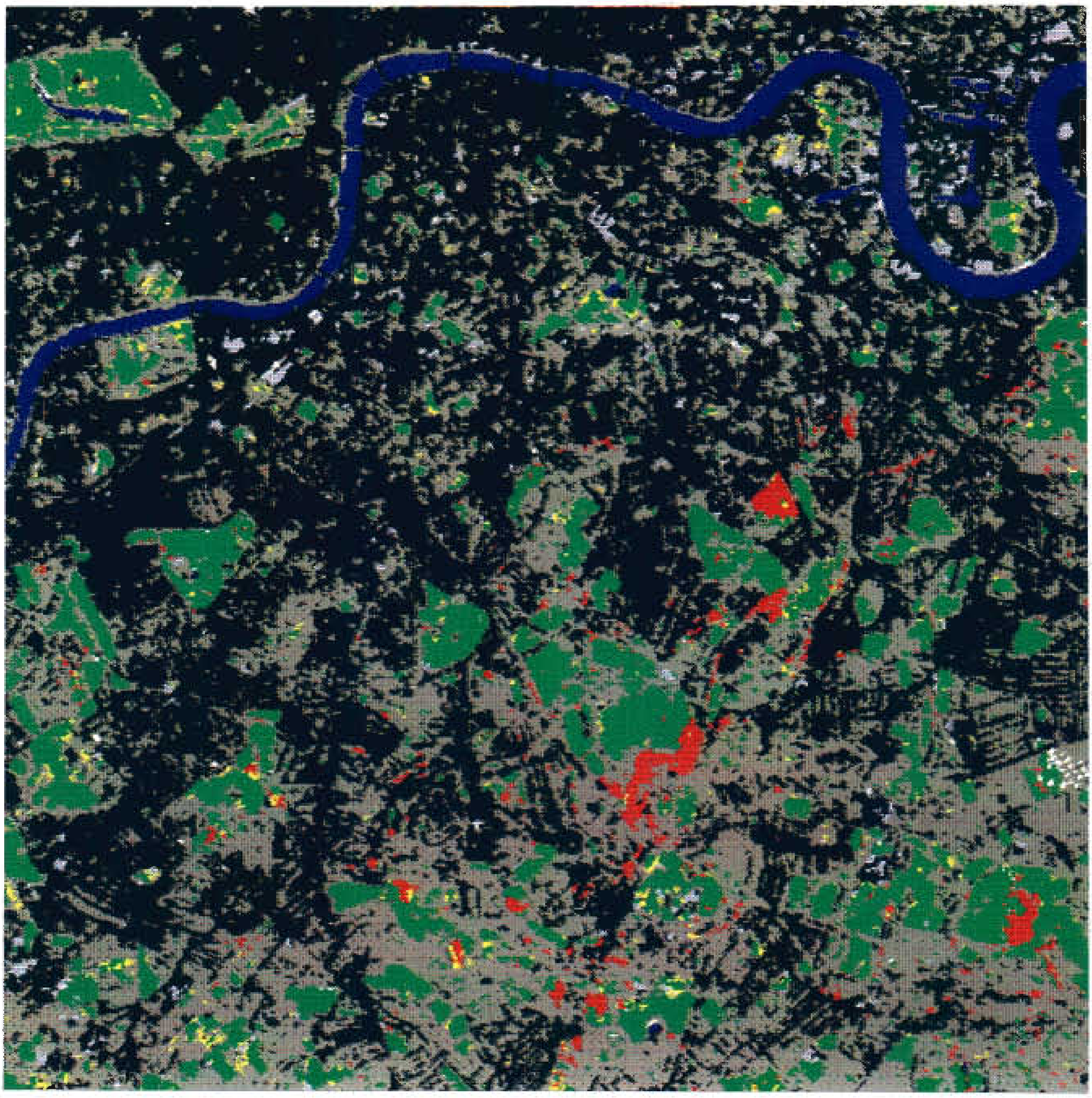

Figure 4. A 12.8 km x 12.8 km section of the land cover map for central London: it is possible to see the urban centre (dark grey) giving way to suburban areas (light grey) and the grass areas (green) of the London Parks such as Hyde Park (top left) with the Serpentine (blue); note the fine detail, for example the 'herring-bone' of suburban streets or the bridges (grey) across the Thames.

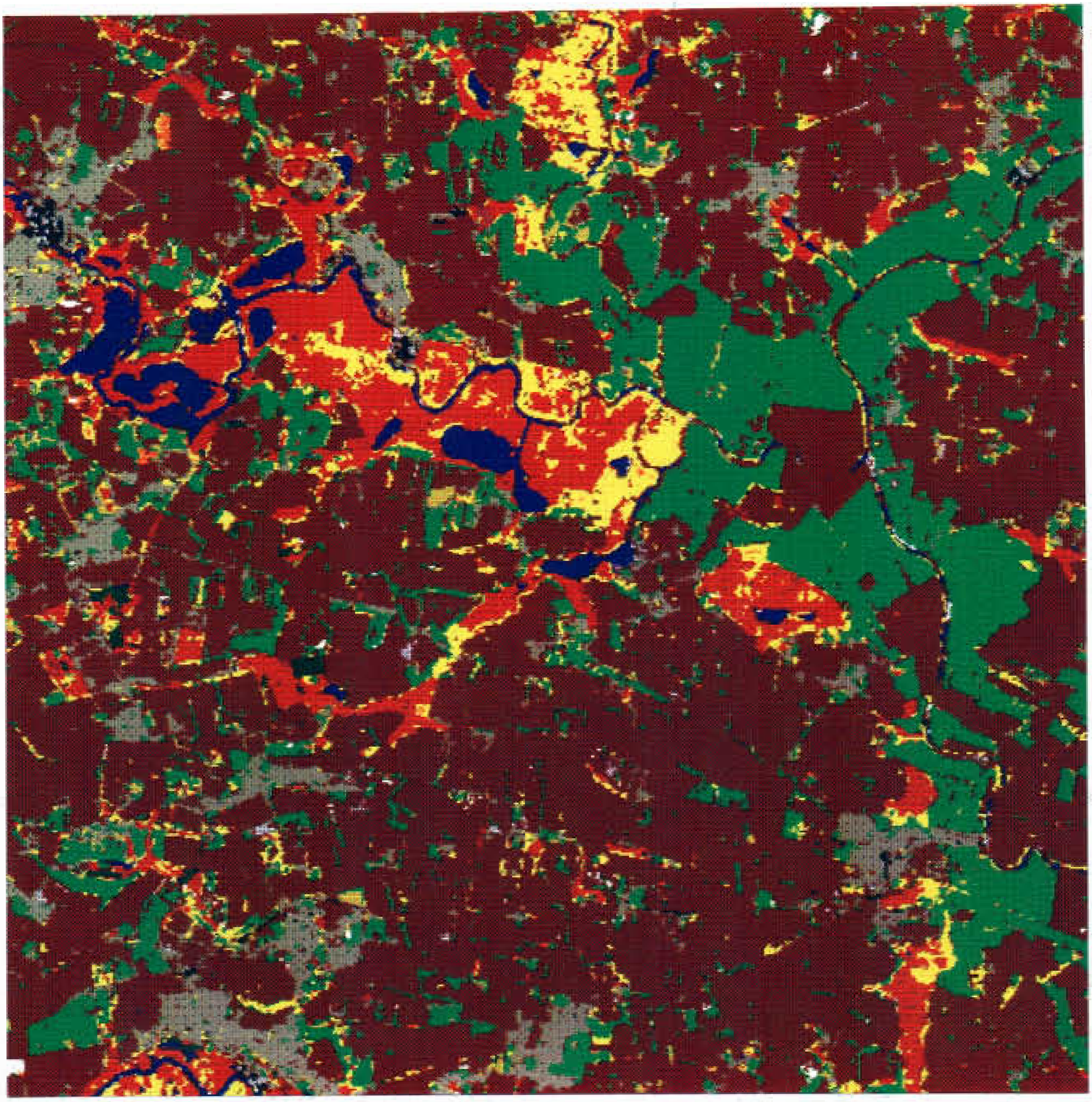

Figure 5. A 12.8 km x 12.8 km section of the land cover map for the Norfolk Broads: it clearly shows the semi-natural vegetation of river valleys; for example the River Bure from Wroxham (grey - top left) is lined by wet 'carr' woodlands (pink) with extensive reed beds (yellow); the River Ant (top, centre) also has extensive reed beds which give way to grasslands (green) where the Ant and Bure meet; by the time the River Thurne (top right) meets these Rivers, grasslands are punctuated by extensive areas of drained land used for arable farming (dark brown). The surrounding landscape is also predominantly arable.

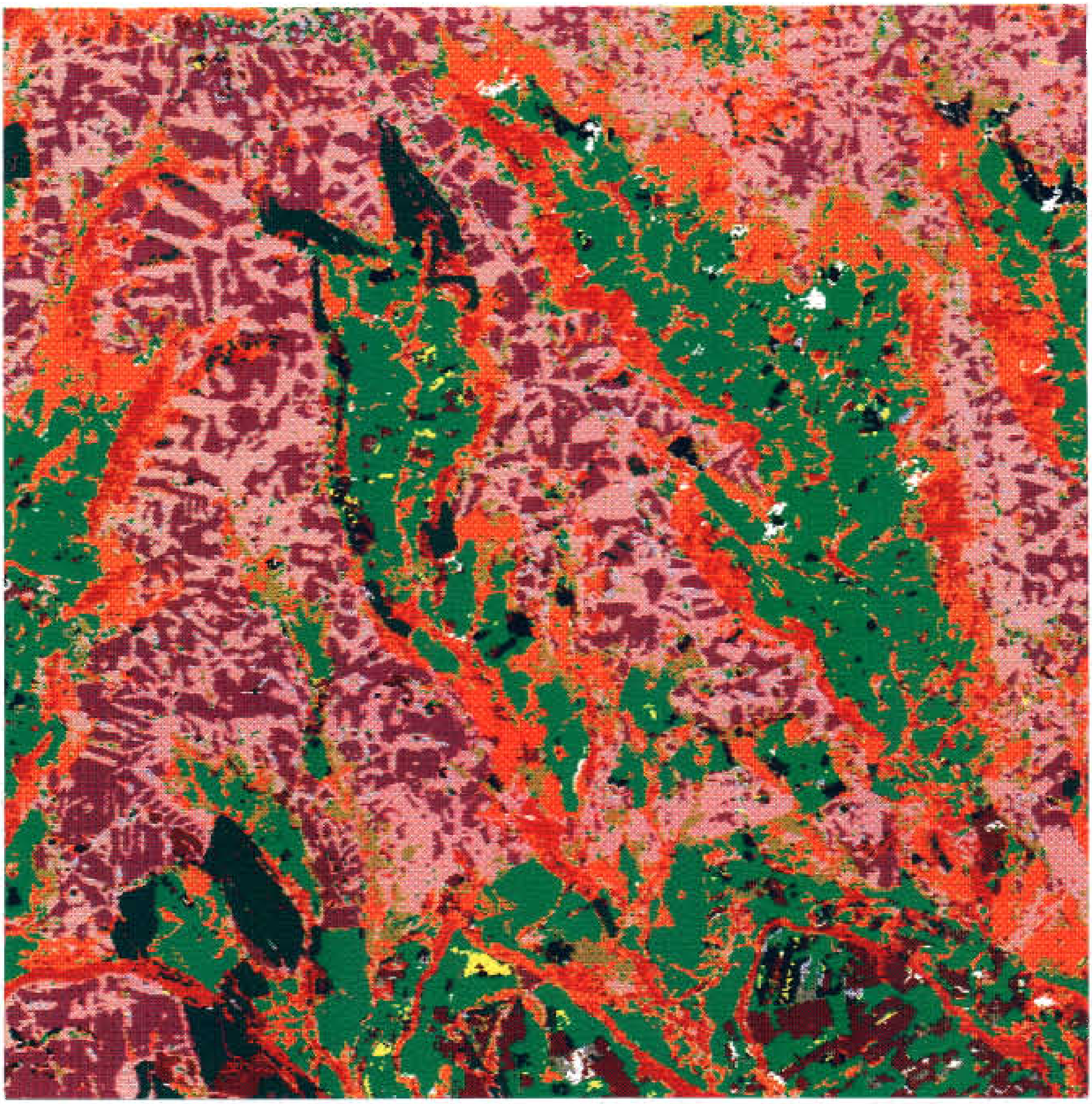

Figure 6. A 12.8 km x 12.8 km section of the land cover map for the North York Moors: it shows the heather moorlands (mauve), with the regular patterns of burnt moorland (dark green) comprising mixed grass and the regenerating heather which is so important to grouse. Note the steep valley sides with bracken (orange), dropping down to the valley floor of pastures and meadows (green).

