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INSTITUTE OF TERRESTRIAL ECOLOGY
(NATURAL ENVIRONMENT RESEARCH COUNCIL)

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Countryside Survey 2000
Module 7

LAND COVER MAP 2000

FIRST INTERIM REPORT

incorporating the

Second Quarterly Progress Report

CSLCM/Int1/Prog2

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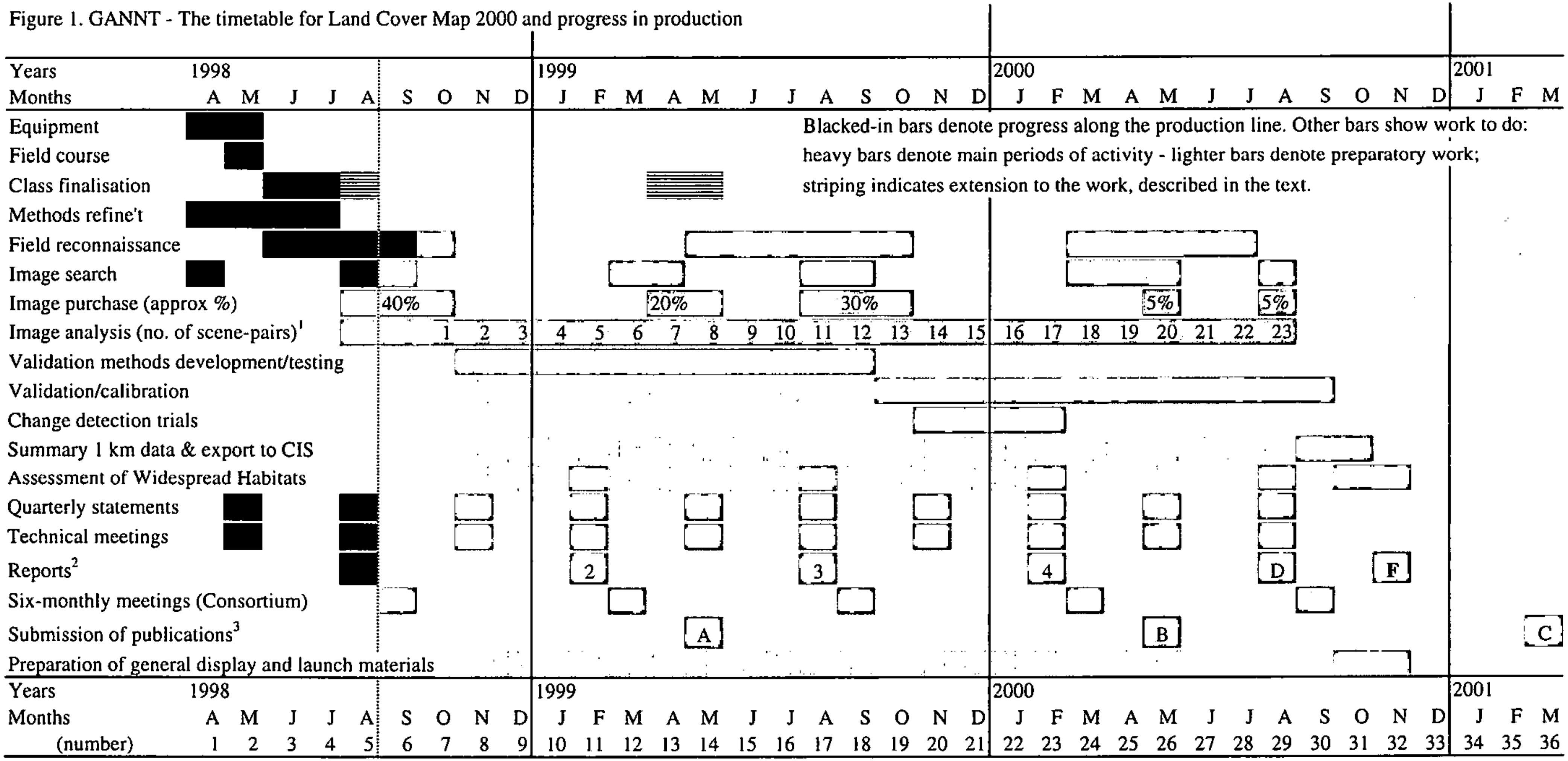
EXECUTIVE SUMMARY AND QUARTERLY PROGRESS REPORT

- This is the second quarterly Progress Report on Land Cover Map 2000 (LCM2000); it prefaces the First Interim Report and acts as the Executive Summary for that Report.
- Progress, itemised below, is reviewed against the GANNT chart of the original Specification (Figure 1).
- Image searches are on schedule. The searches show that, with substitute second scenes as necessary, there is 90-95% coverage in the target 1997-98 winter.
- Acquisition of summer images has been more problematic:
  - Landsat TM successfully imaged a 185 km strip from Devon to NE England, a narrow strip of East Anglian coast, and some of W Scotland.
  - IRS-1C LISS III recorded complementary data over England and Wales, giving 60%-70% summer cover; although the data-distributor reports that the middle infrared LISS III sensor is decaying, the corrupted data are <5% of the scene and the corruption can largely be overcome in later analytical stages;
  - the available August TM imagery, although too late for arable crop mapping, complements the May IRS-1C data for detail of semi-natural cover.
- Overall, it is known that well over half of Britain has been covered by both summer and winter imagery.
- ITE proposes to purchase winter TM imagery and matching summer TM and IRS imagery of England and S Wales and to delay work in Scotland until next year, when the availability of August 1998 and summer 1999 imagery will also be known.
- The LCM2000 team attended the field surveyors' Training Course to ensure application of the Broad Habitat classifications matching, as near as possible, that of field surveyors; this and further reconnaissance training has met the intended schedule.
- The Specification for LCM2000 sets the aim to map, as far as possible, widespread examples of Broad Habitats, as defined under the Biodiversity Action Plan.
- A *Key to Vegetation and Land Cover Types*, produced by Bunce *et al.* and given in the *Field Handbook*, uses vegetation and contextual indicators which the LCM2000 reconnaissance team can identify in the field.
- Target LCM cover classes generally match widespread Broad Habitats (excluding small scale features, those incorporating land use or contextual characteristics and marine types).
- However, there is some difficulty: Broad Habitats based upon the presence rather than the dominant coverage of vegetation (e.g. woodlands described as >25% trees, bogs based upon >25% cover of peatland species) may not be discernible on images and contradict the concept of a cover map: thus, woodland polygons might be mapped as their dominant cover per-parcel but with the mosaic of trees measured per-pixel; bogs and heaths will be the focus of especial attention, with expert advice, in the field reconnaissance surveys of 1999.
- Further Subclasses and Variants will allow relation to the National Land Use Stock Survey and other classifications.
- Ground reference data collection has consisted of 6 reconnaissance surveys, structured to maximise diversity of cover recorded. A total of 163 image subsets were marked up, giving *c.* 10 000 items of land cover information for future training. Reconnaissance surveys are ahead of the planned schedule.
- Laser-Scan IGIS, intended for analyses, now has a new per-parcel classification which attaches probabilities for all potential classes. Laser-Scan also have an operational version of the Cambridge University segmentation package. Hardware needs are being met by a

combination of existing and newly acquired workstations; these meet scheduled expectations.

- Likely processing refinements, in addition to those outlined in the Specification, include image-destriping, removal of atmospheric effects, and correction of differential illumination due to topography; such refinements are on schedule for probable operations.
- Validation procedures, outlined in the Specification, have been agreed in principle with ITE statisticians and ground reference data are those collected by field surveyors.
- Overall progress for this pre-operational phase of the project (Figure 1) is, on balance, on schedule.

Figure 1. GANNT - The timetable for Land Cover Map 2000 and progress in production



MAIN REPORT

1. INTRODUCTION

1.1 *Countryside Survey 2000* (CS2000) is a major national audit of the habitats, plants, landscape features and land types of the British countryside at the end of the Millennium. CS2000 will repeat and extend previous surveys undertaken at intervals over the last 20 years. The Survey is a jointly funded research programme involving several Government Departments, Agencies and the Natural Environment Research Council (NERC).

1.2 CS2000 will provide information necessary for reporting on biodiversity in the wider countryside, measuring progress towards sustainable development and detecting the impacts of human activities and global environmental change.

1.3 CS2000 will relate to the land surface of Great Britain. It will be co-ordinated with a parallel programme of work in Northern Ireland, thus providing information for the United Kingdom as a whole.

1.4 Land Cover Map 2000 (LCM2000) will provide a census of the countryside of Great Britain, in the form of digital maps and databases, plus a range of derived products, held in a geographical information system (GIS). LCM2000 is being funded by a Consortium of funding agencies (Table 1).

Table 1. The proposed Consortium of funding agencies for Land Cover Map 2000.

Countryside Council for Wales
Department of the Environment, Transport and the Regions
Environment Agency
Ministry of Agriculture, Fisheries and Foods
Natural Environment Research Council
Scottish Natural Heritage
Scottish Office
Welsh Office

1.5 There are currently proposals, under negotiation, to extend the project to include Northern Ireland and thereby generate the Land Cover Map of the United Kingdom

2. BACKGROUND

2.1 The *Land Cover Map of Great Britain* (LCMGB), in 1990-92, pioneered a British land cover census by remote sensing. The LCMGB recorded 25 cover types, on a 25 m grid, for all of Britain (Fuller *et al.* 1994a). The generalised census complemented the sample-based detail of the field records of CS1990. Since 1992, map data have been made available, under licence, to over 250 end-users with a further 300 recipients of generalised data through the *Countryside Information System* (CIS).

2.2 The *Scoping Study* for CS2000 (Haines-Young & Swanwick, 1997) recommended that LCM2000 should provide an improved base-line, integrated with the main field survey of

CS2000, rather than pursuing the measurement of change through a direct repeat of the 1990 exercise.

2.3 Hence, ITE included refinements based upon the wide experience of applications and user-needs:

- Improved accuracy of classification,
- Added thematic detail,
- Compatibility with other systems of environmental survey and evaluation,
- Closer integration between field and satellite data.

