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Countryside Survey 2000 Module 7

LAND COVER MAP 2000
A GUIDE TO THE CLASSIFICATION SYSTEM

EXTRACT FROM THE DRAFT FINAL REPORT

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1. LAND COVER AND BROAD HABITATS

1.1 Background

As an aid to the implementation of, and reporting under, the UK Biodiversity Action Plan (BAP), the UK Biodiversity Group identified a framework of '**Broad Habitats**' to encompass the entire range of UK habitats. The descriptions of Broad Habitats (see Appendix I) was developed by the Joint Nature Conservation Committee (JNCC: Jackson, 2000). LCM2000 aimed to contribute to the assessment of habitats by mapping, as far as possible, the widespread examples of terrestrial, freshwater and coastal Broad Habitats. While their mapping was always treated as a key objective, LCM2000 also aimed to record further details where possible, giving land cover classes sought by other users.

1.2 Broad Habitats and LCM2000 classes

LCM2000 is a thematic classification of spectral data recorded by satellite images; external datasets add context to help refine the spectral classification. The spectral classes defined in this process can be combined into thematic components which can in turn be aggregated to build various classification schemes (Figure 1). LCM2000 aimed, where possible, to distinguish BHs; in practice, **Target classes** were considered the nearest match which could be achieved consistently and with a high level of accuracy. **Subclasses** were then defined to give, as far as possible, the full complement of BHs; they also defined details beyond the BH classification. However, there are fundamental differences in the exact definitions of BH-equivalent Target classes and Subclasses; differences in nomenclature reflect these.

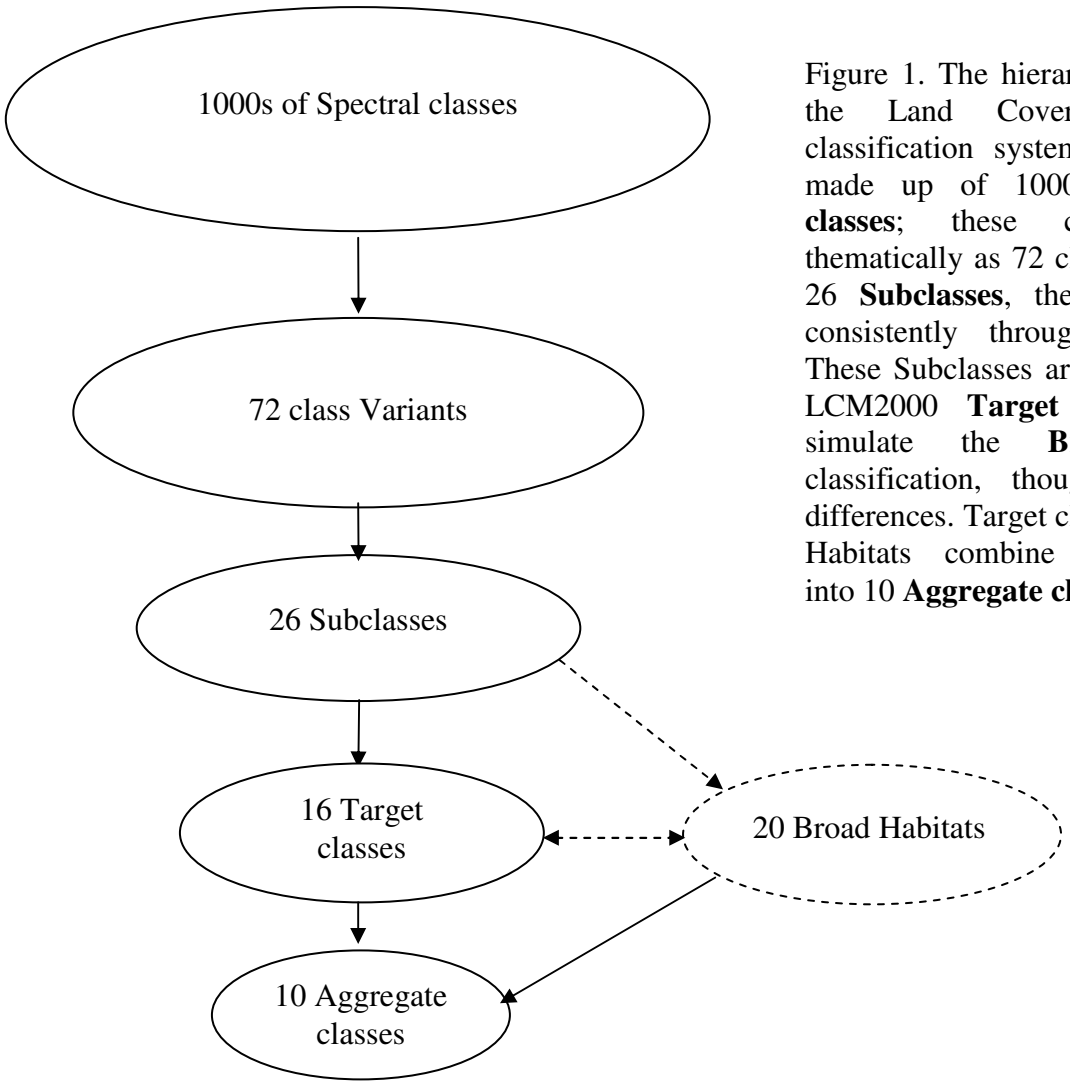

Figure 1. The hierarchical nature of the Land Cover Map 2000 classification system. LCM2000 is made up of 1000s of **Spectral classes**; these come together thematically as 72 class **Variants** of 26 **Subclasses**, the latter mapped consistently throughout the UK. These Subclasses are combined into LCM2000 **Target classes** which simulate the **Broad Habitat** classification, though with some differences. Target classes and Broad Habitats combine unambiguously into 10 **Aggregate classes**.