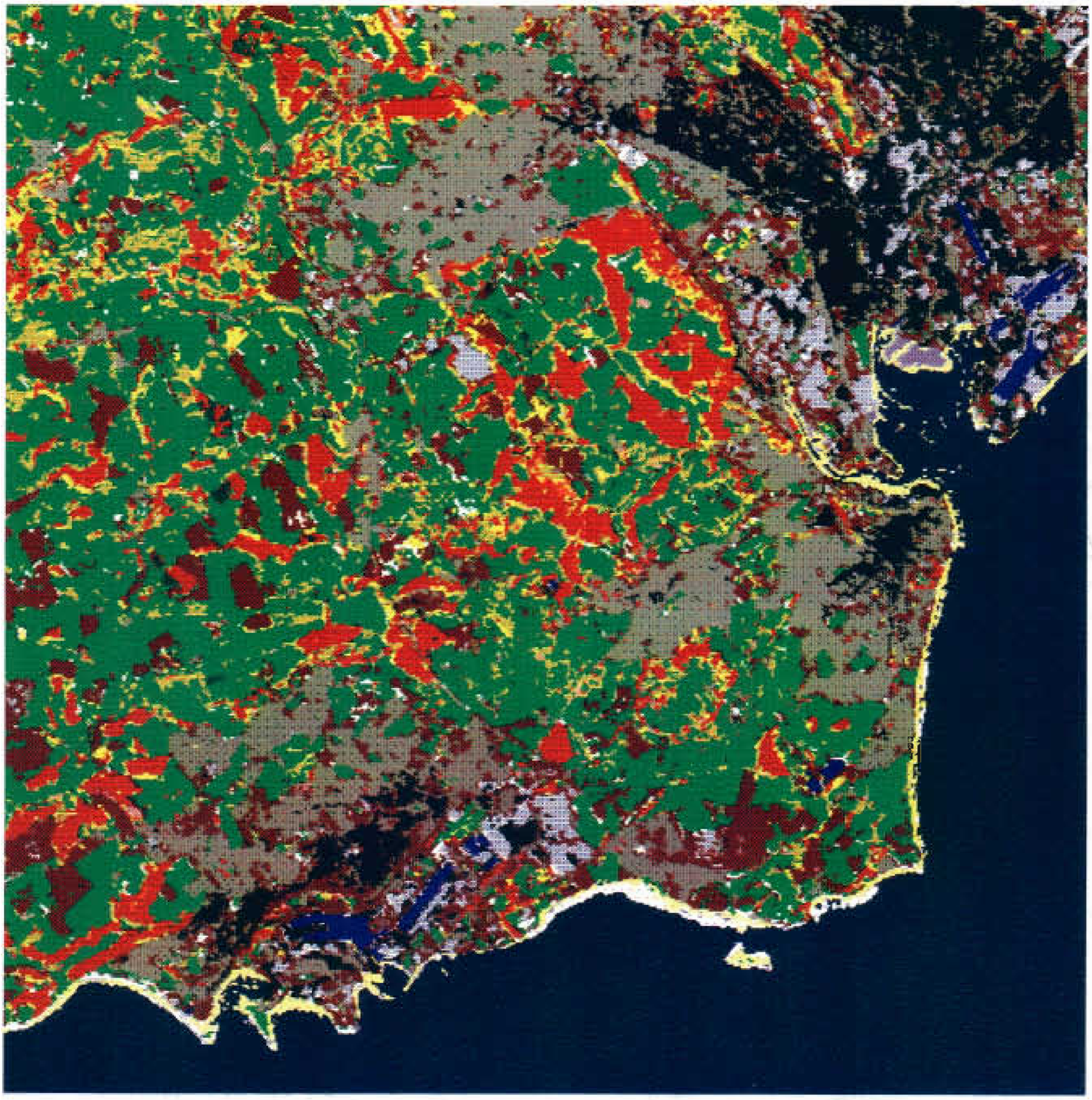

Figure 7. A 12.8 km x 12.8 km section of the land cover map of Cardiff. The urban centre (dark grey) and suburban (light grey) fringes are fronted by seashore (sand colour) with docks (very light grey), all surrounded by a landscape of grassland (green) with scattered deciduous woodlands (red).

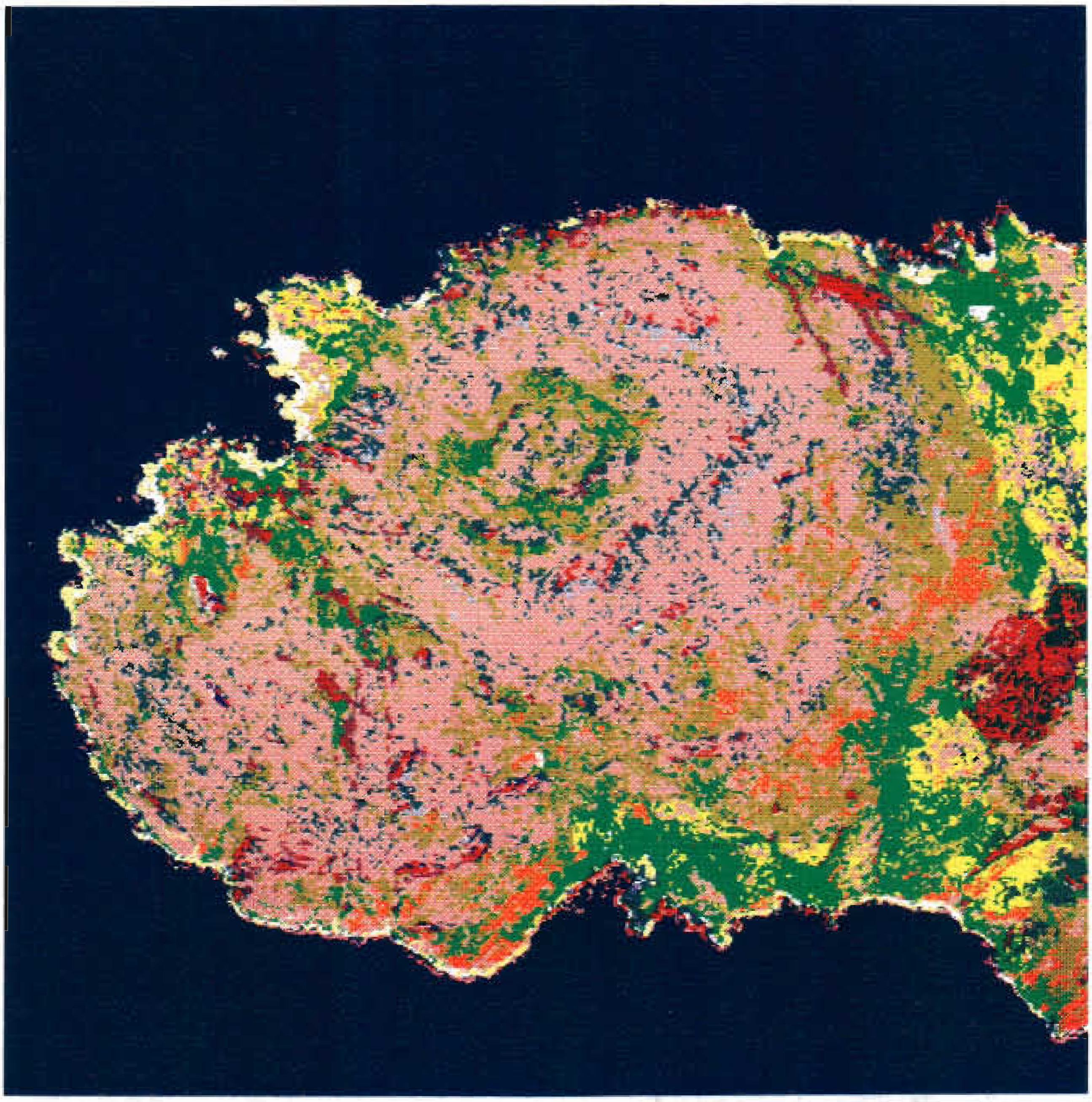

Figure 8. A 12.8 km x 12.8 km section of the land cover map at Ardnamurchan: it shows upland grass-heather moor (pink) with bogs (khaki) and moorland grassland (light tan) in a distinctive ring of hills associated with the underlying geology. Note the bracken (orange) of lower slopes giving way to grasslands (green) in the valleys, with a shoreline beaches and rocks (sand coloured).

The Cardiff map (Figure 7) shows the urban centre of cardiff with its suburban fringe, with docks on the coast and at nearby Barry. The surrounding landscape is dominated by grasslands with many areas of woodland.

The Ardnamurchan map (Figure 8) shows upland grass-heather moor with bogs and grass moorland in a distinctive ring of hills associated with the underlying geology.

The whole of Britain has now been plotted on the Spectrascan filmwriter at the Image Data Facility of the Defence Research Agency. To keep within the 8 x 10 inch (203 x 254 mm) limit of the negative, plots were made at 10 microns per pixel, with Great Britain split into 4 quadrants. A negative for all of Britain has also been made by photographing a composite of four prints produced from the quadrant negatives.

The land cover of Britain

Table 2 gives land cover statistics for Great Britain and the breakdown of land cover within England, Scotland and Wales. The total land area measured for GB, 227 275 km^2, is within 178 km^2 of the 227 453 km^2 quoted by Whitakers Almanac (Anon 1992). The difference (0.08%) is negligible and may partly relate to tidal conditions; also to the missing sections of Coll and Tiree. The accuracy of the Whitakers' data is unknown but presumably derives either from the sum of a very large number of smaller parcels or is a measurement made from small scale generalised maps. What is perhaps remarkable is the fact that the results are so very close.

In England, the predominance of tilled land and managed grass is notable with both covering 34% of the surface. Suburban and urban land in England amounts to 11%, a much higher proportion than in Scotland or Wales. Woodlands cover 8% and heath/moorland/bog categories add to make 9%. Semi-natural vegetation (including managed grasslands) covers about half of England.

In Scotland, the much higher cover of heath/moor/bog at 57% was to be expected, with managed grasslands also important at 17%; arable land covers just 9% of Scotland and urban areas amount to only 2%. Established coniferous forestry now covers 4% of Scotland, but field survey figures show how much new planting there is in addition to this. Semi-natural vegetation (including managed grasslands) covers over 80% of Scotland.

In Wales, managed grasslands dominate with 40% cover, arable covers just 10%. Woodlands are important with 16% cover and heath/moor/bog areas cover 20% of the country. Suburban/urban areas only cover 3%. Significant, in view of the many problems associated with it, is the 0.6% cover of bracken in Wales (NB bracken is the only species to deserve a cover class of its own - in Wales it is at its most prevalent). As in Scotland, semi-natural vegetation covers more than 80% of Wales.

Table 2. Land cover (square kilometres) of 17 key classes in England, Scotland and Wales.

cover	ENGLAND	SCOTLAND	WALES	GB
unclassified	2157	1454	1065	4676
suburban/rural development	11349	1328	639	13316
urban development	2453	109	57	2619
sea/estuary	2943	6079	631	9653
inland water	406	1245	71	1722
beach/mudflat/cliffs	644	546	142	1332
saltmarsh	277	52	44	373
inland bare ground	1010	1388	154	2552
tilled (arable crops)	43312	6878	1095	51285
pasture/meadow/amenity grass	44426	12918	8230	65574
marsh/rough grass	1981	1638	666	4285
bracken	1281	1159	1173	3613
rough pasture/grass moor/dune	7598	10681	1938	20217
bog (herbaceous)	277	3779	233	4289
grass/shrub heath	2342	23822	1502	27666
shrub heath	1232	5378	577	7187
deciduous/mixed	7794	1918	2534	12246
coniferous/evergreen	2199	4668	883	7750
Grand total	133681	85040	21634	240355
Terrestrial area	129817	78363	20817	228997
Land area	129411	77118	20746	227275

INTEGRATION WITH THE COUNTRYSIDE 1990 FIELD SURVEY

The CS1990 field surveys used a stratified random sample of 1 km squares to characterise the landscape of Britain. As well as detailed recording of land cover and land use, the surveys recorded landscape features such as hedges, verges, ditches, streams and ponds; species information was collected including plant quadrats, recording of individual trees and a survey of aquatic organisms.