2.4 With these improvements in mind, ITE developed a range of methodological developments. Most important of these is CLEVER-Mapping - the Classification of Environment with Vector- and Raster-Mapping[1].

3. AIMS

3.1 The aims for LCM2000 are:

- To undertake a census survey of the land cover / widespread broad habitats of Great Britain at the turn of the Millennium;
- To apply the best appropriate satellite imagery and automated image processing techniques in order to achieve a classification accuracy of 90% for target classes;
- To produce and make available, under licence, a range of geographically referenced data outputs on land cover characteristics, tailored to the needs of Consortium members;
- To calibrate and validate satellite-derived classifications against ground reference data, publish results of the correspondence analyses and provide a guide to their interpretation.

3.2 This Report is the first six-monthly *Interim Report* on Land Cover Map 2000 (LCM2000). It incorporates the brief, quarterly *Progress Report.* It follows the earlier reports, i. to the Joint Management Team of CS2000, ii. the *First Progress Report* to the LCM2000 Consortium and iii. inclusion in the *Countryside Survey 2000 First Integrated Progress Report* (Fuller *et al.* 1998a, b & c).

3.3 The key components of this Report are:

- Image acquisitions in year 1;
- Details of proposed land cover types and their relation to widespread habitat and National Land Use Stock Survey (NLUSS) classifications;
- Operational applications of chosen of methods.

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[1] A British National Space Centre, LINK-funded, project

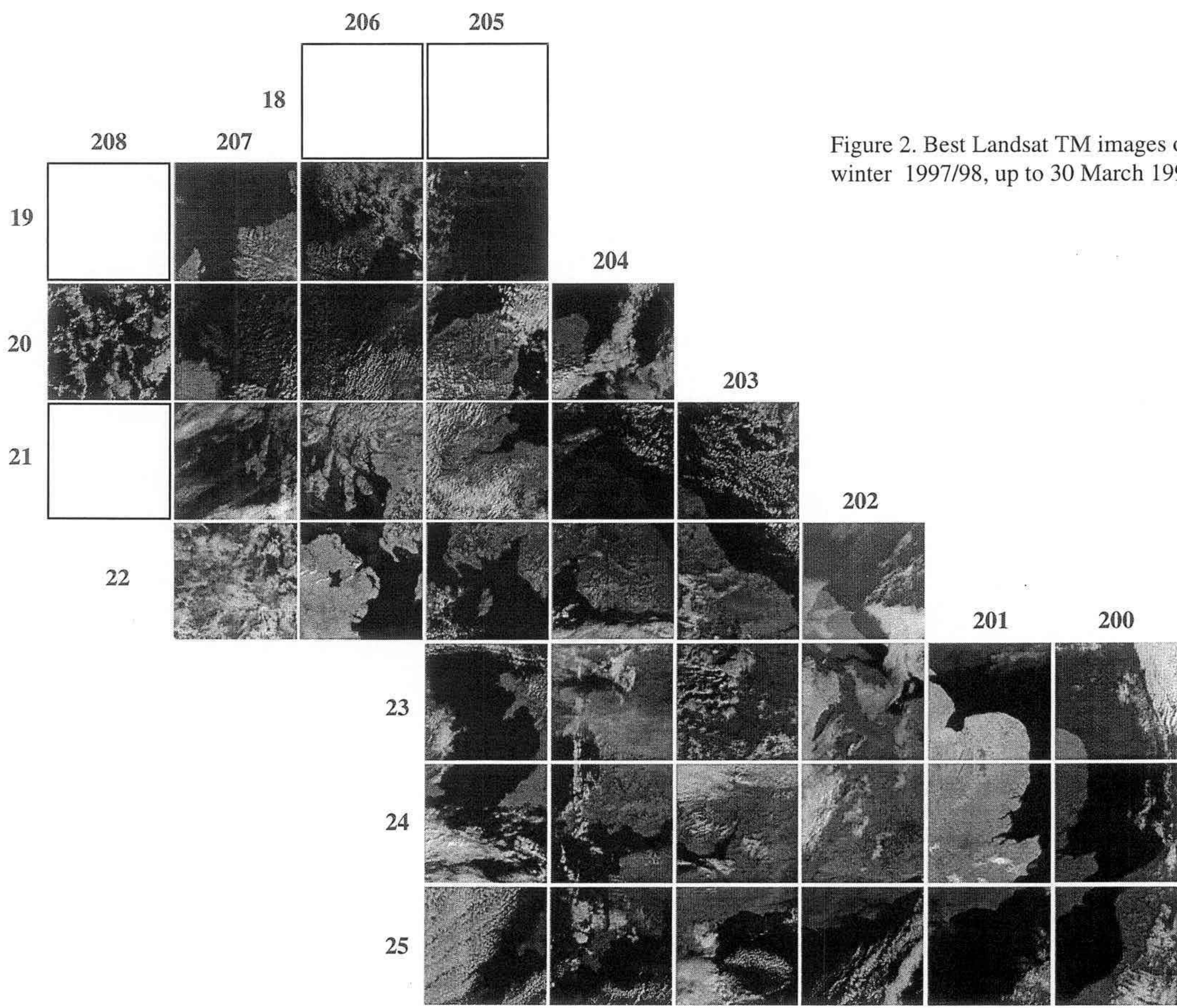

Figure 2. Best Landsat TM images of winter 1997/98, up to 30 March 1998.

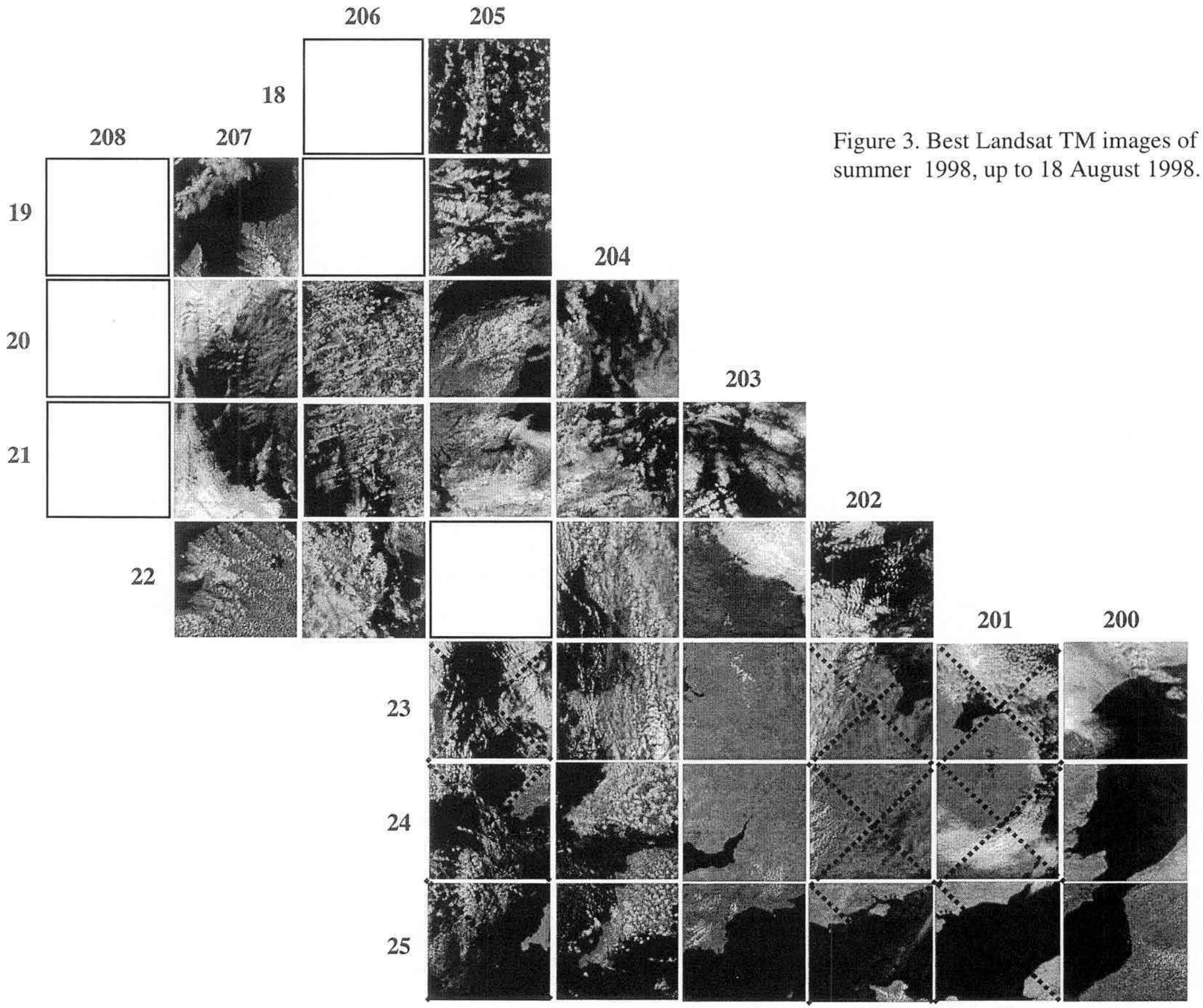

Figure 3. Best Landsat TM images of summer 1998, up to 18 August 1998.