Subclasses were mapped consistently throughout the UK but sometimes with compromises on accuracy. Some BHs were subdivided at Subclass level where this was considered valuable for wider use of data. The class **Variants** are the thematic components of Target classes and Subclasses; they were recognised wherever possible (e.g. individual crops were distinguished where possible but could not be recognised once harvested).

Hereafter, Broad Habitats are referred to simply as BHs. In order to distinguish specific BHs, when mentioned, italic text is used (e.g. the *Coniferous woodland* BH). LCM2000 classes are given in bold text (e.g. LCM2000 **Continuous urban land**). Where an LCM2000 class closely matches a BH class, the same nomenclature is used. (e.g. LCM2000 **Coniferous woodland**). Where the LCM2000 class, while broadly similar, differs in significant respects, the name is designed to reflect that difference (e.g. the LCM2000 class **Broad-leaved / mixed woodland** differs from the BH *Broad-leaved, mixed and yew woodland* in that yew woodland is not sufficiently extensive for consideration in LCM2000. In tabulations and figures, the BH nomenclature is sometimes abbreviated but any reference to a BH is a reference to the original BH class and name.

There are situations where spectral / contextual distinction is difficult, and there is a mismatch in the 'read-across' between some BH and Target class distinctions. The *Bogs* BH, for example, may be confused with LCM2000 **Dwarf shrub heath (wet / dry)**. A mis-match in reading from a BH to a Target class applies in turn to Subclasses (e.g. the *Bog* BH may be confused with **Dense** and **Open** components of **Dwarf shrub heath (wet / dry)**). Similar problems exist in the distinction of *Improved*, *Neutral* and *Calcareous grassland* BHs. Rough (unmanaged) grasslands include elements of 'improved' and 'semi-natural' swards which are spectrally indistinguishable. LCM2000 places these with the semi-natural types as a Target class called **Neutral / calcareous semi-natural / rough grasslands**; improved and semi-natural components are distinguished at the Subclass level but neither the spectral nor the contextual data are adequate for consistent distinction. Forced to allocate rough grasslands to a single BH, LCM2000 used the *Neutral grassland* category. However, contextual analyses with soil-acidity maps may later have changed such a sward to a *Calcareous* or *Acid grassland*. LCM2000 **Acid grass** may include some stands of the *Bracken* BH.

Class Variants are shown according to their **best fit** with BHs. The 'read-across' shows the actual aggregations used to generate BHs for attribute coding in the GIS and for calibration. Further information is given later. **Aggregate classes** combine Target classes and Subclasses to a simplified 10-class level where they compare closely with equivalent BH-aggregations: at this level, maps and statistics broadly coincide. Thus Aggregate classes are used for reporting purposes.

1.2 Map display classes

Map displays use cartographic conventions which balance the reliability of mapping and the importance and extent of a class whilst bringing out important patterns in the landscape. Table 2 shows the colours used on hard-copy maps, and compares the map nomenclature with the BHs. Displays are designed for national or regional plots and avoid the distinction of the rarest or most dissected classes which would be obscured at those resolutions. Thus, *Supra-littoral* BHs, mostly small in extent, are aggregated to **Supralittoral rock and sediment**. Because the mapping of BHs is not exact, some separate BHs are aggregated thematically in LCM2000 plots: the spectrally similar *Littoral rock* and *Littoral sediment* BHs are aggregated in LCM2000 plots. Where there is not a direct match with the BH-classification, components may be mixed at BH level; the **Neutral grass (grazed / rough)** category of LCM2000 includes setaside and other derelict grasslands, some of them 'improved'. **Map-display classes** are essentially the Target classes, but some Subclasses are shown below the BH level where they are deemed widely useful and accurately distinguished. The **Saltmarsh** Subclass is shown specifically. The *Built up areas and gardens* BH is subdivided into important **Suburban / rural developed** and **Continuous urban** components. Dense and open Subclasses of **Dwarf**

shrub heath (wet / dry) are shown separately as they bring out very distinctive patterns (e.g. of muir burning) in what would otherwise be extensive tracts of seemingly uniform landscape. The mapping closely matches the widely familiar colour-scheme adopted for LCMGB 1990; the exceptions are the introduction of new colours for *Supra-littoral* classes and the distinction of semi-natural grasslands from *Improved grasslands*. While GIS-displays generally adopt the same colouring, detail is available at Subclass and Variant levels and any user-defined colour scheme can be applied.

2. CALIBRATION

2.1 Introduction

CS2000 field survey (FS) data provided information to assess the quality of LCM2000. There were two basic objectives:

- To measure correspondences to get a broad picture of LCM2000 map-accuracy;
- To calibrate LCM2000 to the FS, to allow the generation of BH cover-statistics, equivalent to those of FS, from the comprehensive coverage of LCM2000 data.

The following text summarises the processes and findings of calibration. A full account appears in the LCM2000 Final Report.

The FS in Britain examined 569 one-kilometre squares, 549 of them in 1998, the others in 1999; it recorded much greater detail than LCM2000. A separate survey was conducted in Northern Ireland but the data are not yet available in a digital format suitable for testing. Filed surveyors recorded great detail However, the FS data are not 'ground truth'. An independent quality assurance survey showed 88% repeatability for the primary codes from which, essentially, the BH labels were generated. In addition to the coding uncertainties, the mapping of boundaries in unenclosed uplands proved impossible to achieve with repeatable results. Consequently, discrepancies between FS and LCM2000 in upland mapping cannot be attributed entirely or even predominantly to LCM2000 errors. The process of inter-comparison was one of 'calibration' rather than 'validation'. Indeed, inter-calibration is more appropriate when comparing two surveys with such different spatial resolutions.