Stratification of the field surveys

The stratification of the field-survey was based on a computer-classification of all Ordnance Survey, National Grid, 1 km squares in Britain. This stratification drew on summary data from thematic and topographic maps; a multivariate analysis of the data identified 32 land classes. It was then possible to allocate each 1 km square in Britain to one of the 32 classes (Bunce *et al.* 1992). **NB. These 32 biogeographical Land Classes should not be confused with the 25 cover types of the Land Cover Map.**

A stratified random sample of 508 squares was chosen, with the sample-size weighted according to the National extent of each class. This sample was used for detailed field survey.

Field recording of 1 km squares

The sample-based field survey was successfully completed in late summer 1990. Field surveyors annotated maps, which included OS outlines supplemented with airphoto-interpreted vegetation boundaries, linear and point features (eg hedges, trees). Field records gave ground cover, plant species dominance, land use, with specific information on linear and point features, and detailed plant-quadrat data at selected sites.

Digitising of 1 km squares

The field data have been digitised within an ArcInfo geographical information system (GIS) to form GIS files for each square, with species- and other attribute-data held on an ORACLE database. Summary methods are reported by Barr (1990). From these digital map sections, data were created for comparison with the Land Cover raster data.

Comparisons and Integration of field data with the Land Cover Map data

The results of land cover classification have been compared with data from the CS 1990 field survey of 1 km squares at three levels:

1. vector-digitised field-survey squares (ie as boundary line-work), converted to raster (ie as grid cells) for comparison purposes: the procedure was applied to 143 squares (a minimum of 4 per land class). Field data were aggregated to give 25 cover-types

corresponding to those used in Landsat mapping: simple decision-rules were made to deal with multiple cover-attributes; for example, a land parcel, comprising both grass and tree cover, would have taken the visually and structurally dominant tree classification. The data were compared, pixel-by-pixel: assessment of accuracy was made separately for parcels including their boundary pixels and within-field pixels excluding boundary pixels.

2. scores of land cover on a grid of 25 points, within field-survey squares and corresponding Landsat areas, for 256 squares: 25 Landsat cover types (and LCD aggregations to 17 key cover types (Table 1)) to be compared with a short list of 59 Baseline Cover Types defined under the LCD project (Wyatt et al. 1993).

3. comparisons at a 1 km summary level, for all squares, comparing 25 Landsat target classes (and LCD 17 key classes) with the 59 LCD field classes.

The vector-based validation has been completed and summary results are included in this report. However, point-score analyses and the summary cover data for all squares are incomplete: furthermore, the full integration and analysis of correspondence involves many complexities which are more appropriate to the LCD Project. Hence full results will be presented in the LCD contract report to DoE.

It is important to note that the two surveys set out with different methods, different objectives and also differing potential in terms of the details they could record. Therefore, differences in results should not necessarily be taken to indicate errors on the part of either or both surveys. In many cases, errors are identified, but in others, the differences are due to generalisation procedures. The aim of this comparative exercise is primarily to quantify correspondences, so that the two surveys can be intercompared and so that datasets can be integrated: thus the generalised census of the Land Cover Map can supplement the sample-based details of the field survey, and *vice versa*.

Vector-to-raster intercomparisons

Correspondence between field and Landsat surveys was quantified by intercomparing the maps in a GIS. After converting vector field-maps to raster form, intercomparisons were made, raster-to-raster. At first, all pixels in a 1 km square were used (Table 3). Then a second series of comparisons excluded pixels which fell under a vector boundary (Table 4). The results are summarised in Table 4 which gives a breakdown of correspondences for arable, pastoral, marginal and upland landscapes.

Direct agreements between surveys is only 46%. However, there are substantial differences in class definitions. For example the field survey used a 'botanical' definition of bogs which included heather growing on wet peaty soils. Such areas are quite dry enough to walk on and would not be classified by topographic mapping as 'bog'. The Landsat survey used the cover composition, namely the heather dominance, to allocate such areas to the dwarf shrub category, whether the soil was wet or dry. The Landsat classification therefore only targeted bogs in the 'dictionary sense', those with standing water, at least for the winter period: 'Landsat bogs' were characterised by bog myrtle, cotton grass and sedges, typical of bog conditions, virtually inaccessible on foot and conventionally mapped as 'bog'.

Table 3. Correspondence (%) between 1 km field survey squares and equivalent areas mapped by classification of Landsat data: results include within-field and boundary pixels.

FIELD/LANDSAT	Uncl	Subn	Urbn	SeaE	IWat	Beach	Smsh	InBa	Tilled	Pastr	M/RG	Brkn	GMD	Bog	GSH	SH	DecM	Conf	Total %
Unclassified																			1
Suburban/urban		2	1						2	2									8
Sea/Estuary				2															2
Inland Water					1														2
Beach/mudflat/cliffs				1		1													3
Saltmarsh																			0
Inland bare ground																			1
Tilled (arable crops)	1	1							14	3									21
Pasture/Meadow	1								3	18	1		2		2		1		29
Marsh/Rough Grass										1									2
Bracken																			1
Grass moor/Dune													2		2				6
Bog (herbaceous)													2	1	5	1			10
Grass/Shrub heath													1		2	1			5
Shrub heath																			1
Deciduous/Mixed									1	1							2		6
Coniferous															1		1	1	4
Field-surveyed	3	4	1	3	1	2	0	1	21	27	2	2	9	3	13	3	4	2	100
Hits (diagonal)	46																		
With interp. diffs	67																		
Inc. poss. change	76																		

Table 4. Correspondence (%) between 1 km field survey squares and equivalent areas mapped by classification of Landsat data: results exclude pixels on vector boundaries.

FIELD/LANDSAT	Uncl	Subn	Urbn	SeaE	IWat	Beach	Smsh	InBa	Tilled	Pastr	M/RG	Brkn	GMD	Bog	GSH	SH	DecM	Conf	Total %
Unclassified																			1
Suburban/urban		2	1						1	1									6
Sea/Estuary				2															3
Inland Water					1														2
Beach/mudflat/cliffs				2		1													3
Saltmarsh																			0
Inland bare ground																			1
Tilled (arable crops)	1	1							19	3	1								27
Pasture/Meadow	1								3	21	1		2		1		1		31
Marsh/Rough Grass										1									1
Bracken																			1
Grass moor/Dune													2		1				5
Bog (herbaceous)													2	1	4	1			9
Grass/Shrub heath															2	1			4
Shrub heath																			0
Deciduous/Mixed										1							1		4
Coniferous															1		1	1	4
Field-surveyed	3	4	1	4	2	1	0	1	24	28	2	1	8	2	12	3	4	2	100
Hits (diagonal)	54																		
With interp. diffs	71																		
Inc. poss. change	82																		

These differences are reflected in the lower direct correspondences measured for marginal uplands and upland landscapes.

There were also differences in how the two surveys divided the continuum from grass heath, through heather-grass mixtures, and on to dense shrub heaths. There were differences, too, in dividing the continuum from rough grasslands to managed swards.

These various differences in definitions show themselves as departures from the diagonal line in the correspondence matrix. However, because the Table is arranged so that similar classes lie next to each other, the diagonal trend is still clearly evident. The differences cannot be thought of as errors either way, but rather as differences in interpretation where neither survey is more 'correct'.

Some differences show up as clear departures from the diagonal. For example, managed grasslands within urban/suburban areas are ignored by the field survey, which treats an urban zone as uniform and continuous. The Landsat classification did not stop at the urban boundary.

Allowing for different definitions, overall correspondence is 67%. Hence the summary Table 5 shows much greater agreements once different definitions are taken into account.

Some 40% of all pixels straddled a vector boundary and were thus made up of mixed cover types, and additional boundary features. Correspondence was raised to 71% when boundary pixels were excluded.

Other differences reflect changes in cover between the two surveys. For example, a field which was pasture on one date, tilled land on the other, represents the typical rotation farming of mixed agricultural land found in much of Britain. If we allow for time-based changes, overall correspondence is measured at 76% including within-field and boundary pixels: within-field pixels are mapped with 82% correspondence.

When we allow for differences in definitions and time-based changes, the more uniform uplands and arable landscapes show greatest correspondence between surveys. The pastoral and marginal landscapes, with small fields sizes an complex patterns of semi-natural cover, show a lesser agreement, due mainly to differences in spatial generalisations, plus some minor misregistrations when overlaying field and Land Cover data.

A full analysis of correspondence between field and Landsat surveys will be given in the LCD report. This will include further details of the vector analyses in full spatial mode. It will add the spatially generalised, but more detailed, analyses of cover types as made in the point-scoring procedure, where the 25 target cover types will be related, individually, to all 59 classes of the LCD project, for 256 squares. The LCD report will also examine, for all 508 squares, summary 1 km cover data: correspondences at the 1 km level are obviously most relevant to the integrated datasets of the Countryside Information System.

Table 5. Summary correspondence (%) between 1 km field survey squares and equivalent areas of Land Cover Map: results are given including and excluding boundary pixels. The four landscapes are based on ITE Land Classes.

	Direct correspondence	Agreement allowing for interpretation differences	Agreement allowing for possible change
ALL GREAT BRITAIN			
with boundaries	46	67	76
without boundaries	54	71	82
ARABLE LANDSCAPE			
with boundaries	61	70	79
without boundaries	69	75	85
PASTORAL LANDSCAPE			
with boundaries	49	61	74
without boundaries	56	66	80
MARGINAL LANDSCAPE			
with boundaries	37	60	70
without boundaries	45	66	77
UPLAND LANDSCAPE			
with boundaries	28	75	79
without boundaries	31	79	83

CHECKS AGAINST OTHER INDEPENDENT SOURCES OF COVER DATA

Mapping the Moorland Fringe

The 1990 Landsat cover map of Britain was used in an experiment to evaluate various possible methods of mapping the moorland fringe in England. Four 10 km x 10 km sample areas were used in the Lake District (SD49), the Yorkshire Dales (SD98), the North York Moors (SE69) and the Peak District (SE00). The test areas were surveyed independently by a field botanist (N Greatorex-Davies, ITE).

The field survey recorded moorland cover onto Ordnance Survey 1:25 000 maps. Clear definitions of 'moorland' were based on species contents, management and enclosure. The equivalent sections of Landsat map were extracted and printed onto enlarged OS 1:25 000 map sheets. Comparisons were made by scoring the field maps and the Landsat maps using a grid of points. In the Dales and Peak District, where moorlands covered about half the square, the grid was counted at 100 x 1 km grid centres. In the North York Moors, where moorland was of low cover, and the Lakes, where non-moorland was scarce, the count was raised to 200 using grid points displaced to the centres of south-west and north-east quadrants of 1 km squares. Results are given in Table 6, but with equal weighting for each 10 km site. Results show that there was an 89% agreement between Landsat and field maps in assessing the distribution of moorlands and non-moorland areas.

Table 6. Data from four 10 km x 10 km survey areas in the Lake District, the Peak District the Yorkshire Dales and the North York Moors: the Table shows concordance (% agreement as scored at a sample of grid points) between Landsat-mapped and field-recorded moorland and non-moorland vegetation types (values in bold indicate proportion in agreement: total = 89.3%).

	Satellite:		
	moorland	non-moor	total
Field:			
moorland	**51.8**	2.6	54.4
non-moorland	8.1	**37.5**	45.6
Total	59.9	40.1	100.0

Mapping of Environmentally Sensitive Areas

The Ministry of Agriculture Fisheries and Food produced 1:10 000 maps of the Breckland Environmentally Sensitive Area (ESA) in East Anglia. This was done using air photo-interpretation (API) of 70 mm aerial photographs made in 1987. The total study area was 10 km x 10 km. Field checks against ground data had shown the API to be 94% correct (MAFF, personal communication). The Landsat map of the ESA, here based on 1989 data, was checked independently by MAFF (Edwina Clark, Agricultural Advisory and Development Service) against the API product. The 11 original Landsat cover-types present in the area were simplified to a list of 9 aggregate classes to compare with the API. By projecting the Landsat maps (in slide form) onto the API maps, MAFF made direct comparisons, measured at 78%. Allowing that the airphoto-map's 6% error would not coincide with independent errors in the Landsat product, this would suggest an accuracy of nearer 83% on the part of the Landsat map. The major differences were in the exact interpretation of cover-types. If differences in grassland distinctions were removed, overall agreement was raised to 88% for a comparison between arable, grass, broadleaf, evergreen, heather and built-up cover-types. There were also differences in the process of generalisation where photo-interpretation assessed land use rather than cover: for example, API maps of urban areas included an 'urban curtilage' with no attempt to map the vegetation within. However, the impact of these sorts of difference was not quantified.