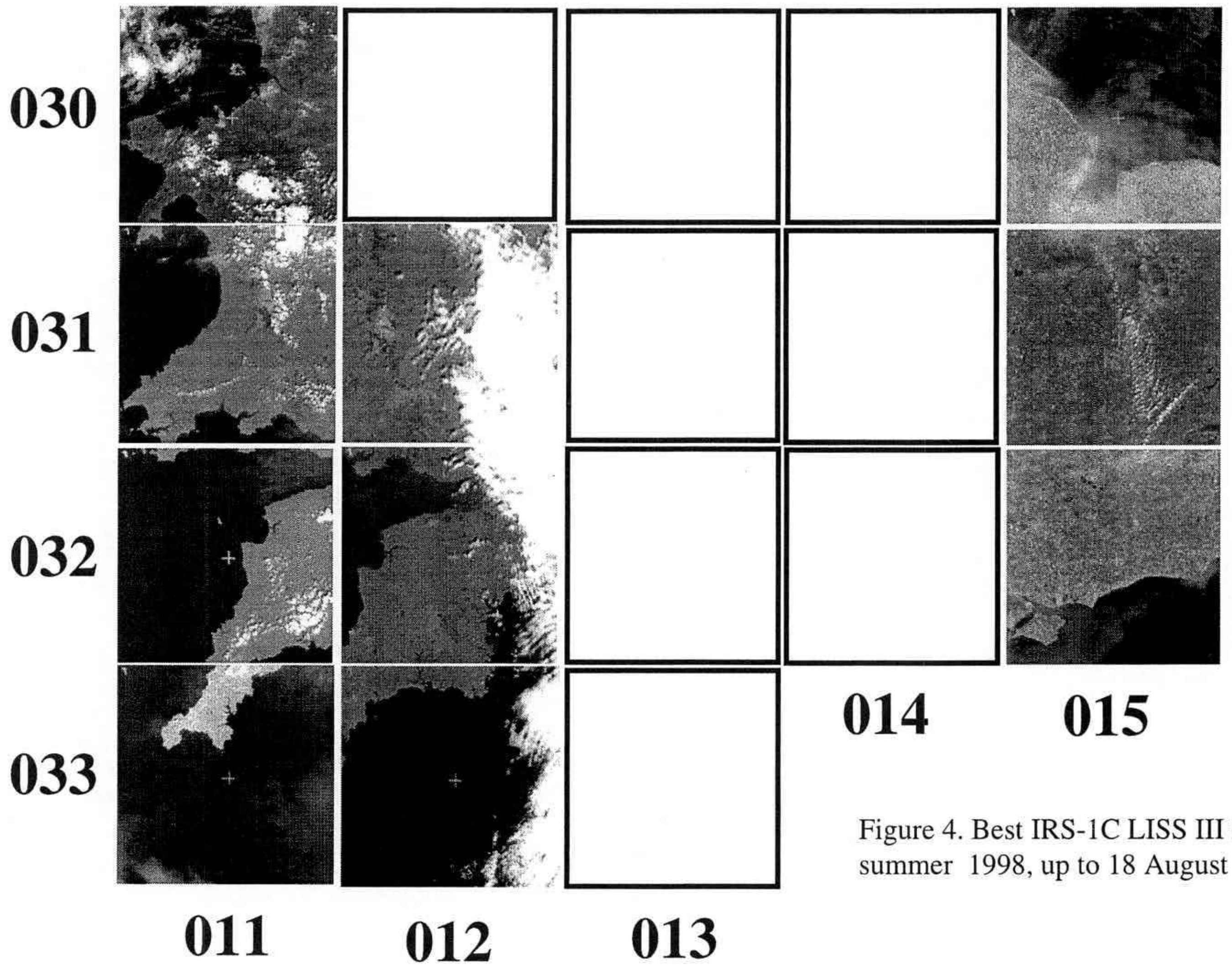

Figure 4. Best IRS-1C LISS III images of summer 1998, up to 18 August 1998.

4. IMAGE ACQUISITIONS

4.1 Winter images

The target 'winter' period started at the time of the first frosts Autumn 1997, about October, and extended to late April 1998 in southern Britain and even into May in the Scottish Highlands (i.e. until deciduous trees were in full leaf). An image search, covering winter 1997-8, showed that all necessary scenes had been imaged with cloud / snow-free coverage varying from about 70-100% per scene (Figure 2). Allowing for duplication of cover in the *c.* 50% overlaps between paths, this imagery probably gives *c.* 95% winter-coverage of Britain in the target 1997-98 winter, compared with 92% coverage over 3 winters in LCMGB 1990. Northern Ireland is also covered, should extension to full UK coverage be adopted.

4.2 Summer images

The period for summer imagery covers the main growing season for arable crops, and runs from May to late July, or rather later in Scotland, excluding May but continuing into August. Acquisition of summer images has proved more problematic. Landsat TM, in mid to late May, successfully imaged a 185 km wide strip from Devon to NE England; also a narrow strip along the extreme east coast of East Anglia; and there are oddments of cover in western Scotland in mid-June (Figure 3). The Indian satellite IRS-1C recorded complementary data over England and Wales in May (Figure 4), giving about 70% cover of Britain. IRS-1C offers 24 m pixels in blue, red and near-IR wavebands, but with only 72 m pixels in middle infrared (MIR), compared with TM's 30 m in all but thermal wavebands. It is believed that the gains in IRS visible/NIR resolutions should counteract losses in MIR such that, on balance, analytical outputs are as good in terms of quality. However, there is some question over the MIR band, in that the distributors report that the MIR detectors are decaying at a rate which may inhibit compensation for 'dead' detector elements: they have supplied sample data for ITE to assess the current potential for such compensation, prior to our purchase of images. Trials show that the corrupted data are <5% of the scene and the corruption can largely be overcome in later analytical stages, i. by correcting offsets in measured reflectance, ii. by spatial interpolation or iii. by omitting use of corrupted data from calculations of reflectance per-polygon (see later). The IRS data can still offer vital summer coverage for distinction between crops, grasslands, semi-natural and built land, but the August TM coverage can be used to refine the distinctions of semi-natural Target classes.

There may be other options for purchase of part-clouded summer scenes and suitable complementary part-clouded data. August imagery would still be usable for much of NW Britain (Lakes to Duncansby Head and westward). Most of Northern Ireland may also be covered if we allow the purchase of part-clouded scenes plus substitute data. However, there is a need to concentrate choice upon the 'best' scenes in terms of coverage, quality and timeliness. These alternatives can be used later if and when they obviously become the best cover of the areas in question.

4.3 Overall coverage

Nearly 70% of Britain has been covered by both summer and winter imagery (as at 4 August 1998). The LCM team probably have enough image cover to last until new summer coverage of 1999. This assumes that full IRS-1C data can be supplied. It will be unfortunate if 30% of

Britain is to be covered in 1999, one year after the field survey; however, this would be preferable to the use of 1997 data. The analysis of acquisitions was presented at the at the LCM Consortium Meeting on 9 September. ITE thus proposes to purchase winter TM imagery and matching summer TM and IRS imagery of England and S Wales and to delay work in Scotland until next year, when the availability of August 1998 and summer 1999 imagery will also be known.

Image costs have been confirmed with NRSCL and match estimates given in the Specification - more importantly, and only confirmed after the Specification was drafted, the prices will be held to 31 March 2000. Thus, it is believed that the allocation requested for images will cover the acquisitions needed for the first year's analyses and that the overall budget will suffice for full GB coverage.

5. BROAD HABITATS

5.1 Introduction

As an aid to the implementation of, and reporting under, the UK Biodiversity Action Plan (BAP), the UK Biodiversity Group has identified an overall framework of 'Broad Habitats' which encompass the entire range of UK habitats. The Group has also identified a number of more narrowly defined 'Priority Habitats' with the Broad Habitats for which action plan targets have been set and agreed by Government. Priority Habitats include some habitats which the Government is required to protect by the EU Habitats Directive. Monitoring of the Broad and Priority Habitats is a requirement of the UN Convention on Biological Diversity. LCM2000 is expected to make a contribution to the assessment of the widespread examples of Broad Habitats for which satellite mapping is appropriate.

The Specification for LCM2000 sets the aim to map, as far as possible, widespread Broad Habitats, with an accuracy of 90%, measured per land parcel against field sample 1 km square data. Minimum accurately mappable units are likely to be 1 ha, though per-pixel classifications will also record finer detail of heterogeneity within parcels. LCM2000 also aims to record, were possible, cover classes sought by NLUSS, crop types valuable to a wide range of users and other detail collected in 1990, to offer, where possible, the opportunity to compare data.

The list of Broad Habitats has been developed by the Joint Nature Conservation Council (JNCC) with inputs from ITE field surveyors; at a meeting on the Broad Habitats at JNCC in March 1998, the LCM2000 team was represented by R M Fuller. The list of Broad Habitats is, we understand, finalised (Table 2); this is a generalisation of 37 originally proposed Habitat types. Detailed definitions are being drawn up by the JNCC for publication in the autumn. In the meantime, working definitions are given in the field survey handbook (Barr, 1998).

Table 2. A classification of Broad Habitats which have been used to develop the target satellite classes.

1. Broad-leaved, mixed and yew woodland	15. Montane habitats
2. Coniferous woodland	16. Supra-littoral rock
3. Boundaries and linear features	17. Supra-littoral sediment
4. Arable and horticulture	18. Littoral rock
5. Improved grassland	19. Littoral sediment
6. Neutral grassland	*20. Inshore rock*
7. Calcareous grassland	*21. Inshore sediment*
8. Acid grassland	*22. Offshore rock shelf*
9. Bracken	*23. Offshore shelf sediment*
10. Dwarf shrub heath	*24. Continental slope*
11. Fen, marsh and swamp	25. Oceanic seas
12. Bog	26. Inland rock
13. Standing open water and canals	27. Built up areas and gardens
14. Rivers and streams	

NB. Broad Habitats recorded in italics (classes 20-24) are irrelevant in the context of a land cover map.

5.2 Broad Habitat definitions

It is clear that the definition of LCM2000 classes must rely upon unambiguous definitions of Broad Habitats and a clear understanding of these by the production team. Until publication in the autumn, of detailed definitions, the brief definitions given in the *Field Handbook* (Barr, 1998) must suffice. Especially helpful, has been the translation of these into a *Key to Vegetation and Land Cover Types* (produced by Bunce *et al.* and given in the *Field Handbook*): this identifies BAP codes using vegetation and contextual indicators which field surveyors and the LCM2000 reconnaissance team can identify in the field. The correspondence between Broad Habitats and the CS1990 Primary Codes (Bunce, unpublished) is also helpful, especially in view of the known and objectively tested correspondences between the Primary Codes of 1990 and the generalised classes of the 1990 Land Cover Map of Great Britain (Wyatt *et al.* 1993).