2.2 GIS Operation

ARC/Info coverage files, labelled with BHs, were generated for all 569 FS squares and equivalent LCM2000 map-sections. Comparisons of FS and LCM2000 then generated 569 correspondence matrices, one for each 1 km square. The evaluation included three main tests:

- **Per-pixel comparisons** between FS and LCM2000 maps; a direct overlay, with no regard for the structure of either dataset, where results show cumulative differences, i.e. due to: i. the FS's greater original spatial resolution, ii. time differences in surveys, iii. class-definition differences, iv. errors in one or both surveys.
- **Per-segment comparisons**, where labels in LCM2000 segments are compared with the segment's dominant class according to FS: a measure of how well the spectral-classification of a segmented image fared.
- **Per-parcel comparisons**, where FS land parcels and their classes were compared with a class-label for the parcel derived from LCM2000: a measure of how effectively the LCM2000 class labels could be transferred to conventional vector maps.

Correspondences were calculated at various thematic levels:

- BH level but excluding *Boundary and linear features* and *Rivers and streams* (below LCM2000 resolution);
- BH level but generalising LCM2000 urban to match FS results (i.e. accepting that the FS records *Built up areas and gardens* without differentiating open spaces);
- Target class level, and allowing FS generalisation of urban;
- Aggregate class level, allowing FS generalisation of urban.

2.3 Confidence limits for measures of correspondence

A 'bootstrapping' procedure was developed to provide confidence limits for measures of correspondence; it estimated the '95-percentile range' (i.e. that encompassing 95% of all estimates of correspondence). Correspondence assessments were made for: GB, England / Wales combined and Scotland. Table 1 gives overall correspondence by country, with per-pixel, per-segment and per-parcel comparisons. Per-pixel correspondence gave the lowest scores. It recorded every minor spatial difference between FS and LCM2000 products, even where these were inherent products of the mapping process. The per-pixel measure, for example, recorded differences in parcel outlines based on the 25 m image pixels as mismatches; also those due to differences in the minimum mappable unit (MMU) with FS maps recording parcels >0.04 ha against LCM2000's MMU of >0.5 ha. Estimated per-pixel correspondence in Britain, at BH-level, is 54% (with the 95-percentile range estimated at 53-56%). In England and Wales the match is 60% (estimated range 58-62%). In Scotland it is lower at just 44% (range 40-47%).

Table 1. Overall correspondence (%) from comparing LCM2000 with the CS2000 field survey squares in Great Britain: results are calculated by a 'weighted bootstrapped' estimate (see text), stratified on the basis of 40 National Land Classes. Mean values, with 95-percentconfidence limits, have been calculated for GB and constituent countries.

		Confidence interval (95%) Bias corrected	
Analysis	Sample mean	lower	upper
GB			
Per-pixel	54	53	56
Per-parcel	62	60	64
Per-segment	58	57	60
England & Wales			
Per-pixel	60	58	62
Per-parcel	69	67	72
Per-segment	64	62	66
Scotland			
Per-pixel	44	40	47
Per-parcel	48	44	52
Per-segment	47	43	50

LCM2000 segments labelled with FS classes are next in the level of correspondence. In Britain, the match at BH-level is 58% (range 57-60%). In England and Wales, the match is 64% (range 62-66%). In Scotland it is 47% (range 43-50%). This measure shows how the segmentation and spectral-classification of segments fared. It accommodated some differences in resolution, hence the improvements over per-pixel measures, but the labels drawn from FS mosaics of small parcels may have distorted the true picture of segment-dominance. Per-parcel correspondence gave the highest matches. Correspondence at BH-level in Britain is 62% (range 60-64%). In England and Wales the match is 69% (range 67-72%). In Scotland it is 48% (range 44-52%). FS parcels down to 0.04 ha MMU were labelled from generalised segments > 0.5 ha, thereby mis-labelling smaller landscape features such as ponds, shelter-belts and isolated farmsteads.

It was known from the outset that there would be mismatches when FS and LCM2000 were compared at BH-level. At the Target class level, correspondence is higher than at the BH level: weighted correspondence is 65% across GB for parcel-based analysis, 73% for England-Wales combined and 51% for Scotland (due largely to bog-heath confusion and general problems in upland mapping). All three methods measure non-correspondences associated with i. the FS's greater original spatial resolution, ii. time differences in surveys, iii. class-definition differences and iv. errors in one or both surveys. To see how these differences contribute to the overall match or mismatch, it is necessary to examine the correspondence matrices for individual classes.

3. LCM2000 ASSESSMENTS AT CLASS LEVEL

Correspondence matrices were combined via the stratification to give summary matrices for GB, England / Wales (combined) and for Scotland: a matrix was calculated for each National Land Class based upon the sample squares in that Land Class; then the Land Class matrices were combined, each with a weighting according to its extent in GB, England / Wales, or Scotland. Tables 5, 6 and 7 give the summary matrices, based on per-parcel comparisons. The matrices are also summarised at the Aggregate class level, where LCM and FS match closely (Tables 8, 9 & 10). The following discussion examines similarities and some of the underlying cause of difference.