THE COUNTRYSIDE INFORMATION SYSTEM

The Countryside Information System (CIS) incorporates field data from sample surveys in 1978, 1984 and CS1990, with the Landsat derived data and with extra thematic information in a PC-based desktop system. These datasets, summarised at 1 km resolution, are accessed by user-friendly Windows-based software, designed to put the datasets and analyses at the fingertips of end-users. For example, users can define administrative regions, impose altitude and geology masks, and then determine land cover within such a region. They might draw upon the field data to estimate species compositions for particular land cover types within the region.

One-kilometre pattern analyses for CIS

In the ECOLUC project Griffiths and Wooding (1989) outlined methods for analyses of landscape patterns of environmental importance and so of interest to DoE. They did this using data derived from Landsat images. The concept of pattern analysis was built into CS1990 as a result. However, the ECOLUC measures were employed locally in detailed studies, rather than for all of Britain. A special meeting of the CS 1990 Advisory Group concluded that pattern data should be provided at a Nationally within the CIS and that the procedures of Griffiths and Wooding should be adapted for implementation at much larger scales. The appropriate resolution was the 1 km grid cell of the CIS. The pattern measures chosen were:

1. % cover per cover-type per 1 km square

2. % boundary pixels per cover-type per square

3. % pixels showing selected pairwise boundary combinations per square

The 17 key classes of the Land Cover Definitions project were used for cover and for single class boundaries; an aggregated list of 9 classes was used for pairwise boundary combinations (Table 1).

The procedure for summarising land cover within per 1 km square counted the number of pixels per cover type per square and expressed the results as a percentage of the 1600 original pixels in the square (results were simplified to an integer percentage value for reasons of storage space). This produced one layer of data per cover type, each layer being 700 values by 1300 values (representing the 700 km x 1300 km rectangle of GB National grid squares). At first there were 25 layers for the 25 cover types. These data have been extracted for the CIS and, so, simplified to the 17 key cover types (Table 1) as recommended by the LCD project.

The data on boundary lengths per cover-type per square have been calculated using software which scanned the full resolution data, a cover type at a time, and marked those pixels which fell on the edge of the cover type. The total number of edge pixels were then scored per square per cover type, to again give 700 x 1300 integer percentage values, one layer for each of the 17 LCD cover types.

Pairwise boundary lengths per square used the shortlist of 9 'major' cover types (Table 1) which give 36 pairwise combinations. The procedure used the same software as above to identify the 9 major-class boundaries, which were then compared for overlap. the overlaps were then scored as percent of overlapping pixels per square. The result was 36 layers of data, each comprising 700 x 1300 values for all GB.

The above analyses add 70 layers of information giving 1 km summary data in the CIS, the data in arrays, 700 x 1300 cells, giving a database occupying 64 mbytes in all (much of this area is sea, so the CIS data storage-requirements may be rather less.

It is important to realise that the provision of these pattern variables will allow users to make their own indices of pattern: for example, diversity measures are available by calculations (tailored to user requirements) based on the summary cover data; an index of patch size per class could be calculated as area of a cover-type divided by its boundary length (or alternative measures eg area divided by the square root of boundary length).

An example helps to demonstrate how it is possible to combine the spatial information of the Landsat based study with the specific details of the field survey. The Landsat study cannot estimate the proportion of, say oak woodland, in a study area: it makes no distinction between different tree species. The field survey can examine the study area in terms of the extent of the individual Land Classes. By reference to the Land Class-means for oak woodland, it can calculate an estimated cover value for oak based on a weighting the extent of the different cover-types. However, it cannot take local peculiarities into account, for example in areas where woodland is particularly extensive or perhaps completely absent: it could certainly not predict the continuous variability of woodlands across a region, except insofar as these related to a Land Class. By examining the deciduous woodland area according to the cover map, and referring to the 1 km pattern of Land Classes it would be possible to estimate oak cover as a proportion of the known deciduous woodland cover. Addition of pattern data might use area-to-boundary ratios to estimate fragmentation of woodlands and even the predominant neighbouring cover types. Thus, for example, the data might be used to build up a detailed picture of regional patterns and composition of woodlands for studies of, say, habitats for woodland birds.

Quite simply, wherever, there is a correlation between a Landsat cover-type and a specific variable of interest, then the land cover map can help predict the specific details: as the extent of crops can be related to the area of tilled land through the field data, so a map of tillage can refine local crop estimates; if hedges are positively correlated with managed grasslands the map could be used to improve local and regional hedgerow estimates. Correlative predictions could be further improved by use of soils, altitude and other thematic data in the CIS.

GIS APPLICATIONS AND DEMONSTRATOR PROJECTS

A geographical information system (GIS) is a very flexible way of analysing environmental data in its many forms. Although raster based image analysis systems offer powerful raster analysis functionality they are not best suited to the examination of spatial relationships or for integrating attribute data, held within relational databases. GIS offers the opportunity to carry out these additional analyses.

Demonstration of GIS capabilities studied a 75 km x 50 km test area centred on the Thames estuary. This area was exported from the I^2S to a Laserscan GIS and there converted from raster to vector format. It was possible, then, to build polygons and to analyse the spatial geography of land parcels, for example, to make routine calculations of mean and total polygon areas, boundary lengths and ratios of the two. However, this relatively small area, one-sixtieth of all Britain, contained 80 000 polygons. This led to problems in data handling, particularly in terms of time taken to make the analyses.

Handling of polygons concentrated on individual polygon areas and lengths for the study area. A number of test runs were carried out on a range of different sized classes. Classes with less than 100 polygons, such as the bare ground class, took less than one minute to run, whereas classes with thousands of polygons needed to be run individually overnight. These findings highlighted the common disadvantage of running 'in house' developed macro routines that do not necessarily make the most efficient use of the GIS functionality.

This functionality is being improved by the GIS manufacturer but due to time constraints, it was decided to run these type of analyses on some smaller test areas extracted from the land cover map. The spatial analyses developed in the course of this work found practical applications in a number of projects some of which are described below.

The British Trust for Ornithology (BTO) related land cover patterns to bird species diversity. The BTO used their census information recording the distributions of common breeding birds on a tetrad basis (ie for a 2 km x 2 km National Grid square). The Landsat data for Norfolk were summarised on the same 2 km grid basis. A Shannon Diversity Index was calculated for the land cover in the study squares. The land cover diversity was then regressed against bird species number. Results showed a clear positive relationship between the cover diversity and bird diversity which was significant at $P<0.001$ (Gates *et al.*. in press).

In another ornithological application, a 20 km^2 trial area of Cambridgeshire was analysed to study sparrowhawks in relation to woodland habitat. The cover map was analysed to show variations in woodland sizes relative to sparrowhawk numbers.

A procedure is being developed using the land cover map to interpret the recorded movements of radio-tagged birds of prey. The map forms a 'back-drop' onto which digitised tracks of the tagged birds are superimposed to ascertain the type of land used, duration and frequency of occupation. Subsequently, survival statistics are related to habitats in the home range of individuals.

Another pilot analysis carried out in this Cambridgeshire trial area used the ability of the GIS to construct 'regions of interest' from other data sources and use these to restrict the selection of relevant woodland polygons. With the proposed upgrading of the A1 motorway status, there was an interest in measuring the land cover within predefined distances of the road. A vector topographic map was introduced to the trial area and the A1 road selected. A standard GIS function created a 'buffer zone' 1 km wide (an arbitrary value chosen by the user). This corridor was used to select out all woodland polygons within one kilometre of the road for a length of about 12 km. It was found that there were 68 woodland polygons within this corridor with a total area of 1.3 km^2. This simple GIS function can be further refined by adding other parameters or including other selections of vector land cover data.

A demonstrator project examined the extent of gaseous emissions from proposed industrial sites, assessing the sensitivity of the surrounding vegetation. A vector map of the extent of the emission was created by models of plume dispersal. The map was superimposed over the Land Cover Map to locate sensitive vegetation classes and to assess amounts of such vegetation within the predicted plume extent. Vegetation that was sensitive to these specific emissions was then the subject of detailed field survey.

The Natural Environment Research Council/Economic and Social Research Council Land Use Project (NELUP) based at Newcastle University is building decision support systems for management of river catchments. The project is using the land cover data to examine land use in relation to water quality and wildlife distributions in river catchments, using the Tyne and Cam as study areas (O'Callaghan, 1992).

The Key Habitats Project is an excellent example of an application where land cover data from the Landsat mapping exercise have been enhanced by, or, in some cases, add information to, external geographical data. Various GIS techniques have been combined to direct a field study of 'key habitats' for managing conservation practices. The means of definition demonstrated an interesting combination of the land cover map with the ITE Land Classification (into 32 strata) and with other external geographical data including grid cell summaries (eg soils) and vector inputs (eg rivers) to define landscapes and habitats which could not have easily been defined by other means. In heathlands, the external data (soils in grid form, geology as digitised vectors) provided the basic landscape definition, and the cover data added information on the land use and on distributions of surviving or potential habitat within the landscape. In the case of uplands, the ITE Land Classes defined the landscape and the cover map added detail on habitat. In waterside landscapes, the external data were vector waterways, combined with grid cell soils, supplemented with generalised cover data. In coastal landscapes, the Land Cover Map provided the basic information to identify the landscape and the GIS provided the means (a 500 m buffer zone) of identifying its geography: the Land Classification added supplementary data. This study gives an excellent example of how these disparate data sources, in varied forms, can be brought together in a GIS to build a classification of landscape.

In all some 40 specific applications of the Land Cover Map are either current or proposed and likely to go ahead. many of these are either submitted for initial publication or have papers in preparation. Other studies will follow shortly. Table 7 gives a list of current or planned uses. In due course, it is intended to produce a bibliography based on these and further studies. This will be available for consultation.

Table 7. Some specific GIS Applications of the Land Cover Map

Existing applications

Key habitats mapping (conservation and designation)

Conservation survey

Less favoured area assessment

Moorland landscape management

Heathland restoration potential

Species and landscape (plants, invertebrates, birds)

Species movements and biogeography

Biological quality of catchments

Water quality of catchments and aquifers

Land Ocean Interface Studies

The Water Information System

Terrestrial Initiative in Global Environmental Research

Critical loads mapping (environmental chemistry)

Environmental Impact Assessments

GIS research and development

Planned or expected

Provision of other maps and atlases

The epidemiology of Lymes disease (spread by ticks which live in bracken)

Relationship between leukaemia and bracken

Modelling the potential spread of rabies

Evaluating dealer-network for an agricultural machinery company

Table 8. General areas of use and suggested applications

1. National land use planning
Balancing competing land uses, CEC and International obligations

2. Strategic regional planning
County structure plans

3. Agriculture and forestry
Planning, stocktaking, impact assessment

4. Water resources
Quality - aquifers, waterways, estuaries, seas, effluent, wildlife, planning, engineering

5. Conservation
Stock-taking, impact assessment, prediction, management, monitoring, ecological understanding

6. Education
Geography, ecology, sociology, remote sensing, GIS - primary to tertiary

7. Cartography & GIS
Atlases, GIS demonstrators, and as an extra to all GIS users

8. Development & Civil Engineering
Site identification, preliminary site assessments, route planning (roads, pipelines, cables), EIA

9. Pollution, effluent and waste
Assessment, planning, monitoring, control

10. EIA
Roads, power stations, chemical works, dams, sea defences

11. Epidemiology
Human diseases (Lymes), animals (rabies) and plants (Dutch elm)

12. Recreation and amenity
National parks, open space, access to different landscapes, leisure maps

13. Mining, quarrying and landfill
Measuring impacts, site-identification

14. Petrochemical/energy
Impacts, monitoring, planning, management

15. Agrochemicals and seeds
Market assessment

16. Industry and commerce
Market assessment

17. Sociological
Population, urbanisation, landscape and amenity

18. Statistical information
National Audit Office, Central Office of Stats, publishers

The current uses, most underway before the launch of the Land Cover Map, represent a small proportion of an obviously large potential range of interests. Table 8 gives general areas of use which have been suggested in discussions by customers for data. The launch itself attracted over 200 positive expressions of interest with about 160 outside visitors to the event. The list of organistations represented at the launch helps demonstrate the widespread interest, and is attached as Appendix 2 to this report.