To help objective analyses and the interpretation of Broad Habitats, the LCM2000 team aims to code the Broad Habitat attributes (deduced from JNCC definitions, the Key and the Primary Codes) into the ITE *Program for the Inter-comparison of Land Classifications* (Wyatt *et al.* 1998). This software package was developed in a programme of research for the European Environment Agency (with funding from the European Topic Centre on Land Cover), *Correspondence to other themes as a basis for integrated approaches*. The PC-based, Windows-95, software uses detailed coding of class attributes (e.g. based upon cover descriptions, species, land use, geo-climate context etc.) to translate between classification systems. The encoded data already include the Land Cover Map of Great Britain and can thus compare and contrast 1990 component classes with LCM2000. The software is capable of identifying ambiguity and uncertainty in definitions and locating unintentional overlaps due to inadequate distinctions in definitions. It will thus point to problems and help clarify the exact definitions of the Broad Habitats. The results will be valuable to the CS2000 team (both the field and LCM2000 surveyors), the CS2000 customers (e.g. the LCM2000 Consortium) and to CS2000 end-users who wish to have objective definitions and ready translations between Broad Habitats and other classifications / nomenclatures. Outputs from this software (to be demonstrated at the Consortium meeting of 9 September 1998) can only be provisional until JNCC finalises Habitat definitions.

5.3 Broad habitat recognition for the purposes of image classification

The derivation of classmaps for each summer-winter composite scene is dependent upon the acquisition of representative ground reference data to act as a sample, giving so-called 'training' areas which can be used to calculate reflectance statistics per class, per waveband, per scene, per date. These statistics can then be used to allocate each pixel or land parcel to its 'maximum likelihood class' using a statistical Melanhobis distance measure (Schowengerdt, 1997).

The principles for ground reconnaissance survey involve locating and identifying the thematic class associated with each unique 'spectral class' on the image: the examples should, for each combination of summer and winter data, form a representative sample, offering an adequate number of pixels, for a replication of sites. As an ideal minimum, this sample would be set to record several replicates giving >30 pure pixels overall (Fuller *et al.* 1994); in practice, the typical sample includes many more pixels (>200) and generally many replicates (e.g. up to 10). However, in rarer and smaller examples (e.g. bracken patches) even the minimum sample might prove elusive if not impossible to locate. Under such circumstances, it is necessary to establish whether a chosen sample is, first, adequate and, second, whether the resulting extrapolation provides correct classifications of the target without capturing many stray pixels of other classes: this is done by reference to, and scoring correspondence against, the samples themselves and, better still, against independent examples of the class (e.g. other areas, perhaps too small even to train upon). Where adequate training areas are absent, the class must be omitted from that classification, at least until contextual interpretation in the post-classification stages.

It is important to recognise that, in order to achieve the above demands, field reconnaissance must take a generalised approach in a large area of coverage. LCM2000 surveyors must, for each satellite scene, ensure that they include, as far as possible, the full range of target classes (and variants) in all their spectral forms. This means finding:

- sunlit and shaded examples in severe terrain,
- local climatic variants (e.g. due to localised rainfall),
- different species compositions (e.g. of deciduous woodlands – beech, birch, oak, ash etc.),
- phenological variants (e.g. due to differing leaf emergence, flowering or senescence),
- variable mosaics of species and vegetation types,
- crops on different soil backgrounds.

Such details generally have to be collected in a very few days per scene. Thus, the approach uses a broad stratification within scenes, selecting examples (as available) of coastal, lowland, marginal and upland land, covering arable, pastural and semi-natural land uses, and focusing attention on oddities within the images (assuming that the commonplace is picked up routinely in passing). To achieve this, the strategy has been to drive slowly through the landscape, recording cover *en route*, and marking this onto hard-copy images. The team stops, as necessary, to investigate specific details which might determine the classification.

5.4 The Field Training Course

It is clear that the Broad Habitat definitions and the principles for ground reconnaissance survey and training need to be put together operationally for application in LCM2000. The Field Training Course for CS2000 ground surveyors was the opportunity to explore such operations. The LCM2000 team attended the field-based days of the first week of the CS2000 Field Training Course of May 1998. In that week, the surveyors were learning and practising, amongst other things, the land cover mapping elements of the fieldwork (week 2 concentrated on the quadrats and species recording). The course greatly helped the LCM2000 team to understand and apply the Broad Habitat classifications in way which (allowing for scale and resolution differences) matches the field surveyors' applications.

The LCM2000 team combined field recording of the trial 1 km squares, used for training field surveyors, with wider reconnaissance trials around the southern Lake District to test more widely the application of the derived knowledge, and to assess the BAP Key in field operations. For such purposes, 1990 images were extracted and hard copies made for evaluation on the field survey course. The Key proved particularly helpful in separating the classes, generally unambiguously, and remaining questions were discussed with trainers on the field course. Good examples of most Broad Habitats, suitable for training and classification, were identified in the trial reconnaissance surveys.

Grasslands
Confusions between unimproved and improved grasslands, on LCMGB 1990, were clarified in the exercise, ensuring a much more meaningful discrimination of unimproved grasslands than was applied in 1990. It remains clear, however, that distinction of acid, neutral and calcareous examples of unimproved grasslands (excepting deciduous moorland grass) may on occasions need the field surveyors' botanical skills; more important is the fact that such distinctions cannot be made routinely while driving through the landscape - the detail is commensurate with ground-based survey rather than the satellite classification. It had always been expected that mapping would require more than just spectral distinction, drawing upon contextual map information such as soils or geology maps in later post-classification operations.

Bog / dwarf shrub / grass moor
The distinction between heaths, bogs and grass moors is complex. The discrepancy between field and LCMGB 1990 bog / dwarf shrub / grass moor classes (Wyatt *et al.* 1994) was investigated in a continuation of LCM2000 training exercise in the north Pennines. Application of the field *Key to Vegetation and Land Cover Types* showed that the complex mosaics of upland cover, which have been shown to elude field mapping, also defy simplistic image annotation in reconnaissance surveys.

The key makes it clear that distinctions between Bog and Dwarf shrub heath or Bog and Moorland grass, are based upon peatland indicators such as *Eriophorum*, *Tricophorum*, *Molinia*, *Sphagnum* and *Myrica*. Blanket bog is dominated by *Eriophorum vaginatum* and that dominance gives spectral characteristics, recognisable in reconnaissance surveys and distinguishable through image classification. The broader 'Bog' class presents greater difficulties: here, the peatland species may be present in quantities as low as 25% cover, mixed either with a dominant cover of dwarf shrubs or of moorland grasses (or perhaps a combination of both). Despite a lack of cover-dominance, the peatland species denote membership of this 'Bog' Broad Habitat: they are indicators which modify the cover category into a contextual class where soil type and wetness are inferred from sub-dominant species. Cover dominance is the only thing that the field reconnaissance can record quickly and effectively, over large areas, unless it is to become a painstaking ground survey of quantitative species compositions; and such a scant cover of indicators is not likely to be enough to allow spectral distinction either; nor is the deep peat and waterlogging certain to influence spectral signatures such that 'boggy' examples of heath and grass moor cover can be distinguished.

Reconnaissance surveys of uplands in 1998 have included the North York Moors, the Pennines and the hills and mountains of SE Scotland around Edinburgh. They demonstrate some unambiguous examples of Dwarf shrub heath, of Moorland grass and a few examples of blanket bogs; but the unambiguous distinction of large tracts of the 'Bog' Broad Habitat, has proved elusive. In addition, there are complex mosaics of heath, grass and bog, usually at scales approaching the minimum mappable units of field and satellite surveys; and local transition zones do not readily fit into any one category. Similar problems were evident in lowlands.

The fact is, then, that the Bog class is not purely a cover class but contextually based. Indeed, the class may contradict the concept of a cover map, as the contextual class ignores whether grass or heath are dominant in the Bog. It thus remains uncertain, despite the original aim to match field definitions and Broad Habitats, whether LCM2000 will be able to distinguish the waterlogging and consequent soil compositions which give wet heaths and grasslands the key attributes of a 'Bog'. It will become clearer, once images have been examined, whether there is a spectral distinction which would allow the LCM2000 team to distinguish 'Bog' variants of heather cover and moor grass cover to satisfy Broad Habitat mapping needs. If not, it is clear that cover dominance will determine the satellite image classification and that there will be a need to integrate field survey detail (defining bogs through quadrat data) with the satellite census data to give fuller estimates of 'Bog' quantity and distribution.

In order to classify better peatlands and heaths, it is proposed to delay field reconnaissance trips of the major upland areas until spring 1999, when the LCM 2000 team will arrange to meet with representatives of the Peatland Survey team in Scotland and with Welsh Phase 1 surveyors (and, possibly, with CS Surveyors in Northern Ireland) to clarify their definitions and thereby help class recognition. This phasing will not conflict with the image processing aims, as image shortage has focused attention on lowlands and marginal land (see section on 'Image acquisitions').

Woodlands

There is some concern that the woodland Broad Habitat categories operate where tree or shrub cover is >25% (see Key). Scattered trees may not offer sufficient spectral distinction to allow their mapping at these low levels of cover: the spectral signatures may be dominated by the background vegetation such as grass, bracken or heather (the dominant class in cover terms). It is likely that per-parcel classifications could record cover as either the dominant class or as a mosaic category and that per-pixel recording could attach to these parcels an estimate of the proportional cover of trees and understorey cover (as demonstrated to the LCM2000 Consortium during the development stage, using test sites in the Cairngorms (also reported under CLEVER-Mapping, Smith *et al.*, 1998)). Continuing trials will investigate ways to maximise the usefulness of such discriminations to match field interpretations. A similar potential problem with dwarf shrubs is considered soluble as the scale of the mosaics is much smaller and the spectral signatures of ericaceous species sufficiently distinct to allow the definition of an open Dwarf shrub heath subclass (as was done in LCMGB 1990).