Broadleaved and mixed woodland / Coniferous woodland in LCM2000 and the FS record very similar amounts of *Broadleaved, mixed and yew woodland*: UK coverage is 6.3% from LCM2000 and 6.2% from FS. However, direct agreement in the 569 squares is rather lower (44% of LCM2000 **Broadleaved /mixed woodland** is mapped similarly by FS). This is due partly to the fact that many woodlands are small, below the 0.5 ha minimum mappable unit of LCM2000, and so they are excluded. Hence, a lot of FS *Broadleaved woodland* shows on the map as grassland or arable farmland, the typical situation for small copses and shelter belts. The converse also applies: that openings in a woodland, mapped by FS, are mostly too small to record on LCM2000, so woodlands may appear continuous where they are really open. Differences in the exact outlines of woodlands also contribute. *Coniferous woodland*, generally planted and in larger blocks, records similar coverages (UK 5.5% on LCM2000 and 5.8% through FS) and a far greater direct correspondence (70%).

Arable and horticultural land covers just over 23.4% of the UK according to LCM2000 and 21.5% by FS estimates. LCM2000's higher estimate relates in part to small features such as woodlands, prevalent in arable landscapes but generalised out by LCM2000. About 70% of LCM2000 **Arable and horticultural land** is coincident with FS *Arable*. There are apparent confusions between *Arable and horticultural land* and *Improved grassland* in LCM2000 mapping; these probably relate largely to rotation farming in squares where the survey-year differed in field and satellite surveys. However, there are also misclassifications of grass as arable and *vice versa*. Though this problem is relatively small, because grass and arable farming together make up so much of the UK, the misclassified elements contribute a significant proportion of the total map error. Confusion between arable and built up land is a small but nonetheless significant problem: it relates mostly to erroneous classification of satellite images, where part-grown or ripening crops have spectral signatures readily confused with those of partly vegetated suburban areas.

Improved grassland, 25.7% according to LCM2000 and 25.8% by FS, is the largest single BH / Target cover type in GB. Generally, it is readily recognisable and well-classified on LCM2000. However, the distinction of 'improved' grassland from semi-natural types can be both difficult and controversial. The 'improvement' of a grassland is a continuous process which may start with minor attempts at surface drainage and end with ploughing and reseeding. Other treatments include control of grazing, fertiliser application, liming and herbicide treatments. There is potential for reversion; and abandonment or extensification can give the

impression (and the spectral character) of semi-natural swards. Field surveyors use species records and a range of contextual observations not open to the image analyst, though field surveyors also face difficulties in dividing the continuum. There is, inevitably, scope for differences in interpretation by FS and LCM2000; a significant proportion (near 20%) of FS 'improved grassland' is recorded by LCM2000 as semi-natural.

Semi-natural grasslands, bracken, fens and marshes present some problems in their distinction. Specific *Neutral*, *Calcareous* and *Acid grassland* BHs are not well separated by LCM2000. Differences relate first to problems with 'rough grasslands', some of which are semi-natural, others derelict and abandoned swards of unknown origin. The derelict swards may have been agricultural in origin, such as abandoned / neglected grazing or long-term setaside; they may be associated with tree-felling or new planting; or they may have arisen from development, for example, motorway verges, urban rough ground, derelict industrial sites, railway yards, vegetated dumps and quarries. Those associated with urban open-space go largely unmapped by FS. Most rough grasslands fit into the *Neutral grassland* BH, though some are 'improved'. If the dividing line is hard to draw in the field, satellite imaging has even greater difficulties subdividing these habitats. The rough grasslands of LCM2000 were all treated, for BH mapping purposes, as *Neutral grassland*. In contrast, rough grasslands with species compositions indicating improvement were mapped by FS as *Improved grassland.* This is the primary source of the difference between LCM2000 and the FS. LCM2000 distinguished swards trained as 'rough grassland' at class Variant level; this distinction may give scope to refine the classification later, through integrated analysis of LCM2000 and FS data.

There is a general problem in distinguishing *Neutral, Calcareous* or *Acid grasslands*. Quite simply, there is no consistent spectral characteristic which allows accurate distinction by image analysis. All LCM2000 semi-natural swards, whatever their origin, were thus subject to acid-sensitivity masking. There were inevitable weaknesses in a mask based on a 1 km grid, which generalised soil heterogeneities at an even coarser scale and took no account of management practices such as liming. Not surprisingly, results gave a poor match with FS data.

The *Bracken* BH was not a Target class of LCM2000. The Subclasses identified **Bracken** for BH-mapping purposes, but included only that which is growing in open conditions. Because so much of the imagery used to make LCM2000 was recorded in May, when the amount of bracken on the ground would be at the absolute minimum, there was often the tendency for stands to be recorded as *Acid grassland*.

The *Fen, marsh, and swamp* BH is defined as being '... characterised by a variety of vegetation types that are found on minerotrophic (groundwater-fed), permanently, seasonally or periodically waterlogged peat, peaty soils, or mineral soils. They include fens, flushes, marsh ... and swamps. This BH does not include neutral and improved grasslands on floodplains and grazing marshes, nor bogs, nor areas of carr woodland.' The FS identifies much more *Fen, marsh, and swamp* (2.4%) than does LCM2000 (0.1%), largely because the surveys treat rush-pastures very differently, with LCM2000 including the these in the **Acid grassland** class while FS records them as *Fen, marsh, and swamp*. This distinction led to the FS recording a much greater extent of *Fen, marsh, and swamp* in 1998 than it had in 1990 and has raised questions over the classification. If these rush pastures are to be included in the *Fen, marsh, and swamp* BH, they are identified at LCM2000 Variant level: it will be helpful to check such examples against FS data during follow-up work on integration of the two datasets to see where patterns match.