DISCUSSION

Land cover mapping

The classification produced 25 target classes, aggregated to 17 key cover types with correspondence to CS 1990 field and other surveys (details to be presented to DoE in the Land Cover Definitions report). The classes were further simplified to 9 major cover types for pattern analysis.

A new suite of image analysis procedures was developed for this project, especially some novel approaches to contextual and knowledge-based corrections of classmaps. These have been incorporated into a standard methodology for land cover mapping from remotely sensed data which can be routinely applied elsewhere and on future occasions

Image classification was completed by the end of March 1993. The results take the form of computer files of raster data, stored as 100 km^2 sections.

Out of 2% which remains unclassified, perhaps 0.5% of Britain is unclassified due to cloud on summer and winter images. Elsewhere (the other 1.5% unclassified), unusual cover types are most likely the cause. The missing areas of Coll, Tiree and Shetland total perhaps 200 km^2, and represent just 0.1% of Britain.

Operational classification at a national scale

Image issues

Image searches have shown that acquisition of cloud-free images is irregular, but the considerable overlap between adjacent Landsat paths gives a repeat cycle which has provided summer and winter cover for all of Britain within the 1988-92 target period. The paucity of image cover in upland western Britain shows that routine availability of winter-data may be unreliable. Future developments may require the use of alternative data, perhaps other multi-spectral data, or radar images, if we are not to be restricted by the uncertain acquisitions of cloud-free data. However, Landsat is unique in supplying spatially high resolution data, with a middle-IR waveband, and this has been crucial in separating certain cover types, so immediate alternatives may not prove so successful.

The geometric correction of images is achieved with cover maps registered to ground reference data to within 0.8 pixels (equivalent to 20 m) average displacement. This error rate is quite acceptable for a wide range of applications. However, one problem remains, that of summer-winter registrations: misregistrations will undoubtedly have increased mixed pixels in images and caused confusions in classifications. Improved registration might substantially raise accuracy levels.

Cover classification

The operational use of these data at a national scale relies on the development of a land cover classification which is applicable to all the cover-types to be encountered in such a survey. The definition of target cover types was based on a wealth of experience in such mapping, for, in practice, the cover of Britain has been widely mapped, but in a piecemeal way. The important step was to bring together the range of cover-types identified by other surveys and to test the feasibility of mapping these. The classification which has been used is hierarchical, giving 25 target classes, based on previous surveys and matched to current user-requirements. The aggregation to 17 classes recommended by the Land Cover Definitions project compares with the 59 class list of LCD: however, the LCD list included a wide variety of crops and various elements of land use which were not discernible on images. The fact that the semi-natural cover types were aggregated from 25 to 17 types indicates that the final choice in this area was adequate.

Consistency is the key to a successful conclusion and this must be dependent on the images in use. For this reason, features such as arable crop type are not distinguished, being transient features of the landscape. In practice, their exclusion was also convenient because the definition of crops would have greatly restricted the date of suitable summer imagery, perhaps to just late June through to mid-July; even then some crops would have been missed.

The use of a hierarchical classification allows any user to opt for detail, but with reduced accuracy, or to simplify classes with more consistent results. Many users will choose a compromise between the two extremes. Beyond the target classes, for which a consistent classification is intended, lies the subclass structure used in training and preliminary classification which allows users the option of specifying subclasses of particular interest.

Post-classification procedures

The masking procedure has provided a simple, innovative approach to improved classification and represents a 'spin-off' from the project in terms of wider applications. In the case of urban and maritime areas, the masks corrected errors. In the case of upland-lowland masks their use was to help subdivision: users who wish to draw on other data such as terrain models can re-aggregate the classes and substitute their own procedure.

Filtering procedures provide an acceptable level of complexity without loss of detail. If users wish to further simplify, they could filter again using majority filters, perhaps even 5 x 5 kernel regions.

The merging procedures for joining two scenes are effective in obscuring the join and producing a 'seamless' effect locally. However, it has to be said that, in overview, the differences between adjoining images can be discerned, sometimes quite clearly, depending upon the colours applied to output maps. The greatest contribution to this effect seems to be the quantity of unclassified image either side of a join. It is proposed to examine improved procedures for minimising differences, in particular, using post-classification corrections.

Comparisons with field surveys

Checks against ground reference data are usually presented to quantify the accuracy of classification achieved by the image analysis procedure. However, to do this, we need access to 'ground truth data'. Unfortunately, there is no such thing - conventional maps are most commonly used, but their division of a continuum of landscape patterns into discrete classes, with hard boundaries is not 'truth' but an artificial generalisation. Such generalisation achieves different results according to the rules and methods employed. The LCD project has revealed wide variations in the treatment of land cover by recent UK surveys.

The largest part of the difference relates to the fact that both surveys generalise according to different rules. The field survey concentrates on physical boundaries (fences, walls, ditches), and maps what is the perceived dominant cover type in of a field. The Landsat study takes no account of boundaries but attempts to allocate a 25 m square patch on the ground to the most likely cover type. As both surveys operate within different rules and with different objectives they can give different results with neither being wrong. Such complexities are discussed in the report on the LCD project (Wyatt *et al.* 1993).

The impacts of different generalisation procedures operate even when objectives remain the same: a quality assurance exercise, which examined the 1 km field data, showed an average 84% correspondence when the surveyors primary coding of land cover was compared with a quality standard. If the Land Cover Map were 'correct' in its distinctions, agreement with field data would be expected to match the 84%.

Tests of accuracy indicate that, depending on the classification and spatial details examined, an overall 46-90% correspondence rate is achievable. Once differences in definitions are removed, 67% overall correspondence is recorded (Tables 3 & 5). This correspondence would arise if comparing a Cover Map which is 80% correct with a reference set which is 84% correct.

Misclassifications are normally between similar cover types. The reasons for differences are many and varied. These are considered in turn.

The biggest component of the error is attributable to misclassification of mixed boundary pixels. A Cambridgeshire pilot study showed that 10% of the arable scene (15-25% in the arable fens) would comprise boundary pixels at a 20 m pixel size (Fuller & Parsell 1990). The larger 25 m pixel size of the current study served to increase the number of mixed edge pixels. The pattern analyses and comparison with vector data showed that some 40% of pixels adjoined or crossed a boundary between classes.

There are minor geometric discrepancies, where a feature is correctly classified but displaced in its exact map position: this is true of both the OS base maps and the Land Cover Map. In a dissected landscape, this can have a major impact. It is necessary therefore to distinguish between misclassification and misregistration. A class map might be an accurate measure of cover, pattern and relative distribution, but with minor spatial differences relative to, other equivalent products.

There are also time-dependent differences between the two surveys: the Land Cover Map used 1988, 1989 and 1990 data whereas all field observations were made in 1990. Rotation farming is prevalent in some areas: the project's field reconnaissance had already showed that a 1-year lag might re-distribute half of arable and grass fields in areas of mixed farming and that a 2-year lag between imaging and field work might mean an almost total exchange in the distributions of arable and grass. The field survey recorded newly planted conifers as coniferous woodland, even if the trees were just 0.5 m saplings with scarcely 5% cover: under such circumstances the Cover Map would have recorded the 95% background of, say, moorland grass. The field survey used the low tide line shown by OS, the Landsat survey could only depict beaches as they appeared at the time of imaging. Allowing for likely changes, agreement between surveys is raised to 81%. This approaches the level of correspondence achieved by intercomparison of original field data and 'quality assurance' field data.

If the field survey correctly recorded 90-95% of the landscape (thus overlapping about 85% with an equivalent quality-assurance survey), and if the Landsat survey achieved its target 80-85% success, then the overlap would likely be around 75%, the figure obtained if we allow for the obvious interpretation differences, with perhaps an element of change.

Integration with other data in a GIS

The integration of cover-data into a GIS opens many opportunities for analyses. There are a number of raster-based GIS capable of using the data in their standard grid-cell format. Conversion of a test area from the grid-cell or raster format into outlined polygons or vector format currently has advantages for analysis of linear features and for the recognition and handling of discrete polygons. However, such conversion of the cover map highlighted the problems of dealing with such large databases. An area, one-sixtieth of all Britain, generated 80 000 polygons. There is no commercial GIS which could realistically handle such detailed vector information for all of Britain where 5 million parcels might result. Simplification, by filtering out all small parcels, would be possible, but risks throwing away useful information. Simplification was a necessary part of conventional cartography when a cartographer had to individually draw and classify every parcel. It is not a necessary part of raster image classification, so, unless it can be shown that the fine detail is 'noise' rather than data, the detail should not be lost for mere convenience and without careful thought. In the meantime, there is still the prospect of sophisticated analysis at full resolution at the local scale, for handling smoothed data at regional scales, and for generalised analyses at national scale. This is an enormous step forward from the situation facing Stamp (1962) and Coleman (1961) where completed maps were in paper form and where sophisticated spatial analyses at regional and national scales would have been impossible.

CONCLUSIONS

1. BNSC and NERC funding has helped to produce the first map of the land cover of Great Britain since the 1960s. The Land Cover Map of Great Britain has been made by a semi-automated classification of Landsat Thematic Mapper data, by the Institute of Terrestrial Ecology. It is the first such survey since the 1960s (Coleman 1961) and only the second this century (see also Stamp 1962). Most important is the fact that the information is available in digital form. This greatly facilitates access to the map-information and manipulation towards applications.

2. The map gives a field-by-field scale of detail with patterns recorded on a 25 m grid. This represents the first ever digital map of Britain's land cover. The land cover mapping project has successfully recorded the land cover of all Great Britain.

3. The methods for mapping the land cover of Great Britain worked the length and breadth of Britain from sea level to highest peaks. The landscapes range from urban London, through arable eastern Britain to semi-natural communities, throughout Britain, which include coastal habitats, grasslands, wetlands, heaths, moorlands, woodland and forest classes.

4. Image availability is somewhat patchy but mostly adequate: 12% of Britain was not covered by winter data and much of the remainder was only covered by one winter-scene in the study period. Sometimes, 2 summer scenes have been needed to ensure near full coverage. Such an approach adds costs in time and imagery.

5. Field reconnaissance offers a pragmatic solution to a significant problem, namely that of covering large areas in order to maximise the diversity of information collected per-scene. Field reconnaissance has occupied between 5% and 10% of the time taken in the mapping of Britain.

6. Geometric correction and co-registration leave some problems in achieving exact summer-winter correspondence. However, mixed boundary pixels are a feature even of single date images: the 20% of boundary pixels which cause problems here should be seen in the context of the 80% which do not and which are better classified by the two-date approach. Geometric misregistrations may also highlight errors in per-pixel validation methods: however, such minor misregistrations will not significantly affect cover statistics except when dealing with small areas or linear features.

7. Maximum likelihood classification works, despite statistical problems involved in training area-selection (Kershaw & Fuller, 1992). The use of summer-winter composite images gives cover-distinctions which can better accommodate the training data where these do not fulfil exact requirements eg of normal distribution in radiance values. The use of subclasses gives closer adherence to this condition. The iterative approach, with built-in checks, delivers the required results despite problems created and corrected *en route*. A fuller statistical evaluation would be desirable, but is not available within the current I^{2}S software package. Operational uses, where feasible, should not be delayed in the quest for ever-better methodology.

8. The chosen classification of British land cover will not satisfy all users. It is a compromise between the 'simple but accurate' separation of few cover types and the complex but

impossible distinction of many. The classes are based on tried and tested cover types of other surveys, agreed with end-users, and shown in pilot exercises to be feasible. In some cases, they exceeded the recommendations of the Land Cover Definitions project. The hierarchical structure enables users to reconstruct their own simpler classes. Conversely, the subclass structure offers detail for specialist consultation.

9. Knowledge-based correction, taking account of context, offers a simple solution to the obvious criticism that per pixel classifiers employ no intelligence in making classification, and hence make ludicrous mistakes.