Inter-tidal
Littoral rock and sediments may be difficult to distinguish from each other spectrally and the former may be at too small a scale to map routinely; the same might apply to supralittoral examples; and supralittoral rocks and sediments covered with vegetation will classify according to the plant cover (e.g. coastal heaths, dune grasslands).

Other classes
Other classes are expected to present very few significant problems arising from their definitions, except in borderline situations (e.g. in spatial mosaics, gradations or temporal transitions). As stated above, borderline and transition habitats will not be used for training and will be classified objectively using the statistical Melanhobis distance measure of the maximum likelihood classifier (Schowengerdt, 1997). Where field recording marks transition zones, these will serve as checks to ensure that they are being handled sensibly by the classifier (i.e. classifying as one of the two optional mixed components). For a more detailed assessment of the Broad Habitats, the expectations in mapping, local difficulties and likely solutions, see Annex Table 1.

5.5 Target classes, Subclasses and Variants

The list of **Target** classes for accurate mapping in LCM2000, as given in Annex IV of the original Specification, has been revised (Annex Table 2); these are related to Broad Habitat categories in the light of the above comments. LCM2000 aims to subdivide the Broad Habitats (images permitting) to meet wider user needs (e.g. DETR NLUSS classes, crop types). Thus the Target classes will be divided into **Subclasses** where it is believed that users require extra thematic detail (note that such subdivision may mean accepting a reduced level of consistency nationally). Annex Table 2 outlines 26 possible Target Classes / Subclasses, related to Broad Habitats, NLUSS and LCM1990. This list might in turn be further divided giving **Variants** of Subclasses, with perhaps 33 types overall (Annex Table 2). While some of these classes exceed the demands of the Broad Habitat classification, it is believed that they offer much wider scope in later applications; thus consistent recognition is desirable, though not essential.

It can be seen from Annex Table 2 that the Target classes, in many cases, relate directly to Broad Habitats. However, those which are likely to be too difficult to distinguish routinely as Target classes are, wherever possible, included as Subclasses or Variants. Thus, all widespread Broad Habitats will be recorded, except linear features which are 'not applicable', through difficulties of resolution, and marine Habitats which are outside the scope of the survey.

It is important to remember that the final classification is achieved by appropriate combinations of what will probably be many hundreds of spectral subclasses: this aggregation can be managed in any combination which is needed. It is intended that a key characteristic of LCM2000 will be that the spectral classes will remain accessible for tailor-made classifications and that the Broad Habitat and NLUSS classifications are just the two most important of these.

5.6 Operation of ground reconnaissance surveys for reference data collection

Field reconnaissance surveys are needed to identify representative examples of all significant cover types, in all their spectral forms. These data are additional to the 1 km data recorded by the field surveyors of CS2000, needing, first to be much more extensive and widely distributed and, second, needing to leave the 1 km data as independent for validation purposes.

To be sure that the ground reference data correspond with what is shown on the images, the field reconnaissance survey would ideally match the date of the satellite summer-overpass. However, there is an obvious difficulty here: in order to collect field data by the best and most efficient methods, we would ideally have the images recorded, delivered, co-registered, printed and then used to direct the reconnaissance; but, by the time the images have become available for fieldwork, the ground features, especially arable crops, would have changed considerably (e.g. been harvested) and evidence of true cover may have been lost. The aim to subdivide Broad Habitats and, especially, to include some distinction of crops, has had implications for the strategy and sequence for reconnaissance surveys; however, generally, no difficulties arose at the Broad Habitat level as these are not transient classes. In the two-year period of surveying (certainly for reconnaissance and possibly for the satellite recording), only rotation grass/arable is likely to show much change at the Broad Habitat level (and this is always very obvious on images). On a one-year timescale, change is irrelevant at the Broad Habitat level, as rotation grass is to be considered an arable crop. Coniferous plantation, harvested on perhaps a 30-70 year cycle, is likely to record 2-3% change in a single year (and this is always very obvious on the images). It is very unlikely that any more than 1-2% of other classes would have changed between 1998 imagery and say 1999 field reconnaissance.

The above observations, while hardly problematic, nonetheless require pragmatic solutions. In practice, because there is frequently a lack of coincidence in the dates of imagery and field reconnaissance surveys, solutions have been developed, tried and tested in almost **all** satellite surveys of land cover. Two ways have been used: first, to survey in anticipation of probable imagery; second, to survey after imagery has been completed, accepting the possibilities of change. The former is most important when transient features (e.g. arable crops) are to be identified specifically, the latter when (as in semi-natural landscapes) the patterns are slowly changing but their complexity makes it logistically advantageous to be directed by existing image coverage.

LCM2000 has adopted both principles. Arable areas of eastern England, south east Scotland, the English Midlands and southern central England were visited in 1998: as well as being subject to annual changes, they were also those parts of Britain most likely to be imaged successfully in 1998. In order to maximise the possible coverage of transient arable landscapes, 6 reconnaissance surveys were completed before the harvest in late July 1998. This compares with 4 reconnaissance trips originally scheduled in the Specification (see GANNT chart).

Northern and western Britain will be covered in 1999, using (as available) imagery of 1998 to help direct the reconnaissance. As noted above, in order better to classify peatlands and heaths the LCM 2000 team will arrange to meet with representatives of the Peatland Survey team in Scotland and with Welsh Phase 1 surveyors and, if directly relevant, with Countryside Surveyors in Northern Ireland to clarify the upland habitat definitions and thereby help class recognition.

5.7 The field recording base

Fieldwork requires a basemap or imagery to annotate with the current cover. In 1998, two options were possible: 1:25 000 Ordnance Survey maps to record cover field-by-field); alternatively, and much more realistically, LCMGB 1990 imagery shows, with few exceptions, the field patterns of 1998 and the general zones of semi-natural cover. OS Maps are not helpful in complex mosaics of semi-natural unenclosed land (where field surveyors have already identified the extreme difficulties of demarcating discrete zones of cover); the costs of using OS maps would also amount to thousands of pounds. With 1990 images, the exact land management might have changed, but the management units are essentially unchanged; and the use of imagery draws attention to the diversity of land cover, focuses attention on such detail, and ensures the capture of as much relevant information as is realistically possible: costs are small as images are available within ITE. Use of 1990 images was tested satisfactorily on the field training course.

The LCM2000 team have the advantage over field surveyors as they are, in essence, attempting to locate samples of 'pure' cover of each of the Broad Habitats. The classification will rely upon the same general principles as operate in spectral mixture modelling: it can be demonstrated that mixed pixels of two classes show a spectral signature which is intermediate between the classes and proportionate or a 'linear' mixture model of the two components' individual signatures. On a similar basis, a well-trained maximum likelihood classifier will calculate the spectral (Melanhobis) distance to the individual class centroids in the multi-band feature space (Schowengerdt 1997) and allocate mixed pixels or parcels to the nearest spectral class using probabilities. If a mixed pixel of two components is encountered, the class given would be the nearer of the two in statistical/spectral terms, i.e. the majority component. Segmentation and per-parcel classification, ensures that parcels are, in broad terms, single cover types: and the CLEVER-Mapping segmenter identifies odd pixels which are unallocated to parcels due their strong differences from either neighbour. They can be allocated to a class and/or parcel by a host of intelligent post-classification procedures combining spatial, contextual and probabilistic measures.

5.8 Reconnaissance in 1998

The zones for the first 6 reconnaissance surveys are listed in Table 3. There was some adjustment to the originally planned areas of coverage to include the west Midlands and the Pennines, once information on the availability of image data was obtained. A route was planned through the area of coverage to visit the range of landscape types present and also visit particular areas of interest.

Table 3. First phase of reconnaissance surveys.

Trip number	Coverage	Duration (days)
1	East Anglia	3
2	South east	3
3	Lincolnshire and North Yorks	3
4	Hampshire and Dorset	3
5	Midlands, Welsh Marches and Cotswolds	3
6	Central Scotland, Scottish Borders and Northumbria	5

For each reconnaissance survey, the summer-winter composite images were identified from those used for LCMGB (Fuller *et al.* 1994). If necessary the images were recovered from the 1990 backup tapes and imported into ERDAS Imagine via the image processing system used to create LCMGB. Subset images were then located within each summer-winter composite image which covered the selected route. The subset images were exported separately and printed in colour. The colour prints of the subset areas were then covered with a clear plastic sheet to allow additional information to be overlain without obscuring the image. This information included: areas of overlaps with adjoining images; all major (A and greater) roads across image; the route to be taken with all side road and tracks marked; visible woodland and water features; view points; areas of interest and the numbers of corresponding OS 1:50 000 sheets. During the reconnaissance surveys, areas of identifiable land cover along the route were marked on the subset image overlay with a land cover code (Annex Table 3) and any other notes which would be useful during the classification training procedure. These codes identify thematically different cover types which will probably form spectral subclasses, each in turn likely to be subdivided into further spectral subclasses, for example, on the basis of phenology, or topographic location. Each code can be related directly to a Broad Habitat (Annex Table 4).

5.9 Improvements in reconnaissance surveys from LCMGB

A number of improvements have been made to the reconnaissance survey procedure, compared to that for LCMGB in 1990. Using the experience of the LCMGB it was possible for the reconnaissance survey to be more effectively planned and targeted to cover a range of landscape types and areas which had caused problems in previous classification. Since 1990 the development of improved colour printing capabilities allowed the production of higher quality, hardcopy, subset images for marking up in the field. These improved prints allowed additional information, such as side roads and tracks, to be added to the overlay to help the recorder to locate cover objects in the landscape and transfer their positions accurately onto the images. The land cover types were recorded and their associated codes were designed to allow easy integration with other data of CS2000 giving full scope for aggregation to the Broad Habitats classification and wider classes. The recording was also extended with, for instance, woodland classes divided by age class and, in some cases, species and with multiple codes being recorded for mosaics.

During the 6 reconnaissance surveys a total of 163 image subsets were marked up. This represents somewhere in the region of 10 000 items of land cover information.