Heath, bog and montane habitats presented problems in distinctions to BH definitions. LCM2000 targeted dwarf shrub and bog communities knowing that LCMGB of 1990 had already shown the problems in defining bogs to floristically-based standards. Dwarf shrubs grow on many bogs; but not all dwarf shrub coverage signifies bog; and not all bogs have dwarf shrub coverage. Underlying soil and moisture parameters, particularly peat-formation, dictate the classification. *Dwarf shrub heath* and *Bogs* BHs are mapped very differently by

LCM2000 and FS. LCM2000 shows 11.1% cover of heath and 2.3% cover of bog. FS estimates 6.1% heath and 9.6% cover of bog. It is necessary to understand the BH definition in order to explain these differences.

JNCC (Jackson, 2000) state that the *Bogs* BH '... covers wetlands that support vegetation that is usually peat-forming ...' They note that the '... habitat type also includes modified bog vegetation that essentially resembles wet or dry dwarf shrub heath but occurs on deep acid peat which would have once supported peat-forming vegetation. Modified bog also includes impoverished vegetation dominated by purple moor-grass .... or hare's-tail cotton-grass ... Although there is no agreed minimum depth of peat that can support ombrotrophic vegetation, unmodified bog can be identified floristically by the presence of characteristic species such as cotton-grass ... and peat-forming sphagna ...' This use of indicator species is the main way that CS2000 field surveyors identified *Bogs*. The JNCC report goes on to say that 'Peat depth, although somewhat arbitrary, is used as the primary criterion to separate types of modified bog vegetation from the '*Dwarf shrub heath*' broad habitat type ... Therefore vegetation dominated by dwarf-shrubs, cotton-grass ... or purple moor-grass ... on peat greater than 0.5 m deep is classified as bog for the purposes of the Broad Habitat Classification.' Field meetings with conservation agency staff involved with Phase 1 survey gave support for such a definition.

With this in mind, peat depth was set as the main criterion for distinction of **Bogs** in LCM2000; a British Geological Survey map showing peat drift >0.5 m was used to determine the context of 'heath' and 'moor'. Any 'heath' or 'moor' on deep peat was recoded to bog and any 'bog' which did not coincide with peatland was recoded to heath or grass moor (depending on the key cover-component). In the event, the peat mask gave a very conservative picture of the true extent of peatlands: it generated a bog-coverage amounting to a quarter that of the FS estimate and much less than that suggested by Reid and Quarmby (1997). The issue is clearly controversial and needs careful examination. Bog surveys are currently being made by CCW and SNH. Peatland is being mapped by MLURI and SSLRC. It is proposed to re-examine LCM2000 bogs and heaths in a follow-up programme which will integrate LCM2000 with FS and external data. For the time being, the LCM2000 bog class is described as '**Bog (deep peat)**'.

Field reconnaissance for LCM2000 seldom visited *Montane habitats*, as they are not easily accessible. The BH was defined by altitude criteria, with all vegetated ground >600 m (see Ratcliffe & Thompson 19**) being treated as *Montane habitats*. LCM2000 records 1.6% coverage against the FS estimate of 0.2%. Clearly there is a difference and there must be questions over whether the altitude-based distinction is well made in this circumstance.

The *Inland rock* BH, while treated as part of the **Heath, bog and montane** aggregate habitat, actually covers both natural and artificial exposed rock surfaces. Potentially, they include exposed mountain tops, screes and limestone pavements, as well as various forms of excavations and waste tips such as quarries and quarry waste. LCM2000 distinguished these components as **Inland bare ground**. However, it may erroneously have included temporary bare ground, particularly bare arable land, in this category, where contextual corrections have failed to identify the arable context. Unlike the FS, LCM2000 also included **Inland bare ground** in an urban context: this included gravel car parks, railway sidings and derelict industrial land. The consequence is that LCM2000 records four times as much **Inland bare ground** as the FS does *Inland rock.* The overall quantity is however small at 0.9% of LCM2000 or 0.2% of FS cover for the UK. Where, locally, coverage is extensive, it relates generally to the uplands and inclusion with the aggregate **Heath, bog and montane** habitats is appropriate.

It can be seen from the above that the **Dwarf shrub heath**, **Bogs, Montane** and **Inland bare** categories of LCM2000 do not directly match the BH definitions. It is for this reason that the classes are put into the **Heath, bog and montane** Aggregate class for some map-presentations and data tabulations.

Water (inland) on LCM2000 is an aggregation of the *Standing open water and canals* and *Rivers and streams* BHs. **Water (inland)** is mapped where >0.5 ha in extent and where its width substantially exceeds the 25 m input pixel size (only being recognised consistently where width is 2 pixels (50 m) and the area >0.5 ha). Smaller water bodies and narrower waterways are not included. There is no attempt to distinguish standing from flowing water. Despite these differences, the LCM2000 cover of **Water (inland)** is near identical to FS estimates for *Standing open water and canals* in GB. (UK statistics are not available from FS as the NICS does not report on the class).

Built up and gardens are mapped by LCM2000 from the FS *Built up areas and gardens*. LCM2000 distinguished open spaces >0.5 ha in the built landscape. FS treated urban land as continuous without recording open spaces in the urban zone. Consequently, the FS recorded more 'built up' land and less grassland, woodland and waterway. And as a result, FS *Built up* includes LCM2000 woodlands, grasslands and water. LCM2000 recognised urban areas comprising a mixture of built and vegetated surfaces as **Suburban and rural development** and those with little if any vegetation as **Continuous urban**.