10. The use of filtering algorithms to remove 'noise' in the data is regular practice. The choice of one which only removes isolated pixels was based on the observation that coarser filters reject useful information. However, a range of options are available and applicable to the current cover maps, for those wishing to further generalise.

11. The conclusion of the various checking exercises are:

i. Agreement with ground reference data is between 67% and 90% depending on the level of subdivision of cover types, the cover types involved and the complexity of land cover patterns in a test area.
ii. Minor geometric misregistration of otherwise good land cover maps is recorded as misclassification of pixels when comparing directly with ground or API maps, although the effect on areal estimates is minimal. This problem requires a novel approach to per-pixel checks of accuracy.
iii. Even when geometric misregistration is not a problem, discrepancies are largely associated with boundaries, due to the difficulties of classifying mixed boundary pixels.
iv. Differences in resolution are important: the class map does not seek to identify linear features and may underplay or misclassify them: field maps, based on OS, may greatly exaggerate them.
v. The spatial quantisation of the pixel-based maps, imposes an artificial structure on the digitised field and Landsat maps which causes apparent error.
vi. Misclassification is a problem attributable to the classmaps; however, field data incorporate errors which may be less apparent and less easily quantifiable.
vii. Many discrepancies between the Landsat and alternative reference products are explained by interpretation differences or by differences in objectives: there is not necessarily a universally 'correct' answer in dividing a continuum of cover types into discrete classes.
iix. The division of continua of vegetation classes into 25 types also imposes an artificial quantisation on the results.
ix. The field survey, like other methods of conventional cartography simplifies and generalises, treating fields for example as uniform in content.

12. The potential to inter-relate land cover data with other geographically referenced data in a GIS opens many opportunities for environmental analyses. Use of cover data in conjunction with maps of topographic information, soils, geology, climate, administrative boundaries etc. open avenues of analysis hitherto far too difficult to contemplate except at the local level.

13. The Countryside Information System holds summary data at 1 km resolution. Even spatial context is provided by the CIS summary, giving boundary data and information on neighbouring cover types. Although losing the full spatial details of the original survey, this dataset nonetheless offers an enormous quantity of information and is suitable for most analyses where the exact spatial context of habitats is not needed.

14. The 1 km summary of cover data, boundary data and pairwise boundary data in CIS offers a dataset, which is unique in its provision of full National cover for all the land of Britain. The combination with specific details from field surveys, backed with thematic data is most important for applied analyses. The data are in a particularly accessible form with CIS's user-friendly, Windows-based processing. The CIS allows planners, policy makers and landscape managers to access a wide range of information on the landscape and support their decisions with data and tailor-made analyses.

15. The CIS incorporates the CS1990 field and Land Cover Map data, together with the map giving the stratification into biogeographical Land Classes; 1978 and 1984 field data are included; various maps include thematic information on administrative boundaries, topography, geology and climate.

16. The integration of a detailed, sample-based, field survey with the generalised but complete coverage of the Land Cover Map has given greater potential than either survey could offer in isolation. - "the value of the whole is greater than the sum of parts". Integrated use can operate with the data at the 25 m grid scale of the Land Cover Map; more frequently it will be using the 1 km resolution of the field survey stratification.

17. The procedure is now established for routine updating of the land cover map and it is the intention to regularly update the information. However, continuing research and development work within ITE will, it is hoped, refine the methods to improve speed and efficiency, boost accuracy, increase the detail available and incorporate other images to overcome shortages of cloud-free Landsat TM data.

18. Applications are the true mark of success of the cover data. The data have found already some 40 users in areas of policy and planning, landscape management, environmental chemistry, management of natural resources and environmental impact assessments. The positive response to the launch-invitation, numbering over 200, with a turn out on the day of 160 guests, is evidence of the importance of the Land Cover Map. Furthermore, the audience included a wide range of potential users in the Government Departments, Government Agencies, the Utilities, Industry, Commerce and the consultants working for all such organisations. Three weeks after the event, enquiries are running at several per day and accelerating. Media coverage has been good in breadth of interest and quality of cover.

FUTURE UPDATES

The methods are in place to continue to update the Land Cover Map of Great Britain on a regular basis. The 'learning curve' has been climbed and a repeat survey might only take two-thirds of the time of the original survey. However, there are still a number of areas for improvement. ITE has plans to refine methods, to better exploit supplementary data, and to build in greater automation where these will improve accuracy, speed, efficiency:

1. Some 12% of Britain was not mapped using composite summer-winter data and 0.5% was unmapped even from a single date, both due to cloud, despite 1988-90 being best period for many years (we would still have used much 1988 imagery if we were to have started in 1993). An update could not be guaranteed for some target date in the future. Technological developments should try to exploit radar's 'all-weather' capability to supplement missing data. If SAR analyses were able to only distinguish bare from vegetated surfaces, it would nonetheless serve a major role of the winter data, namely to distinguish between semi-natural vegetation and crops.

2. In this project, ITE has built a library of spectral signatures made for all major habitats, most recorded throughout the year. The data tell future users of TM data what various cover-types should look like at various seasons. ITE hopes to investigate how far existing knowledge on spectral signatures could be used to make a fully automated classification of new images.

3. Improved registration of summer-winter composite images would improve accuracy levels. It might be possible to examine local correlations between composite data, or to use edge detectors to better achieve coincidence.

4. The Land Cover Map represents a 'knowledge base' to help in future mapping: an update will not need to start from scratch.

i. The original map would form the masks for knowledge-based corrections.
ii. The map might help to define training areas.
iii. It might be used to determine the classes in a new unsupervised classification.
iv. The existing map might help segment an image for within-segment classification.
v. New maximum likelihood classifications could be checked against the original (consistent classifications would be accepted, inconsistent ones questioned and probability levels used to help decide whether changes were real or the result of error (original or new)).

5. Ordnance Survey boundary data exist, yet we have been unable to use these in classification. The OS data might help achieve a better summer-winter registration. We need to integrate satellite and OS map data for improved segmentation and better within-segment classification. The procedure would define boundary pixels and allow their allocation by mixture modelling or according to their major content.

6. There is a need for greater cover-detail. Some users require knowledge of specific crops, or wish to identify unimproved agricultural grasslands. Methodological improvements should ascertain feasibility of adding these details.

7. New generations of sensors will combine improved spatial resolution with enhanced spectral resolution. These may help to increase the details available to map users. They will, however, offer new problems which will require new solutions if maximum output are to be expected.

8. A combination of old and new methods might give accurate updates in a fraction of the time, by fully automated means. Research and development work should investigate procedures for combining improved methods so that updating can become routine and hence frequent.

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APPENDIX 1:

THE LAND COVER MAP OF GREAT BRITAIN

LAND COVER CLASSES: A DESCRIPTION

INTRODUCTION

The following descriptions outline the ITE Landsat-derived cover types used in the Land Cover Map of Great Britain. The choice of classes was based on personal experience within the ITE Remote Sensing Unit, in surveys made from ground, air and space; it was made after consulting other published surveys, and after personal communication with other surveyors. The list represents a compromise between what would be ideal for wide-ranging users, and what was feasible to map, at this scale, from remote sensing. End-users and other surveyors have had the opportunity to comment on, and thereby influence, the final classification - the comments are built into the class descriptions. The numbering of classes reflects the time at which they were added to the classification.

The classes chosen represent an aggregation of many subclasses: for example, wheat, barley and oilseed rape are subclasses of the 'arable' class. These subclasses have been reduced to a short-list of target 'classes' which are considered ecologically meaningful, consistently recognisable from the selected imagery, and realistic in terms of their likely accuracy.

It would be possible to recombine subclasses differently, for example a map of 'graminoids' might be produced by aggregating all grass subclasses, including natural grasslands, agricultural pastures and arable cereals. Very likely, specialist users will require a 'tailor-made' aggregation to meet specific objectives, and this could be done digitally, by reference to the original maps of subclasses. Such users would have to accept that subclasses might not be distinguished consistently (eg not all images were of appropriate date to separate, for example, wheat from barley within the arable class).

The descriptions aim to record any limitations which would prevent further subdivisions to consistent standards. All classes are subject to the provision that they are only mapped if they are above the minimum mappable size, namely two pixels, ie 0.125 ha, though in practice it cannot be said that all 0.125 ha features are shown - this will depend on how strong the spectral signature of a feature is and how pixels fall with respect to that feature. Minimum consistently mappable area could be 5 ha (Townshend 1983). In practice, the real value is probably between these two extremes, and perhaps nearer to 1 ha.

At present, the list distinguishes lowland and upland categories which are similar, for example lowland heather and upland dwarf shrub. These classes have spectral characteristics which allow their separation, but not with the same level of accuracy as would be available in separating classes with entirely different characteristic species. Regional upland and lowland masks have been created from the cover-classes and coarsely filtered in order to generalise the classification into lowland and upland types. Some users may feel that other measures of context (eg altitude) are better criteria for separation, in which case such separations are best made in a geographical information system (GIS).

Agricultural grassland subdivisions have been taken further than spectral signatures may justify, because of the importance and extent of agricultural swards (see later). The situation with grasslands is complex: in addition to the interplay of species and altitude, there are extra difficulties imposed by soil-acidity, wetness and, more especially, by complex and ever-changing patterns of grassland-management. In the continua from lowland to upland, from wet to dry, from basic to acid soils and from natural to intensively managed, many classes might be identified. Agriculturalists and conservationists may not necessarily define the same classes, nor would a class be consistent from one agricultural region to another - a rough pasture in SE England might be considered to be good in montane Scotland for example. It is also true that discrete classes may not be spectrally separable, especially where management (eg mowing) obscures the characteristic appearance of the various components. Those classes which are defined here are thought to be ecologically meaningful and separable with good reliability. They are, most importantly, intended to be consistent throughout Britain.

HOW TO USE THIS CLASS DESCRIPTION

This class description document is structured in terms of the two levels of classification at which the Land Cover Map of Great Britain is being made available as a standard digital product: as either the full set of 25 'target' cover-types, or as an aggregation of these into 17 'key' cover-types.

The 25 classes are those provided as standard in the 25 m spatial resolution data; the 17 classes are those provided as standard in the 1 km summary data. In the former, there is just one layer of data, with values or 'labels' between 0 and 25 representing the designated cover type of each 25 x 25 m grid cell. In the 1 km summary data there are 17 layers, one for each 'key' class. Each layer records the cover for one 'key' class. The values for each 1 km grid cell represent the proportion of that cell that has been designated as being of a particular key cover-type. So, layer 1 holds the cover per 1 km cell for 'key'class A, layer 2 the summary cover data for 'key' class B, etc. This proportion is expressed as an integer percentage value, eg if 320 of the original 1600 25 m cells within a particular 1 km cell were of key cover-type G (marsh/rough grass) then the layer for this class would have a value of 20 (%) for this 1 km cell in the 1 km summary data. (As indicated in the *Introduction* it is also possible to provide non-standard 'customised' data, eg the 25 m data could be provided as the 17 key cover-types, rather than as the 25 target cover-types.)

Table 1 shows the correspondence of the 17 key cover-types to the 25 target cover-types. To avoid possible confusion the 17 key cover-types are referred to by uppercase letters (A - Q), whilst the 25 target cover-types are referred to by the numerical label that the category carries in the 25 x 25 metre digital data.

In the 1 km summary data the integer percentage values are presented class by class and these may be thought of as distinct sets or 'bands' of data. The second column of Table 1 shows that in the full 17 class data set the order of these bands follows that of the letters A - Q. If a subset of the 17 key cover-types was requested then the corresponding band numbers would change, eg if data for only classes B, G, M and Q were requested then these would be bands 1, 2, 3 & 4 respectively.

Table 1. The correspondence between the 25 'target' cover-types and the 17 'key' cover types of the Land Cover Map of Great Britain.