5.10 Reconnaissance in 1999

Continued reconnaissance in 1999 after, hopefully, the near-completion of successful imaging, is not expected to cause insuperable problems. The Broad Habitats are only subdivided to a generalised level, which makes no distinction of arable crops, nor the exact management of grasslands (e.g. haycut, silage, grazed) or of semi-natural areas (e.g. burnt and unburnt heather). It is thus to be expected that the vast majority of Broad Habitats in 1998 will be in the same class in 1999. The one exception might be rotation grass-arable land but there will be innumerable examples of improved grass and arable to act as training areas and the rotation from grass to arable or *vice versa* will be clearly evident when interpreting images in the field (just as it was using 1988-89 images for 1990-91 reconnaissance in production of the LCMGB). Moreover, it is important to recognise that a failure to cover all of Britain in 1998 will not preclude mapping, from 1998 images, those transient features which have changed and thus gone unrecorded in 1999 reconnaissance (e.g. arable crops). Adjacent image paths overlap by up to *c.* 50%. A cover type mapped against ground reference data on one path will appear on the adjacent path: thus, there will potentially be thousands of examples on an unsurveyed scene, which can be deduced from comparison with its neighbour, from which to generate sample statistics for spectral signatures. If conversely, the path is not imaged in 1998 but waits until 1999, then the 1999 reconnaissance surveys will pick up the contemporary cover identification.

6. IMAGE ANALYSIS REFINEMENTS AND OPERATIONAL TESTING

6.1 CLEVER-Mapping

Many refinements are planned in LCM2000, to replace methods used in LCMGB 1990. The most important of the various improvements will be the analysis of satellite images on a per-parcel basis using CLEVER-Mapping. The principles of CLEVER-Mapping were spelled out in detail in the Specification. The approach corresponds more closely to the true character of much of the British landscape with its widespread subdivision into fields, rather than using the arbitrary grid of pixels from which satellite images are built. CLEVER-Mapping will segment Britain into parcels using the spectral data from the satellite images. Analyses within land parcels will give improved classifications and can readily incorporate contextual information, such as terrain height, soil or climate data, for further refinement of the results. The main tasks prior to operation have been to facilitate access to procedures and to check their operation over the extent of a full scene (see section 6.3).

6.2 Pre-processing of image data

Pre-processing of the image data can remove geometric distortions, remove systematic noise, eliminate unwanted changes in response due to differential illumination and normalise the data from different images to physical units of reflectance rather than the arbitrary engineering units of the raw data. All such problems, except geo-registration, were treated pragmatically in 1990, largely through compensation in the training process. However, pre-processing can help to improve the classification within images and the consistency of this classification between images. Image data in units of reflectance can be directly compared to other images in the same units or other spectrally calibrated spectral data sets. For these reasons, and with the main aim of increasing overall accuracy of LCM2000, pre-processing procedures are being tested and their enhanced capabilities, where relevant, will be demonstrated in early trials, with the aim that they be put into operation. Pre-classification improvements will include (where possible):

- Image-destriping
- Removal of atmospheric effects due to haze,
- Correction of differential illumination due to topography.

De-striping
The TM sensor, rather like the eye when it has registered a very bright object, can record distortions in subsequent reflectance data caused by sensor 'memory' due to the brightness having 'burnt in' to the sensor, continuing to compensate for a signal which is no longer present. While the distortion may only cause displacements in data by only a few digital numbers (a few percent in relative terms), it may nonetheless distort classification results and, if removable, should be removed. A correction method has been demonstrated by Helder (1997) of South Dakota State University, who has offered use of the software to ITE. There are questions regarding its ability to handle the slightly different format in which European TM data supplied and there may need to be modifications. We have been supplied with the software and expect to have tested it and, if necessary, altered the software for use in LCM2000.

Atmospheric correction
Atmospheric haze both attenuates the amount of light reaching the surface and also scatters light which has not interacted with the surface into the sensor. These effects are most pronounced in shorter wavelengths and distort the information recorded by the sensor. Various algorithms are available which attempt to model the effects of the atmosphere on the light passing through it, based on the information recorded in the image. The algorithms generally try to identify areas in the image for which the true reflectance can be estimated and in this way assess the distorting characteristics of the atmosphere at the time of imaging. These characteristics are then used to model the atmosphere and remove its effects from the image.

Liang (1997) of the University of Maryland has developed such a method for TM data which automatically seeks out examples of cover types whose reflectances can be estimated and interpolates the 3-dimensional atmospheric characteristics between the examples to correct the image. The software has been made available for ITE use. It has been tested with full Landsat scenes. The correction is highly effective removing not only haze but even areas which look like thin cloud on the uncorrected image. Operation is quick, 90 minutes per scene. Results were demonstrated at the Consortium meeting on 9 September, 1998.

The correction of IRS LISS data cannot directly use this software which relies upon the presence of the greater number of TM bands. However, the same principles can apply, using combinations of bands with different sensitivities to atmospheric haze, to estimate and thereby compensate for atmospheric effects. Procedures will be investigated in the early usage of LISS data.

Illumination correction
Undulating terrain is illuminated differentially according to whether facets of terrain are horizontal, face the sun, face away from the sun and, if the latter, do so sufficiently to be shaded from direct solar illumination. Differential illumination and its consequent effects on

radiation recorded by the sensor can be modelled using digital elevation models (DEM) and compensated for, offering corrected data based upon a theoretical horizontal surface illuminated from directly overhead. Such correction is important if facets of land surface are not to have a highly significant and perhaps dominating effect upon the results of segmentation.

ITE have contributed financially to the operationalisation of software, developed by Cambridge University in the CLEVER-Mapping programme. The software will offer the option of full National terrain correction prior to segmentation and classification. The software will operate within an Erdas framework using the Spatial Modeler [*sic*] of Erdas.

There are questions remaining over the choice of the DEM. OS data are complete, offer a near-ideal resolution but are prohibitively expensive - £20k nationally - and come with restrictions regarding onward use of outputs. A US dataset (made from OS 1:63 360 maps which have passed their copyright date) similarly costs £18k, but without restrictions. Lower resolution products (e.g. Bartholomew's data) are much cheaper but perhaps of inadequate resolution; tests will need to be conducted prior to the operational use of such low resolution data. There is, alternatively, the option of selecting only those parts of Britain where terrain is likely to be significant (e.g. marginal and upland regions) and purchase full resolution data for these.

Undoubtedly the best solution would be the current possibility that an affordable DEM may become available, within a few months, through CHEST and/or the Institute of Hydrology (a partner with ITE in the NERC Centre for Ecology and Hydrology). These options are both under negotiation and worth waiting for. In view of the enforced delays in acquiring and processing images of upland, especially in Scotland, such a wait need not compromise processing schedules.

6.3 Testing CLEVER-Mapping methodology with IGIS on a full scene

During the CLEVER-Mapping Project (Smith *et al.*, 1998) and the production of the Land Cover Map of Jersey (Smith & Fuller, 1998) the classification procedure within IGIS was tested at a number of sites, but all of these were subsets of the full TM scenes. To test the classification procedure within IGIS on realistic data volumes a simulated data set was created from a subset of a 1990 summer-winter composite image and its equivalent segmented image. The tests were run on an Ultra 1 workstation but, hardware facilities have been reviewed and two new workstations are on order to supplement the existing suite of computers running Erdas, IGIS and ARC/Info. Operational processing will generally be on a machine with a higher specification and performance. Results are outlined below.

Polygonisation of segments
Laser-Scan is implementing a prototype version (suitable for ITE operations though not ready to market) of the Cambridge University segmentation software used to generate image-based polygons for per-polygon classification. This will be operable in time for production of LCM2000. In the meantime, earlier Cambridge University segmentations from the CLEVER-Mapping programme (Smith *et al.* 1998) have been used to test procedures in IGIS.

The segmentations were of areas smaller than a single scene so, for trail purposes, large areas have been generated by mosaicking together multiple copies of the smaller segmentations.

The resulting segmented image was used to generate a land parcel data set using the polygonisation functionality within IGIS, which identified the segments within the image and created an vector area object for each one. The segmented image consisted of over 850 000 parcels and polygonisation procedure took 15 hours to execute. It is envisaged that the simulated image had rather more segments than be expected, as the subset image from which it was generated had a fine scale spatial pattern which is not found consistently across whole TM scenes.

Per-parcel classification probabilities
IGIS now has an additional per-parcel classification which attaches probabilities for all potential classes. The capture of probabilities, per-parcel and/or per-pixel, for all potential classes has proved particularly interesting with substantial value in operation: results show, reassuringly, that most pixels / parcels are allocated to a single class with 80-90% probability, that the second class generally has only 10% probability and that the others are very lowly rated. Where two classes come close, then generally they are very similar (e.g. woodland and scrub) and the polygons are often mixed. The capture of all probabilities will allow a much more intelligent approach to knowledge-based, post-classification, correction, identifying only those land parcels where probabilities suggest mis-classifications for onward contextual analyses.

Per-parcel classification
The classification procedures are being tested with segmentations of images equivalent to full TM scenes. They are also being modified to incorporate new developments associated with the reporting of classification probabilities and the use of complex combinations of raster inputs. Preliminary results suggest that the procedure that actually classifies each parcel will be unaffected by the increased data volumes, but some alteration to the procedure which initially trains the classifier may be necessary to make it more efficient.

The target classification outlined in Annex Table 2 will be achieved through appropriate aggregation of spectral subclasses of image data. It is known that, in principle, these cover types can be classified, because most have been recognised either in LCMGB 1990, or later studies and in preliminary analyses for LCM 2000. Reconnaissance surveys, with 1990 data, suggest too that the target classes are identifiable without insurmountable difficulty. However, this remains to be tested in operation and subsequently validated objectively. Later reports will give details.

6.4 Validation

The Specification anticipated that field survey data would be used to validate the GIS database, comparing:

- correspondences per-parcel using reconnaissance survey data;

and from CS2000 field survey squares and extrapolated data:

- the national extent of the target cover classes;
- correspondences between cover per class per square on field survey maps and LCM2000;
- point-sample and/or vector-comparisons between LCM2000 segments and field survey parcels.