Coastal habitats of *Supralittoral rock*, *Supralittoral sediment*, *Littoral rock* and *Littoral sediment* are, with the exception of some notable dune systems and estuaries, relatively small habitats, often near to or below the resolution of LCM2000. They are treated as an Aggregate **Coastal habitats** class for reporting purposes; however, they are recognised at BH level in LCM2000 Subclasses and shown on maps as two classes: **Supralittoral rock and sediment** and **Littoral rock and sediment**. The distinction of these BHs (and aggregations thereof) relies upon definition of a high water mark, and use of OS 1:50 000 maps and local knowledge to indicate whether a surface is solid rock or sedimentary in recent origin. Neither type of information could be provided or applied with the precision to allow accurate separation at the resolution of LCM2000. As a result, the relative quantities recognised by LCM2000 and FS differed; they contribute a negligible amount to overall cover and overall non-correspondence. The greatest difference however relates to the tidal state at the time of imaging. As a result, some inter-tidal areas were under-represented; conversely, other offshore inter-tidal sediments, outside the FS population of terrestrial 1 km squares, were recorded by LCM2000 but not by FS. It must be recognised that neither survey provides nationally consistent and accurate estimates of coastal BHs.

The *Boundary and linear features* BH was not targeted by LCM2000. LCM2000 only includes linear habitats which have an area >0.5 ha: to have been resolved by the images they will also have been ≥2 pixels wide. Linear features were, however, mapped by the FS. As a consequence, the 2.5 m grid samples used in correspondence testing also recorded these items; they constituted about 3% of the landscape area. Because they were intentionally excluded in LCM2000, *Boundary and linear features* (and *Rivers and streams*) were excluded as distinct BHs in calibration.

4. LCM2000 ACCURACY?

The correspondence between LCM2000 and the FS is **not a measure of LCM2000's accuracy**. The FS does not provide 'ground truth'; and differences in resolution, the data-model and timing of surveys contribute to differences in correspondence. Nonetheless, it is possible to identify differences attributable to inherent characteristics of the surveys and others which relate to error. We might thus deduce a broad accuracy-value for LCM2000. Because LCM2000 did not directly map BHs, accuracy is best assessed at Target class level.

LCM2000 segments, compared with FS parcels, show a basic correspondence of 63.4% in per-parcel comparisons at BH level (allowing for the FS generalisation of *Built up areas* and the LCM2000 omission of *Boundary and linear features* and *Rivers and streams*). As correspondence cannot realistically exceed the 88% repeatability of the FS, LCM2000 seems to

be scoring at least 72% of its maximum potential. About 5% of the mis-match is explained by the 25 m grid underlying the image parcels, compared with the continuously variable structure of the field survey (if the field data are resampled onto the 25 m grid, the result shows 95% correspondence with the original input data). The >0.5 ha MMU of LCM2000 contrasts with the 0.04 ha of the FS and explains many of the differences, especially for BHs which occur in less extensive stands (more than 4% of the area recorded by FS comprised parcels, not linear features, which were below the LCM2000 MMU). Time-differences explain other mis-matches: the FS was predominantly made in 1998; LCM2000 used images mainly from 1998-2001; (squares surveyed by field and satellite surveys in the same year are some 6% closer in correspondence than the national average). Evidently up to 15% of differences can be explained by the underlying structure of LCM2000 and, additionally, by its coarser MMU, and by date-differences. This suggest that LCM2000 may record Target classes with 87% success; to quote a figure of *c*. 85% accuracy at Target class level seems realistic.

5. CHANGE DETECTION

Landscape changes interest many users. The measurement of such changes demands high levels of precision to map real differences and to distinguish them from localised errors. Changes between LCMGB 1990 and LCM2000 were probably relatively small - a few percent overall - and detectable changes would generally have been exceeded by error rates. In a comprehensive National survey, the necessary precision for change detection cannot be achieved consistently by satellite-based mapping alone. The LCM2000 classification rightly sought to remove known deficiencies in the 1990 classification and to bring field and satellite surveys into closer match, even though the detection of change would be compromised. The segment-based approach of LCM2000 generated different results from the 1990 raster product. The classification based on BHs precluded direct comparison with 1990 classes.

Nevertheless, there will have been real changes in the period 1990-2000; and it may be possible to select intelligently, from those differences mapped, the elements which are attributable to change and those attributable to error and / or differences in the data products. The way to advance this work will be to use more intelligent approaches. The FS of 1990 and 1998 provided a measure of the expected directions and rates of change (Haines-Young *et al.* 2000). An intelligent approach might use these data. Calibration results identify LCM2000 under-estimates and over-estimates in 2000 which should be taken into account in analyses of change. The probabilities of classification recorded in LCM2000 point to possible errors in classification. All such clues could be used to select apparent changes which fit the known patterns of change. This approach will be the subject of research and development, beyond the scope of the production phase.

Full details of image selection, class definitions, image pre-processing, classification and calibration appear in the Final Report (in preparation for a mid-March release). The Report will include additional details on calibration: in particular, the generation of Broad Habitat statistics through direct calibration against the field survey. This will give the benefits of the comprehensive coverage of LCM2000, combined with the greater precision achieved by the field survey in recognising these Habitats.

Table 2. LCM2000 class Variants mapped onto Broad Habitats, with codes, number and red-green-blue colour mix.