LAND COVER CATEGORY (17 class system)			TARGET CLASSES (25 class system)	
A[a]	1[b]	Sea / Estuary	1[c]	Sea / Estuary
B	2	Inland Water	2	Inland Water
C	3	Beach / Mudflat / Cliffs	3	Beach and Coastal Bare
D	4	Saltmarsh	4	Saltmarsh
E	5	Rough Pasture / Dune Grass / Grass Moor	5	Grass Heath
			9	Moorland Grass
F	6	Pasture / Meadow / Amenity Grass	6	Mown / Grazed Turf
			7	Meadow / Verge / Semi-natural
G	7	Marsh / Rough Grass	19	Ruderal Weed
			23	Felled Forest
			8	Rough / Marsh Grass
H	8	Grass Shrub Heath	25	Open Shrub Heath
			10	Open Shrub Moor
I	9	Shrub Heath	13	Dense Shrub Heath
			11	Dense Shrub Moor
J	10	Bracken	12	Bracken
K	11	Deciduous / Mixed Wood	14	Scrub / Orchard
			15	Deciduous Woodland
L	12	Coniferous / Evergreen Woodland	16	Coniferous Woodland
M	13	Bog (Herbaceous)	24	Lowland Bog
			17	Upland Bog
N	14	Tilled (Arable Crops)	18	Tilled Land
O	15	Suburban / Rural Development	20	Suburban / Rural Development
P	16	Urban Development	21	Continuous Urban
Q	17	Inland Bare Ground	22	Inland Bare Ground
			0	Unclassified

[a] class reference within the 17 'key' cover-type categorisation.
[b] 'band' within the 17 'key' cover-type 1 x 1 km summary data.
[c] label value within the 25 'target' cover-type 25 x 25 metre data.

DESCRIPTIONS OF LAND COVER CLASSES USED IN THE MAPPING OF GB

A SEA / ESTUARY

This category includes all open sea and coastal waters, including estuaries, normally inland to the point where the waterway is constricted to 1 pixel or its continuity is broken by a bridging point. An exception is where waterways open up again into major estuarine features, such as Breydon water near Great Yarmouth or many of the sea lochs on the north-west Scottish coast. The division will be immediately evident by reference to classmaps. It is not intended to accurately show the limit of saline or tidal waters, which may extend much further inland.

Fuller key-name: Sea, coastal waters and estuaries, inland to the first bridging point or barrier.

This category carries the label '1' in the 25 'target' class dataset.

B INLAND WATER

Inland water includes all mappable fresh waters and any estuarine waters which are excluded in the above category. The maps record only those areas which are water-covered on both the winter and summer images. Thus, reservoirs with summer draw-down, or winter-flooded meadows are classified to the summer class (ie bare or grassland in these examples).

Fuller key-name: inland fresh waters and estuarine waters above the first bridging point or barrier.

This category carries the label '2' in the 25 'target' class dataset.

C COASTAL BARE GROUND (BEACH / MUDFLATS / CLIFFS)

The coastal bare ground category includes intertidal mud, silt, sand, shingle and rocks. It also includes bare maritime habitats above the tide-line, such as shingle beaches, mobile sand dunes and bare rocks or soil of coastal cliffs. A covering of sparse vegetation, such as pioneer saltmarsh, dune or shingle species will not put the beach into a vegetated class unless the majority of the substratum is covered.

Distinction of this cover type is dependent on the level of the tide on the days of imaging (the lower tide being used to define the lower limit of the beach). Thus discrepancies can arise where high tides prevailed on imaging.

Fuller key-name: bare coastal mud, silt, sand, shingle and rock, including coastal accretion and erosion features above high water.

This category carries the label '3' in the 25 'target' cover-type digital data set.

D SALTMARSH

Areas of seaweeds are sometimes sufficiently extensive to show as vegetated intertidal plant communities. The may comprise the green alga *Enteromorpha intestinalis* or the brown wracks (*Pelvetia caniliculata, Fucus* spp. and *Ascophyllum nodosum*) growing on rocks, boulders and sometimes gravels, sands and muds. Saltmarshes are intertidal sand-, silt- or mud-based habitats, colonised by halophytic grasses such as *Puccinelia* spp, and herbs such as *Limonium* spp., *Aster tripolium* and *Triglochin maritima.* They remain mostly green in winter. For the purposes of this classmap, only those marshes up to normal high water spring tides (ie those flooded monthly) are included. The upper saltmarsh, inundated only on extreme high-water spring tides, is dominated by coarse grasses such as *Agropyron* spp.. These are classified accordingly as marsh / rough grass (see below).

Distinction of this cover type is dependent on the level of the tide on the days of imaging (the lower tide being used to define the lower limit of the seaweed beds or saltmarshes). Thus discrepancies can arise where high tides prevailed on imaging.

Fuller key name: intertidal seaweed beds and saltmarshes up to normal levels of high water spring tides.

This category carries the label '4' in the 25 'target' class dataset.

F PASTURE / MEADOW / AMENITY GRASS

Agricultural grasslands comprise many types, from newly sown leys, of single species, to largely unimproved swards of indigenous species. This range is subdivided in many different ways by the many different surveys of grasslands (see Fuller 1987). Here we must be constrained by what is possible, with acceptable accuracy, using satellite imaging. Certainly, the class 'pasture/meadow/amenity grass' can be identified with good consistency. It characteristically forms a cropped sward, comprising finer grass species (eg *Festuca, Agrostis, Lolium* and *Poa* spp.) often with many other grasses and herbs. The sward is maintained by mowing and/or grazing, such that coarser species of grass, herbs and scrub cannot become dominant.

In agricultural and conservation terms, there is an important distinction between 'improved' and 'unimproved' swards. Improvement may involve reseeding, herbicide treatments, and/or fertiliser applications which promote the growth of 'preferred' species, especially *Lolium perenne.* Swards which are essentially 'unimproved', or which have reverted, contain a dominant proportion of indigenous species (Fuller 1987).

Improved pastures or close-mown amenity swards are mostly distinguishable on satellite imagery: they remain green in both summer and winter. Unimproved swards are generally used at a low intensity and are typically unenclosed. They are also likely to be discernible from intensive pastures because of their rougher texture, their weed content and the quantity of plant litter they carry in winter (all factors which affect overall reflectance). The problem is that hay meadows, of both the lowlands and the partially improved lower slopes of upland areas, could be confused with either improved or unimproved swards, depending on the stage of management in the particular year of imaging eg growing hay, standing hay, cut hay, aftermath-grazed. This obviously depends on the date of the image available for classification (and only days may separate the four types).

The 25 class classification identifies two types of pasture/meadow/amenity grass, which are be retained as separate class numbers in the database, but could be aggregated to a single colour-class for map and data outputs, depending on the measured accuracy and user requirements. It should be realised that the classes are readily inter-changeable by changing management practices, and such changes may take place on a cyclical basis (eg where swards are mown one year grazed another). The two pasture/meadow/amenity grass subclasses are described below.

Mown / Grazed Turf

Mown/grazed turf grasslands are managed either as agriculturally productive swards or mown as amenity grasslands. They are mostly agriculturally 'improved' by reseeding and/or fertiliser use and would normally contain high quantities of *Lolium perenne* and/or other preferred species. Their key characteristic is that they did not, at either date of imaging (summer or winter), have any detectable quantity of dead plant material, nor a substantial uncropped stand of living material. This implies that the swards were grazed or cut and thus maintained as a turf throughout the growing period. This management prevented the sward from reaching flowering height in summer and ensured that there was little or no standing crop of plant litter to influence the winter-reflectance of the sward.

Fuller key-name: pastures and amenity swards, mown or grazed, to form a turf throughout the growing season.

This category carries the label '6' in the 25 'target' class dataset.

Meadow / Verge / Semi-natural swards

Meadows and verges include grasslands which are managed, but mostly at a lesser intensity than the 'mown/grazed turf' class. Partial improvement favours productive species such as *Lolium perenne*, and herbicide treatment may reduce the content of broadleaved 'weeds' but some of the swards in this category represent the traditional hay meadows which have escaped improvement. The swards may be mown for hay and perhaps aftermath-grazed.

Semi-natural swards may have much the same appearance. *Festuca/Agrostis* swards are typical of the indigenous, essentially unimproved grasslands, of neutral to acid soils, mostly enclosed, formerly covering much of Britain's grazing land, but now restricted to upland margins and odd pockets of lowlands, usually on floodplains. The swards are characterised by *Festuca rubra* and/or *ovina, Agrostis stolonifera, A. tenuis* and/or *A. canina*, often with substantial quantities of rushes (*Juncus* spp.), sedges (*Carex* spp.) and broadleaved plants. Alternatively, the seminatural grasslands may be agriculturally non-productive swards which are managed by occasional cutting to prevent excessive weed or scrub growth, eg roadside verges, country parks, golf course semi-rough areas.

The key characteristic of this class is that the swards were not a short-cropped turf throughout the year - either they were grazed at low intensity such that patches of unpalatable species became sufficiently dominant to produce a higher standing crop than on pastures. Or the swards were used for hay and appeared as a long grass sward awaiting mowing or grazing: or, perhaps, they had recently been mown for hay. The important characteristic is that they were cropped by the time of winter imaging, to remove much of the standing crop of grass. Thus, by winter they were mostly green rather than a straw-coloured stand of plant-litter as would be typical of natural swards of coarse grasses. This class forms a transition, often in appearance, perhaps in species contents and productivity, often in terms of time (ie improving or reverting) and especially space (a transition zone), between improved pastures and the 'natural' grasslands of heaths and moors.

Fuller key-name: Meadows, verges, low intensity amenity grasslands and semi-natural cropped swards, not maintained as a short turf.

This category carries the label '7' in the 25 'target' class dataset.

G MARSH / ROUGH GRASS

In the 25 class data the marsh/rough grass category comprises three types, separated to distinguish established rough swards from new colonisation. In the 17 class list these are amalgamated.

Ruderal weed

The ruderal weed cover-type is generally bare ground being colonised by annual and short-lived perennial plants, usually with a considerable remnant of bare ground, especially in winter. The ground may be naturally bare, eg shingle beaches, or abandoned arable land, eg setaside, or derelict industrial works such as demolished factories, gravel pits etc. This category is rarely extensive enough to map, was chosen to classify what might have been extensive areas of setaside, and is aggregated with the rough grass class for maps and most data summaries.

Fuller key-name: ruderal weeds colonising natural and man-made bare ground.

This category carries the label '19' in the 25 'target' class dataset.

Felled Forest

Recently felled forest, usually with large quantities of brush-wood etc, comprise this class. As they revegetate, felled areas recolonise with ruderal weeds, and then become rough grassland. Although originally selected in the anticipation that they would be relatively commonplace, felled areas are rare. They will be aggregated with 'marsh / rough grass' class for most display purposes and data-summaries.

Fuller key-name: felled forest, with ruderal weeds and rough grass.

This category carries the label '23' in the 25 'target' class dataset.

Rough / Marsh Grass

This class includes lowland herbaceous vegetation of fens, marshes, upper saltmarshes, and rough or derelict ground. The characteristic feature of this category is that the swards are not significantly cropped by mowing or grazed by stock. In fact most are unenclosed grasslands, abandoned from economic use. The result is that they have a high standing crop of vegetation, most of which dies back in winter, leaving a dense plant litter.

Fuller key-name: lowland marsh/rough grasslands, mostly uncropped and unmanaged, forming grass and herbaceous communities, of mostly perennial species, with high winter-litter content.

This category carries the label '8' in the 25 'target' class dataset.

J BRACKEN

The bracken class is herbaceous vegetation dominated by *Pteridium aquilinum*. It may be upland or lowland, mixed with grass and other species. The obvious characteristic is that the distinctive colour of winter bracken dominates the reflectance of the community.

Fuller key-name: bracken-dominated herbaceous communities.

This category carries the label '12' in the 25 'target' class dataset.

E ROUGH PASTURE / DUNE GRASS / GRASS MOOR

There are potential problems of confusion between lowland grass heaths and upland grass moors, largely because the species complements are similar. However, there are sufficient differences that spectral separation may be reliable. It has also proved possible to separate the two using a digital mask to correct regional misclassifications (see introduction). Some users of the maps and data may choose to aggregate the two classes, for later separation in a GIS, but using their own contextual definition based on altitude, climate, latitude and longitude or combinations of any such variables.

Grass Heath

This class includes coastal dunes and inland grasslands typically growing on sandy soils, usually acid in character. The species might include, on coastal dunes, *Ammophila arenaria*, *Festuca rubra* and *Carex arenaria* and a wide variety of herbaceous species, often winter annuals. Inland, and on mature 'grey' dunes, all but *Ammophila* might be present, but acid-loving species are typical, including *Festuca ovina*, *Agrostis* spp. and *Deschampsia flexuosa* set in a carpet of lichens and mosses (Duffey et al. 1974). The latter species are also characteristic of marginal hill-grasslands and a zone of seminatural acid grassland may lie between the agricultural grasslands of lower hill-slopes and moorland communities on the hill tops. These swards are characteristic of north-western Britain, mostly on land between 100-200m, but right down to sea level in north-west Scotland.