The principles of such comparisons have been discussed with Peter Rothery (Statistician at ITE Monks Wood) and these have been agreed as sensible approaches. This in practice means that the basic methods were tested during LCMGB 1990, though still perhaps in a somewhat rudimentary way. Nonetheless, agreement on methods and practical demonstrations mean that we can record early progress in 'Validation methods development / testing' envisaged in the GANNT.

7. CONCLUSIONS

- Image acquisitions have been adequate if disappointing in some respects:

  - Winter acquisitions, ironically the more precarious of the overall imaging plan, proved especially good, giving probably 95% cover of Britain in the target 1997-98 winter season.
  - Summer imagery has been remarkably poor, with virtually no cloud-free conditions through the optimum period of June and July. Nevertheless, May imagery by Landsat and IRS-1C gives 60-70% of Britain (though IRS data might lack the MIR band); August acquisitions (looking good for most of England) might supplement any band deficiencies of the IRS data. Overall costs, currently being reviewed, are expected to be within budget.
  - Much of the image cover has been acquired in long runs such that there will be little need to mosaic together many smaller scenes: this suggests that there will be time to concentrate greater efforts on fewer images for accurate and consistent classifications of large areas.
  - Image acquisitions, purchase plans and likely costs will be ready to present to the Consortium meeting of 9 September 1998.

- The Broad Habitat classification will essentially be achieved by appropriate combination of spectral subclasses, based upon field reconnaissance, training and computer extrapolation:

  - In a few instances, where contextual data other than cover are used by field surveyors, the distinctions may not be made at the Target class level with its intended 90% accuracy. These types will, however, be recorded as Subclasses or Variants. NLUSS classes can also, generally, be matched, though the detailed subdivision of urban land is beyond the scope of LCM2000. Other classes will also be identified to satisfy wider and longer term needs.
  - Identification and field recording of the classes and the use of the data for training a classifier is a tried and tested procedure. Use of the *Field Handbook* and its definitions, plus training in their interpretation, has ensured, as far as it is possible, that a match is achieved between field and satellite surveys.

- Reconnaissance surveys have now collected all the data needed for the next year's analyses, though some further exercises may be conducted, as needed, in the late summer / early autumn, to match any good late summer image acquisitions:
  - On most scenes, there are very many excellent examples of the Broad Habitats. These are readily identifiable by their Key attributes. These examples will form the backbone of the training and extrapolation. There will, however, be, difficulties in matching the general Bog class which includes a Heath and Grass moor cover in wet situations: the

Bog class is essentially contextual, using sub-dominant indicator species, and wide-area mapping may need the detail of the field survey to record and extrapolate those contextual observations.

- Borderline examples of classes will not be used for training and therefore need not be named and classified by the field reconnaissance team. They are dealt with in spectral-statistical terms and need not be categorised during field reconnaissance. Thus, identification of most Broad Habitats, for LCM2000 training, is entirely unambiguous, insofar as we are selecting only the pure examples and can ignore uncertainties: in this respect, the LCM2000 team will not face the problems of the field surveyor trying to 'pigeon-hole' borderline classes to record 100% cover.
- Most of the Broad Habitats, implicitly or explicitly, comprise many sub-types. Where these have their own unique spectral signatures, they will be trained and classified separately and aggregated as appropriate for the generation of Broad Habitats. It is important to remember, however, that the GIS will retain the original spectral subclasses, allowing any combination of thematic classes which may be required by the user.

- Image analyses have demonstrated or are currently being tested to demonstrate fully operational capabilities in time for production mapping; existing capabilities already would allow such production, but refinements, now in final stages, will facilitate efficient and effective use.

- On balance, progress, reviewed against the GANNT chart of the original Specification, is on schedule. Once summer image acquisitions are complete and image orders can be made (the rate-determining step) the systems, software and methods will all be in place for operational use.

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Annex Table 1. A brief review of Broad Habitats with an assessment of their distinguishing features, difficulties in distinctions and their identification in relation to minimum mappable units, in both per-pixel and per-parcel measurement.

1. Broad-leaved, mixed and yew woodland	The vast majority of broad-leaved woodlands with near-closed canopies of e.g. ash, oak, beech, birch and scrub species such as hawthorn and sallow can be interpreted straightforwardly in the field and pure examples used for training the classifier. The Deciduous Woodland of LCM1990 did not include broad-leaved evergreen trees: it is not clear whether these would be spectrally distinguishable from needle-leaved evergreens, though the incidence of stands >1ha, suitable for training and appropriate for classification is probably negligible. Deciduous larch might be confused with deciduous broad-leaved trees, though their summer colour should distinguish them: special attention will be paid to ensure this is so. Mixed woodland will be trained separately though, where stands of broad-leaved or evergreen trees exceed the minimum mappable unit, they will be treated as separate blocks within the woodland: in practice, per-polygon classification is likely to generate 'mixed woodland' polygons and per-pixel assessments will record the mosaics. It is a problem, albeit rare, that open-canopy woodland (the class includes all stands with trees >25% - see Key) will be classified by field surveyors as woodland despite the cover-dominance of the understorey. It is as yet unclear how consistently a 25% cover of trees would influence spectral signatures sufficiently to be classified as an open-canopy subclass: it is likely that the per-polygon results would record the understorey class-dominance and that per-pixel results will show the presence of scattered trees - in practice this would be ideal, giving detail of the heterogeneity while matching the parcel-based generalisation of the field survey. The aggregation of scrub into this class matches the approach of 1990 when the woodland and scrub classes were aggregated in generating 17-class maps from the 25-class originals to match CS1990 baseline classes.
2. Coniferous woodland	The recognition of coniferous woodland is generally more straightforward in that most stands will be planted, extensive and spectrally highly distinct. Open canopy semi-natural pinewoods will need special attention to ensure accurate recording: however, the distribution is limited and well-known, allowing such attention. New plantations will, as in 1990, only be recorded when tree cover is sufficient to strongly influence reflectance. New plantations, predominantly heather and/or grass, for example, will be recorded as such. This is one class where the field surveyors record land use, i.e. forestry, rather than the cover: spectral classification of image data cannot match that. Estimation of new plantation should be based upon a combination of the ITE land class, its broad cover as mapped by LCM2000, and the field-surveyed estimate for the proportional cover of plantation.
3. Boundaries and linear features	Only the largest of linear features might be mapped by the classification of satellite images. The field survey will continue to provide the best information on these.
4. Arable and horticulture	This Broad Habitat will match the 'Tilled arable crops' of 1990. This means that first year ley grasslands will be included as arable but subsequent years will include them with improved grasslands. This matches field-surveyors' aims. Intensively managed perennial crops (e.g. canes, orchards without ground flora) will show as bare in winter and so be included (as with the field survey) in the arable class.

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.
6. Neutral grassland 7. Calcareous grassland 8. Acid grassland	The three semi-natural swards are the converse of the above and rely upon the same assumptions as above. Where acid status is known, separate field-identification, training and classification will be used (though probably with aggregation for most maps and data outputs. Soil maps may also help distinction and could be used as a post-classification modifier (though probably not within the production of LCM2000).
9. Bracken	Bracken was not listed as a widespread Broad Habitat at the time of drafting the Specification. There were problems in the accurate mapping of bracken in 1990 so it was not written into the Specification as a target class. However, hopefully, better focus of image dates and topographic correction of illumination differences will refine the classification to offer a defensible distinction of dense bracken (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 LCM2000 team needs better to understand the exact distinction between 'bogs' where dwarf shrubs may be dominant but where peatland species form 25% of the cover (see Key). The LCM2000 team will liaise closely with the field survey leaders, the Scottish Natural heritage Peatland Survey team, the Countryside Council for Wales Phase 1 surveyors and (if appropriate) the Northern Ireland Countryside Survey to ensure a common understanding of the class. (As early surveys will concentrate on lowlands, there is time to develop this understanding in early 1999 prior to the widespread classification of uplands.
11. Fen, marsh and swamp	This Habitat includes fen, fen meadows, rush pasture, swamp, flushes and springs. It was mapped in 1990 as *Marsh / Rough grass*. As such it included dry rough grasslands. Contextual analyses in GIS (e.g 'blue linework') might help identify and measure this Habitat. Examples of the Habitat are rare, seldom extensive enough to map as pixels, let alone polygons and records for Britain are likely to be localised (e.g. the Broads).
12. Bog	The 1990 classification identified *Lowland* and *Upland Bogs*. It covered blanket bogs; however, it did not include wet ericaceous dwarf shrub heaths (see above). It needs to be clarified what is required in CS2000: distinction of wet heaths from dry might still prove difficult, though GIS context (slope, drainage, aspect) might help. (See notes above re. 10. dwarf shrub heath)

13. Standing open water and canals	This matches the *Inland water* class of 1990. 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) would be 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	The LCM1990 did not distinguish this class: however, their clearly identifiable context and the presence of vegetation cover at a sparse level (to distinguish zones from 26. Inland Rock, should be possible to add this class in LCM2000.
16. Supra-littoral rock	LCM1990 identified *Beach and coastal bare ground* but did not subdivide the category. First we would need to define a high water mark to distinguish supra-littoral zones: this was in effect done for major features (e.g. Dungeness, Culbin sands) in 1990. Distinction between rock and sediment might be spectral but would more likely require contextual (e.g. geological) data though the extent of rocks would usually be too small for accurate satellite mapping. realistically 16. and 17. will probably be aggregated into a single class.
17. Supra-littoral sediment	
18. Littoral rock	These classes are the converse of the above, i.e. those below the high water mark. They are generally much more extensive that supra-littoral sediments and thus much more readily mappable from satellite images. The same difficulties surround distinction between rock and sediment and it is again likely that 18. and 19. will be aggregated. Saltmarsh is included with this Broad Habitat but mapped separately by LCM2000.
19. Littoral sediment	
20. Inshore rock	Classes 20. to 24. are irrelevant in the context of a land cover map
21. Inshore sediment	
22. Offshore rock shelf	
23. Offshore shelf sediment	
24. Continental slope	
25. Oceanic seas	This is equivalent to the sea and estuary class of 1990 and would be matched in LCM2000: distinction between estuarine, inshore and oceanic waters, if needed, should be made contextually by end-users.
26. Inland rock	The LCM1990 identified *Inland bare ground* which would match this Broad Habitat.
27. Built up areas and gardens	This Habitat is a combination of *Suburban / rural development* and *Continuous urban* categories of 1990, though LCM2000 would identify much more of the heterogeneity, e.g. the vegetation cover in parks and larger gardens, bare urban ground and the tillage of allotments.