LCM Subclass	Variants	Alpha-code	Number	R	G	B	Broad habitat
Broad-leaved / mixed woodland	deciduous	D	1.1.1	255	0	0	Broad-leaved woodland
	mixed	Dm	1.1.2				
	open birch	Db	1.1.3				
	scrub	Ds	1.1.4				
Coniferous woodland	conifers	C	2.1.1	0	102	0	Coniferous woodland
	felled	Cf	2.1.2				
	new plantation	Cn	2.1.3				
Arable cereals	barley	Ab	4.1.1	102	0	0	Arable and horticultural
	maize	Am	4.1.2				
	oats	Ao	4.1.3				
	wheat	Aw	4.1.4				
	cereal (spring)	Acs	4.1.5				
	cereal (winter)	Aba	4.1.6				
Arable horticulture	arable bare ground	Aba	4.2.1				
	carrots	Ac	4.2.2.				
	field beans	Af	4.2.3				
	horticulture	Ah	4.2.4				
	linseed	Al	4.2.5				
	potatoes	Ap	4.2.6				
	peas	Aq	4.2.7				
	oilseed rape	Ar	4.2.8				
	sugar beet	As	4.2.9				
	unknown	Au	4.2.10				
	mustard	Ax	4.2.11				
	non-cereal (spring)	Ans	4.2.12				
Non-rotational horticulture	orchard	Ado	4.3.1				
	arable grass (ley)	Agl	4.3.2				
	setaside (bare)	Asb	4.3.3				
	setaside (undifferentiated)	Ase	4.3.4				
Improved grassland	intensive	Gi	5.1.1	0	255	0	Improved grassland
	grass (hay/silage cut)	Gih	5.1.2				
	grazing marsh	Gim	5.1.3				
Setaside grassland	grass setaside	Gis	5.2.1	255	177	0	
Neutral grassland	rough grass (unmanaged)	Grn	6.1.1				Neutral grassland
	grass (neutral/unimproved)	Gn	6.1.2				
Calcareous grassland	calcareous (managed)	Gc	7.1.1	180	255	180	Calcareous grassland
	calcareous (rough)	Grc	7.1.2				
Acid grassland	acid	Ga	8.1.1	153	128	0	Acid grassland
	acid (rough)	Gra	8.1.2				
	acid with *Juncus*	Gaj	8.1.3				
	acid *Nardus/Festuca/Molina*	Gam	8.1.4				
Bracken	bracken	Gbr	9.1.1	255	100	60	Bracken
Dense dwarf shrub heath	dense (ericaceous)	H	10.1.1	128	26	128	Dwarf shrub heath
	gorse	Hg	10.1.2				
Open dwarf shrub heath	open	Hga	10.2.1	230	140	166	
Fen, marsh, swamp	swamp	Fs	11.1.1	255	255	0	Fen, marsh and swamp
	fen/marsh	Fm	11.1.2				
	fen willow	Fw	11.1.3				
Bogs (deep peat)	bog (shrub)	Bh	12.1.1	0	128	115	Bog
	bog (grass/shrub)	Bhg	12.1.2				
	bog (grass/herb)	Bg	12.1.3				
	bog (undifferentiated)	Bo	12.1.4				
Water (inland)	water (inland)	W	13.1.1	0	0	255	Standing water/canals
Montane habitats	montane	Z	15.1.1	0	180	190	Montane habitats
Inland bare ground	semi-natural	Ib	16.1.1	210	210	255	Inland rock
	despoiled	Id	16.1.2				
Suburban / rural developed	suburban/rural developed	Us	17.1.1	128	128	128	Built up areas, gardens
Continuous urban	urban residential/commercial	U	17.2.1	0	0	0	
	urban industrial	Ui	17.2.2				
Supra-littoral rock	rock	Sr	18.1.1	204	179	0	Supra-littoral rock
Supra-littoral sediment	shingle (vegetated)	Shv	19.1.1				Supra-littoral sediment
	shingle	Sh	19.1.2				
	dune	Sd	19.1.3				
	dune shrubs	Sds	19.1.4				
Littoral rock	rock	Lr	20.1.1	255	255	128	Littoral rock
	rock with algae	Lra	20.1.2				
Littoral sediment	mud	Lm	21.1.1				Littoral sediment
	sand	Ls	21.1.2				
	sand with algae	Lsa	21.1.3				
Saltmarsh	saltmarsh	Lsm	21.2.1	128	102	255	
	saltmarsh (grazed)	Lsg	21.2.2				
Sea / Estuary	sea	We	22.1.1	0	0	128	Inshore sublittoral

APPENDIX I. A BRIEF REVIEW OF BROAD HABITATS WITH AN ASSESSMENT OF THEIR DISTINGUISHING FEATURES IN RELATION TO LCM2000 MAPPING.

1. Broad-leaved, mixed and yew woodland	Broad-leaved woodlands are characterised by stands >5 m high with tree cover >20%; scrub (<5 m) requires cover >30% for inclusion in this BH. Such fine distinctions cannot be made through remote sensing. It is a particular problem, albeit relatively rare, that open-canopy woodland (stands with trees <<50% are in the BH); they may not be mapped consistently, due to the dominance of the non-woodland plants. Stands with near-closed canopies can be interpreted straightforwardly in the field and pure examples can normally be found for training the classifier. Broad-leaved evergreen trees (a part of this BH) rarely occur in stands >1ha, suitable for training and thereby appropriate for classification. Mixed woodland (with >20% broadleaved trees) was trained separately though, where individual stands of broad-leaved or evergreen trees exceeded the minimum mappable unit, they were treated as separate blocks within the woodland: in many parts of the UK, truly 'mixed woodlands' as opposed to those with mosaic-blocks of broadleaved and coniferous trees, are unusual.
2. Coniferous woodland	Coniferous woodland includes semi-natural stands and plantations. Cover should be >20%. The recognition of coniferous woodland is generally straightforward. Rare examples of open canopy semi-natural pinewoods may have been classified according to the dominant understorey class. The BH includes new plantation and recently felled areas (this is a class where the BH definition is based on land use, i.e. forestry, rather than cover). New plantations, predominantly heather and/or grass, for example, are recorded as such by the spectral classification of image data. New plantations are only be recorded as conifers when tree cover is sufficient to strongly influence the reflectance. LCM2000 includes newly felled areas. Once they are fully recolonised by rough grass, heath or scrub, they are recorded according to that cover. Deciduous larch is discernible from other deciduous trees and generally, correctly, included with other conifers.
3. Boundaries and linear features	Only the largest of linear features (e.g. shelter belts, motorways) might be mapped by the classification of satellite images. The field survey provides by far the best information on these BHs.
4. Arable and horticulture	This Broad Habitat includes annual crops, perennial crops such as berries and orchards, plus freshly ploughed land, annual leys and rotational setaside. Distinction of rotational setaside relies heavily upon the summer-winter composite images to demonstrate the seasonal characteristic and thereby help spectral distinction. Orchards with a ground flora are hard to distinguish and the class relies upon knowledge-based corrections using interpretations made for CORINE Land Cover mapping (Brown & Fuller, 1996). Setaside vegetated with ruderal weeds and rough grassland are included with the improved grass BH, but distinguished by LCM2000 at the subclass level.
5. Improved grassland	Improved grasslands will be distinguished from semi-natural grass. The criteria used by field surveyors (dominance of palatable grasses) also gives the grasslands a distinct spectral signature. It is recognised that management practices (heavy grazing) can obscure this dominance and might cause mis-classifications with semi-natural swards. However, the field training course and trial reconnaissance surveys suggest separation is feasible. If accuracies are lower than the intended 90% per-parcel, then the target classification will be that of the Specification (without distinction between semi-natural and improved swards), but the distinction will be retained at the subclass level. Integration of the broad assessment with specific field estimates might prove especially powerful as a guide to the spatial distributions and quantities of the various agricultural grasslands. Setaside grass, though to be included in this