In winter, the lowland grass heaths have substantial quantities of dead plant litter, distinguishing the lowland grass heaths from agricultural swards, but the litter content is less than is typical of coarse rough grasslands, offering a spectral distinction from these.

Fuller key-name: seminatural, mostly acid, grasslands of dunes, heaths and lowland-upland margins

This category carries the label '5' in the 25 'target' class dataset.

Moorland Grass

This class includes upland swards, mostly of deciduous grasslands, often referred to as grass moorland or upland grassy heath. They are typically dominated by *Nardus stricta* and/or *Molinia caerulea*, with *Festuca ovina*, *Deschampsia caespitosa*, *Juncus* spp. often including sparse cover of upland dwarf shrubs. These swards form large tracts of mostly unenclosed hill-grasslands, lightly grazed often by sheep.

Fuller key-name: montane/hill grasslands, mostly unenclosed *Nardus/Molinia* moorland.

This category carries the label '9' in the 25 'target' class dataset.

I SHRUB HEATH

In the 25 class dataset dense shrub heath and dense shrub moor are kept separate. In the 17 class data they are aggregated into one class.

Dense Shrub Heath

Dense shrub heath refers to communities with high contents of heather (*Calluna)*, ling (*Erica* spp.) but perhaps mixed with broom (*Cytisus scoparius*), gorse (*Ulex* spp.). It is mostly evergreen, hence different from other scrub communities. Almost invariably, it represents vegetation on sandy soils, in characteristic sites like the Brecklands, and the Dorset and Surrey Heaths, or on extensive coastal dune systems.

Fuller key-name: lowland evergreen shrub-dominated heathland.

This category carries the label '13' in the 25 'target' class dataset.

Dense Shrub Moor

The dense shrub moor communities include heather (*Calluna vulgaris*), ling (*Erica* spp.) and bilberry (*Vaccinium* spp.) moorlands. Though dominated by woody shrubs, these may be mixed with herbaceous species, especially those of the moorland grass. The dense shrub moors may be managed by moor-burning, in which case they may be bare, for most of the first year after burning; then the grass / shrub heath mixture is found until dense shrub growth again dominates the cover.

Fuller key-name: upland evergreen dwarf shrub-dominated moorland.

This category carries the label '11' in the 25 'target' class dataset.

H GRASS / SHRUB HEATH

In the 25 class dataset open shrub heath and open shrub moor are kept separate. In the 17 class data they are aggregated into one class.

Open Shrub Heath

This category complements the above moorland variety of grass /shrub heath. However, because intensive grazing of lowland heaths is no longer practised, the incidence of this class is rare. It will be found where knowledge-correction has identified an area of the grass / shrub heath mixture as being in a lowland zone.

Fuller key-name: lowland, dwarf shrub/grass heathland.

This category carries the label '25' in the 25 'target' class dataset.

Open Shrub Moor

This cover type is fairly commonplace on some marginal hill grazing land, especially in northern and western parts of Britain, where grazing prevents the dominance of dwarf shrub species. It is also extensive in *Calluna* moorland, as a result of moor-burning to maintain young heather regrowth to promote grouse populations. Initial regrowth produces grassy swards, which over a period of years revert to heather-cover. As the heather senesces, so moorland is re-burnt, with a repeat cycle of perhaps 10 years. Whereas other transient cover-features of management (eg haycutting, arable crop-type) are not defined because of their short-lived nature, the 10-year cycle is judged long enough to justify the distinction between currently managed and unmanaged areas. The proportionate cover of *Calluna* which is required to alter the classification from 'burnt' back to 'dwarf shrub' is not yet clear: this will become evident on comparison of classmaps with corresponding 1 km field squares of Countryside 1990.

Fuller key-name: upland, dwarf shrub/grass moorland.

This category carries the label '10' in the 25 'target' class dataset.

M BOG (HERBACEOUS)

Bogs are widespread in upland areas especially to the north and west of Britain. They are also found locally in lowland areas. They are characterised by permanent waterlogging, resulting in depositions of acidic peat. The 'bogs' of this classification are mostly herbaceous communities of wetlands with permanent or temporary standing water (Ordance Survey maps show the same areas using 'marsh' symbols). Wet heather moorlands, which botanists may refer to as 'bogs', are not generally mapped as such on topographic maps (OS maps show them as 'heaths'), and are mapped by this survey as dwarf shrub categories. As with other heathland and moorland classes in the 25 class data, a distinction is made between upland and lowland variants of this class.

Lowland bog

Lowland bogs are rare in much of Britain, due to drainage and peat extraction. However, local large areas of bog are to be found on the west coast of Scotland. They carry most of the species of upland bogs, but in an obviously lowland context, with *Myrica gale* and *Eriophorum* spp. being highly characteristic.

Fuller key-name: lowland herbaceous wetlands with permanent or temporary standing water.

This category carries the label '25' in the 25 'target' class dataset.

Upland bog

Upland bogs have many of the species of grass and dwarf shrub heaths and moors, but are characterised by water-logging, perhaps with surface water, especially in winter. The water-logging promotes species such as bog myrtle (*Myrica gale*) and cotton grass (*Eriophorum* spp.) in addition to the species of grass and dwarf shrub moorlands.

Fuller key-name: lowland herbaceous wetlands with permanent or temporary standing water.

This category carries the label '17' in the 25 'target' class dataset.

K DECIDUOUS / MIXED WOOD

This category comprises all deciduous broadleaved trees, broadleaved and includes mixed stands, where they cannot be separated spatially. The 25 class data identifies two cover types.

Scrub / Orchard

Scrub and orchard areas are deciduous, often with substantial herbaceous vegetation. Typical species include sallow (*Salix* spp.) in wetlands, or hawthorn (*Crataegus monogyna*), brambles (*Rubus fruticosus* agg.) and saplings or small trees: these include, of course, fruit trees. Although commonplace, the scrub category is rarely extensive enough to record more than just a few pixels. The exceptions are in areas of orchards (though these are only found in a few areas), and in semi-natural vegetation, for example, the sallow-carr woodlands of the Broads or hawthorn scrub on chalk downland. For map-production purposes and in most data summaries the scrub and deciduous woodland classes will be amalgamated.

Fuller key-name: deciduous scrub and orchards.

This category carries the label '14' in the 25 'target' class dataset.

Deciduous Woodland

The deciduous characteristic separates it from evergreen species, as it appears bare in winter. However, deciduous woodland has a unique spectral signature which separates it from other deciduous vegetation and from arable land. Mixed woodland may be included with this category, though continuous evergreen stands, where greater than the minimum mappable area, will be separated.

Fuller key-name: Deciduous broadleaved and mixed woodlands.

This category carries the label '15' in the 25 'target' class dataset.

L CONIFEROUS / EVERGREEN WOODLAND

Coniferous/evergreen woodland comprises coniferous species (including the deciduous larch (*Larix spp.*), plus other evergreens such as holly (*Ilex aquifolium*), Rhododendron (*R. ponticum*), yew (*Taxus baccata*) or Holm oaks (*Quercus ilex*). As well as remaining in leaf all year round, the species generally have very dark leaves or needles, giving them unique signatures in both summer and winter.

Fuller key-name: Conifer and broadleaved evergreen trees.

This category carries the label '16' in the 25 'target' class dataset.

N TILLED LAND (ARABLE CROPS)

Tilled land includes all land under annual tillage, especially for cereals, horticulture etc. It also includes leys in their first year, ie if they were bare at the time of the winter imagery. Other land, vegetated at the time of summer imagery but bare soil during the winter, is also included in this land cover type: hence any temporarily bare ground (eg from scrub-clearance, development, mining or soil tipping) would be classified in this category.

Fuller key-name: arable and other seasonally or temporarily bare ground.

This category carries the label '18' in the 25 'target' class dataset.

O SUBURBAN / RURAL DEVELOPMENT

The suburban/rural development category includes all land where the pixels of the Landsat image have recorded a mixture of built-up land and permanent vegetation. Most suburban and rural developments, where the buildings and associated car-parks etc. remain small enough that they do not fill all of each pixel, are included in this cover-type. Small rural industrial estates, glasshouses, railway stations, larger rural roads, villages, small retail sites are all included in this class.

Fuller key-name: suburban and rural developed land comprising buildings and/or roads but with some cover of permanent vegetation.

This category carries the label '20' in the 25 'target' class dataset.

P URBAN DEVELOPMENT

The urban development category covers all developments which are large enough to completely fill individual pixels, to the exclusion of significant quantities of permanent vegetation. It includes cities, large town centres, major industrial and commercial sites, major areas of concrete and tarmac, plus permanent bare ground associated with these developments, such as car-parks and tips.

Fuller key-name: industrial, urban and any other developments, lacking permanent vegetation.

This category carries the label '21' in the 25 'target' class dataset.

Q INLAND BARE GROUND

The inland bare ground category includes all 'natural' surfaces such as rock, sand, gravel or soil, though their origin has often not been natural: the exceptions are coastal features which classify as beach/mudflat/cliffs. Ground which has been bared by human activities, or by livestock would be included. Imported surfaces of sand or gravel (eg car parks) would also be classed as bare ground.

Fuller key-name: ground bare of vegetation, surfaced with 'natural' materials.

This category carries the label '22' in the 25 'target' class dataset.

UNCLASSIFIED

Within the 25 metre data about 2% of Great Britain remains unclassified, ie. unallocated to any of the 25 'target' cover-types described above. These occurrences represent (i) some small areas within scenes that were either obscured by cloud upon both the summer and winter imagery used for the classification, (ii) some locations for which a single scene of cloud free imagery was not available to the mapping project (eg the island of Tiree), and (c) some areas of unusual cover types that were not defined by the classifier training exercise.

In the 25 metre grid cell data these cells are uniquely labelled, with the value '0', in the same manner as those cells designated to one of the 25 target cover-types. In the 1 km summary data the proportion of each 1 km cell that is unclassified is represented by default, by the difference between the sum of the values for the 17 key cover-types and 100.

Fuller key-name: cover-types which did not fit into the 25 'target' classes

This category carries the label '0' in the 25 'target' class dataset.

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APPENDIX 2: LIST OF ORGANISATIONS REPRESENTED AT THE LAUNCH OF THE LAND COVER MAP OF GREAT BRITAIN.

Acer Environmental
ADAS
AEA Technology
AFRC
Aspinwall & Company
Ass. of Drainage Authorities
BNSC
BP International Ltd
British Gas plc
British Trust for Ornithology
British Coal Property Division
British Coal Opencast
CAB International
CBI
Construction Industry
Council for Protection of Rural England
Country Landowners Association
Countryside Commission
Daily Telegraph
Department of Transport
Department of the Environment
Derek Lovejoy Partnership
Ecoscope Applied Ecologists
Energy Technology Support Unit
English Nature
Environmental Resources Ltd
Farmer Guardian
Foreign Commonwealth Office
Forestry Authority
Forestry Commission
Freshfields
Geology Today
Halcrow Fox & Associates
HJM plc
HMIP
Holderness Borough Council
House of Lords
House of Commons
Hunting Technology Services Ltd
Hunting Engineering Ltd
Institute of Hydrology (NERC)
ITE (NERC)

J C Peters Associates
JNCC
John Wiley & Sons Ltd
Land Use Consultants
Laserscan
Laurence Gould Consultants
MAFF
Ministry of Defence
National Power plc
NERC
NRA
Office, Science & Technology
Ordnance Survey
Oxford Forestry Institute
Oxford Brookes University
PowerGen plc
Reigate & Banstead Borough Council
Remote Sensing Applications
Royal Geographical Society
Royal Agricultural Society
RSPB
Rural Development Commission
Scottish Natural Heritage
Scottish Office
Severn Trent Water Services
Simmons & Simmons
Smiths Gore
Soil Survey & Land
Spaceflight
Stone & Webster Engineering
Tarmac Quarry Products Ltd
Thames Water plc
The Game Conservancy
The Crown Estate
The National Farmers' Union
The Independent
The Natural History Museum
UK CEED
University of Cambridge
University of Nottingham
Wall to Wall TV
Water Research Centre
Welsh Office
WRC Alert