Annex Table 2. LCM2000 classes, widespread Broad Habitats and National Land Use Stock Survey classes and LCM1990 classes

	LCM2000 Target class	Subclass /	Variant	widespread Broad Habitats[1]	NLUSS	LCM1990 25-class	LCM1990 17-class
1	Sea / Estuary			25. Oceanic seas	4.1 Sea and estuary	1 Sea / Estuary	A Sea / Estuary
2	Inland Water			13. Standing open water/canals 14. Rivers and streams	4.2 Standing water 4.3 Running water	2 Inland Water	B Inland Water
3	Beach and Coastal Bare	Littoral Supra-littoral		18. Littoral rock 19. Littoral sediment 16. Supra-littoral rock 17. Supra-littoral sediment	5.2 Coastal rocks and cliffs 5.3 Coastal sand and mud	3 Beach and Coastal Bare	C Beach / Mudflat / Cliffs
4	Saltmarsh				4.5 Salt marsh	4 Saltmarsh	D Saltmarsh
5	Dune/grass heath				5.4 Dunes	5 Grass Heath	E Rough Past/Dune/Grass Moor
6	Grass moor[2]		'dry' 'wet'	8. Acid Grassland 12. Bog	3.4 Upland grass moor	9 Moorland Grass	
7	Shrub Heath[2]	Open Closed	'dry' 'wet' 'dry' 'wet'	10. Dwarf shrub heath 12. Bog 10. Dwarf shrub heath 12. Bog	3.6 Upland mosaic 3.3 Heathland	25 Open Shrub Heath 10 Open Shrub Moor 13 Dense Shrub Heath 11 Dense Shrub Moor	H Grass Shrub Heath/Moor I Shrub Heath/Moor
8	Blanket bog[2]			12. Bog	4.6 Bog	24 Lowland Herbaceous Bog 17 Upland Herbaceous Bog	M Bog (Herbaceous)
9	Montane			15. Montane habitats			
10	Deciduous broad-leaf wood	Mixed	Scrub Trees	1. Broad-leaved woodland	2.4 Undifferentiated young woodland 2.3 Broad-leaved woodland	14 Scrub / Orchard 15 Deciduous Woodland	K Deciduous / Mixed Wood
11	Coniferous/evergreen wood	Felled		2. Coniferous woodland	2.1 Conifer woodland 2.6 Felled woodland	16 Coniferous Woodland 23 Felled Forest	L Coniferous/evergreen wood
12	Agricultural/managed grass	Mown / Grazed Uncropped		5. Improved grassland	1.5 Improved pasture 7.2 Outdoor leisure	6 Mown / Grazed Turf 7 Meadow/Verge/Seminatl	F Pasture/Meadow/Amenity Grass
13	Unimproved grassland	Managed Bracken Unmanaged	neutral calcareous acid	6. Neutral grassland 7. Calcareous grassland 8. Acid grassland 9. Bracken	1.6 Rough pasture	12 Bracken 19 Ruderal Weed 8 Rough / Marsh Grass	J Bracken G Marsh / Rough Grass
14	Fen, marsh and swamp			11. Fen, marsh and swamp	4.4 Lowland freshwater marsh		
15	Tilled/arable land[4]	Winter sown Spring sown	cereal other cereal other	4. Arable and horticulture	1.1 Field crops 1.2 Horticulture & woody perennial crops 1.3 Fallow land 1.4 Ploughed land 7.3 Allotments	18 Tilled Land	N Tilled (Arable Crops)
16	Suburban / Rural Developed			27. Built up areas and gardens	7.1 Indoor leisure 8.1 Roads 8.2 Public car park 9.1 Residential 9.2 Inst'l/comm'l 10.1 Inst'l build 10.2 Educational 8.3 Railways 8.5 Docks 11.1 Industry 10.3 Religious 11.2 Offices 11.3 Retailing 11.6 Agricultural 12.4 Vacant 12.3 Urban not dev'd 11.4 Warehouse 11.5 Utilities	20 Suburban / Rural Dev't	O Suburban / Rural Development
17	Continuous Urban		residential/ commerce Industrial			21 Continuous Urban	P Urban Development
18	Inland Bare Ground		natural despoiled	26. Inland rock	5.1 Inland rock 6.1 Mineral workings and quarries 6.2 Landfill waste disposal 12.1 Vacant land previously dev'd	22 Inland Bare Ground	Q Inland Bare Ground
	Not applicable:	**26 target/subclasses** **33 target/subclasses/variants**		3. Boundary and linear features 20. Inshore rock 21. Inshore sediment 22. Offshore rock shelf 23. Offshore shelf sediment 24. Continental slope	8.4 Airports (civil) 2.7 Land cultivated for afforestation 12.2 Derelict land 13.1 Defence land		

[1]abbreviated names
[2]bog/moor/heath distinctions still to be fully resolved
[3]e.g. meadows and verges with standing, uncut grass
[4]perhaps including specific crops

Annex Table 3. Codes used to mark hard copy images during field reconnaissance surveys.

Arable

Aw	Wheat
Ab	Barley
Ar	Oil seed rape
Ap	Potatoes
As	Sugar beet
Af	Field beans
Al	Linseed
Ao	Arable oats
Ah	Horticulture
Ac	Carrots
Aq	Peas
Am	Maize
Ax	Mustard
Ast	Cereal stubble
Se	Set-aside
Ss	Set-aside (sprayed)
Sb	Set-aside (bare)
Sv	Set-aside (vegetated)

Grass

Gl	Ley
Gn	Neutral
Gi (I)	Improved
Gu	Unimproved
Ga	Acid
Gc	Calcareous
Gr	Rough / unmanaged
Gj	With dominant Juncus
Gm	Moor (Nardus/Molinia)
Gh	Hay

Wood

C	Conifer
Cl	Larch
Cn	Recent (<10yrs)
M	Mixed
Mn	Recent (<10yrs)
D	Deciduous
Dp	Poplar
Dn	Recent (<10yrs)
E	Evergreen
Sc	Scrub
O	Orchard
On	Orchard (new)
Ov	Vineyard

Wood (cont.)

Oh	Hop
Fd	Felled[1]

Heath/Marsh

H	Heather & dwarf shrub
Hg	Gorse
Ha	Arctic heath
Hb	Burnt heather
Hbg	Burnt heather now grass
Hga	Heather grass
Br	Bracken
F	Fen / swamp
Fm(g)	Fen marsh (grass)
Fw	Fen & willow
Bo	Bog[2]
Bb	Blanket bog

Urban (other)

U	Urban
Us	Suburban
Ui	Industrial urban
Ud	Despoiled land
Ba	Bare
W	Water

Coastal

Ls	Litoral sand
Lm	Litoral mud
Lr	Litoral rock
Sm	Saltmarsh
Sd	Sand dune
Sh	Shingle
Shv	Shingle vegetated

[1] May require another code.
[2] May be accompanied by an additional code describing the dominant cover type.

Annex Table 4. Widespread Broad Habitats and the field reconnaissance categories which they comprise.

1. Broad-leaved, mixed and yew woodland	M	Mixed	
	Mn	Recent mixed plantation (<10yrs)	
	D	Deciduous	
	Dp	Poplar	
	Dn	Recent deciduous plantation (<10yrs)	
	E	Evergreen	
	Sc	Scrub	
	O	Orchard	
	On	Orchard (new)	
	Ov	Vineyard	
	Oh	Hop	
	Fd	Felled	
2. Coniferous woodland	C	Conifer	
	Cl	Larch	
	Cn	Recent (<10yrs)	
3. Boundaries and linear features	Not applicable		
4. Arable and horticulture	Aw	Wheat	
	Ab	Barley	
	Ar	Oil seed rape	
	Ap	Potatoes	
	As	Sugar beet	
	Af	Field beans	
	Al	Linseed	
	Ao	Arable oats	
	Ah	Horticulture	
	Ac	Carrots	
	Aq	Peas	
	Am	Maize	
	Ax	Mustard	
	Ast	Cereal stubble	
	Se	Set-aside	
	Ss	Set-aside (sprayed)	
	Sb	Set-aside (bare)	
	Gl	Ley	
5. Improved grassland	Gi (I)	Improved	
	Gj	With dominant Juncus	
	Gh	Hay / silage	
6. Neutral grassland	Sv	Set-aside (vegetated)	
	Gn	Neutral	
7. Calcareous grassland	Gr	Rough / unmanaged	
8. Acid grassland	Gc	Calcareous	Gu Unimproved
	Ga	Acid	
	Gm	Moor	
9. Bracken	Br	Bracken	

10. Dwarf shrub heath	H Heather & dwarf shrub Hg Gorse Ha Arctic heath Hb Burnt heather Hbg Burnt heather now grass Hga Heather grass
11. Fen, marsh and swamp	F Fen / swamp Fm(g) Fen marsh (grass) Fw Fen & willow
12. Bog	Bo Bog Bb Blanket bog
13. Standing open water and canals	W Water
14. Rivers and streams	Not applicable
15. Montane habitats	Z
16. Supra-littoral rock	Sr
17. Supra-littoral sediment	Sh Shingle Shv Shingle vegetated Sd Sand dune
18. Littoral rock	Lr Littoral rock
19. Littoral sediment	Ls Littoral sand Lm Littoral mud Sm Saltmarsh
25. Oceanic seas	Ws Sea
26. Inland rock	Ba Bare
27. Built up areas and gardens	U Urban Us Suburban Ui Industrial urban Ud Despoiled land

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