	category, may be confused with rough neutral grass once well-established.
6. Neutral grassland	The three semi-natural swards are the converse of the above and rely upon the same assumptions as above. Where pH is known, separate field-identification, training and classification is used. A soil 'acid sensitivity' map is the main way of distinguishing neutral from calcareous and acid grasses: under the final-stage 'knowledge-based correction' pH >4.5 and < 5.5 denotes 'neutral' soils.
7. Calcareous grassland	The same details apply as did to neutral grass but with the pH > 5.5.
8. Acid grassland	As above, but pH <4.5 denotes 'acid' soils.
9. Bracken	There were problems in the accurate mapping of bracken in 1990 so it was not written into the Specification as a 'target class'. However, dense bracken is distinguished (excepting woodland stands) at the subclass level; it should be recognised that bracken often fails to offer stands sufficiently extensive for classification and training.
10. Dwarf shrub heath	This Widespread Habitat is essentially an aggregation of LCM1990's *Open* and *Dense Shrub Heaths*. This means that the Habitat could generally be identified on LCM2000 with no particular difficulties. However, the Broad habitat classification treats ericaceous vegetation on peat > 0.5 m depth as 'bog'. A drift map showing peat-soils is used to distinguish heaths from ericaceous bogs.
11. Fen, marsh and swamp	This Habitat includes fen, fen meadows, rush pasture, swamp, flushes and springs. Apart from rush pasture, examples of the Habitat are relatively rare, and seldom extensive enough to map as pixels, let alone polygons and records for Britain are likely to be localised. Though there are indications that dominant rush cover influences the spectral characteristics of a parcel enough to make the distinction, the final accuracy with which rush pastures is distinguished will only be apparent after validation.
12. Bog	The bog category includes ericaceous, herbaceous and mossy swards in areas with a peat depth > 0.5 m. The peat drift maps are the final control over the bog category. Areas classified as 'bog' but with <0.5 m are corrected to grass moor or heath, according to dominant cover type.
13. Standing open water and canals	Water bodies > 0.5 ha are readily mapped. There will be few if any canals which can be mapped at satellite image scales - they effectively form linear features.
14. Rivers and streams	Only the widest of rivers (>50 m) are shown accurately, though such information might be drawn from other maps. They will not be distinguished from class 13. Standing water, except perhaps contextually (e.g. through use of digital maps of rivers).
15. Montane habitats	This class should be clearly identifiable by context and the presence of vegetation cover at a sparse level should distinguish Montane habitats from 26. Inland Rock.
16. Inland rock	This Habitat includes natural and man-made bare ground.
17. Built up areas and gardens	This Habitat is a combination of Suburban / rural development and Continuous urban categories of 1990. LCM2000 identifies these as subclasses. It records the heterogeneity of urban land, e.g. the vegetation cover in parks and larger gardens, bare urban ground and the tillage of allotments, in more detail than is required by the Broad Habitat classification.
18. Supra-littoral rock	Distinction between rock from sediment is done contextually, by defining a vector region encompassing rocky coastlines. Distinction of supra-littoral needs us to define a high water mark: this is only straightforward for major features. However, rarely are there extensive areas of supra-littoral rock.

19. Supra-littoral sediment	Sedimentary coasts are also defined interactively. Large areas of supra-littoral sediment occur as beaches, mudflats, dunes and shingle beaches. Distinction of the supra-littoral component uses the terrestrial mask, derived from LCMGB 1990, updated with changes, where appropriate.
20. Littoral rock	These classes are those in the maritime mask zone on a rocky coastline. They are generally more extensive than supra-littoral rock and thus more readily mappable from satellite images.
21. Littoral sediment	Littoral sediments are those in the maritime zone, on sedimentary coasts; they may be very extensive. Saltmarsh is included with this Broad Habitat but mapped as a separate subclass by LCM2000.
22. Inshore sublittoral sediment	All areas of sea and estuary class are assumed to be inshore and sublittoral sediment, without distinction of rocky substrata.
23. Inshore sublittoral rock, 24. Offshore shelf sediment, 25. Offshore shelf rock, 26. Continental shelf slope and 27. Oceanic seas are irrelevant in the context of a land cover map.	