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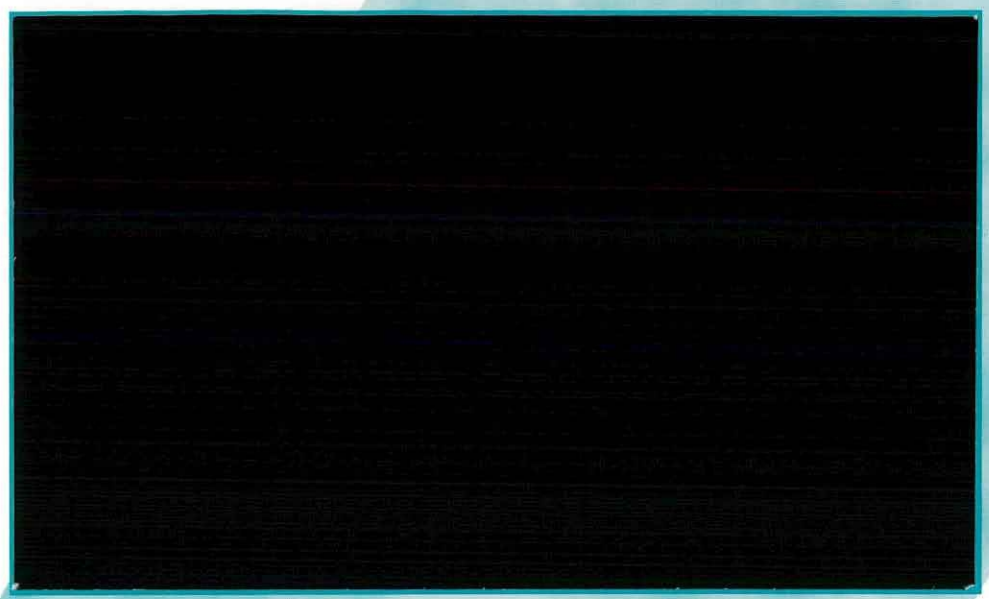

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Natural Environment Research Council

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INSTITUTE OF TERRESTRIAL ECOLOGY
(NATURAL ENVIRONMENT RESEARCH COUNCIL)

Project. T02083j5

Countryside Survey 2000
Module 7

THE LAND COVER MAP OF NORTHERN IRELAND

An extension to Land Cover Map 2000

PRELIMINARY REPORT

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2 March 1999

EXECUTIVE SUMMARY

1. LCM2000 updates and upgrades the Land Cover Map of Great Britain to include Northern Ireland, thereby covering the entire United Kingdom, with improved accuracy, added thematic detail, and closer integration between field and satellite data.
2. The survey will census widespread Broad Habitats using satellite imagery and automated image processing techniques, the results validated and calibrated against ground reference data.
3. LCM2000 will use CLEVER-Mapping based on Ordnance Survey of Northern Ireland (OSNI) vector map data; using image segmentations, coverage will extend to include hydrological catchments which overlap into Eire.
4. This Preliminary Report supplements earlier LCM2000 reports and gives early details on the Pilot Exercise outlining, for Northern Ireland: i. developments in methodology; ii. image acquisitions; iii. generalisation of OSNI data for satellite mapping purposes; iv. demonstrating outputs; and v. recommending an ongoing strategy.
5. Preferred Landsat TM image acquisitions for Northern Ireland in the target winter of 1997-98 and summer 1998 were poor. This shortage can be made good with: i. summer 1997 data; ii. compromises in the definition of 'summer' and 'winter' periods; iii. use of IRS LISS 1998 data; iv. the generation of mosaics of multiple part-clouded 1998 images; v. acquisitions of new images in 1999; and vi. use of imagery acquired in 2000.
6. Complete two-date coverage is available within the 1998± 1 year timespan ensuring that the LCM-NI is feasible. Late winter 1999 and summer 1999 will add to these datasets and should be considered.
7. ITE has been supplied with a 2.4 km x 3.2 km sample area of OSNI data in NTF Level-2 format, which caused some losses of detail. Further consultations with OSNI and Laser-Scan will investigate better options.
8. CLEVER-Mapping requires the vector data to be generalised to a level compatible with satellite mapping (and this will also protect OSNI interests). Vector generalisation is not straightforward.
9. Vector-raster-vector conversion can close polygons and generalise to vector at the image-pixel resolution. There may be difficulties in generation and use of such data.
10. A simpler approach would convert the linework to 25 m raster cells matching the image resolution, and to use the resultant raster edge map as the primary input to seed an image segmentation. There are ways of making the edge-map 'dominant' when generating an OSNI vector-based image segmentation. An example is demonstrated.
11. The OSNI digital terrain model (DTM) will also be needed to compensate for the topographic effects on illumination and for post-classification, knowledge-based corrections.
12. Procedural developments for LCM2000 have involved software refinements; macros have been developed to automate the processes of image analysis; other developments have formalised and made objective the sequence of processing activities; the Unix version of CLEVER-Mapping segmentation is operational.
13. Operations in LCM2000 have included all stages: i. geo-registration; ii. resampling; iii. automated identification of clouds and cloud-shadows; iv. atmospheric corrections and v. illumination corrections for terrain-induced effects.
14. Bands have been examined and selected for edge-detection and segmentation; the Sobel edge-detector is to be used in GB and for catchments crossing into Eire.
15. Classification has: i. collected and used field reconnaissance data; ii. trained objectively using segments; iii. reviewed and refined training data; iv. emplyed a dynamic shrinking

procedure on polygons to ensure the selection of 'pure' core pixels of each cover type; v. applied a maximum likelihood algorithm to the polygon mean statistics; vi. recorded probabilities for all subclass options; vii. recorded the heterogeneity associated with polygons, using per-pixel classifications.

16. Validation has been designed as a two-stage process: i. using check-polygons to validate the results per-polygon; ii. using field survey data to fully calibrate results.
17. Production has involved processing 5 scenes in parallel, from initial atmospheric corrections through geo-registration, illumination correction, co-registration of summer-winter data and segmentation stages. Preliminary classifications of each will be produced in March 1999. The procedures will all apply in Northern Ireland.
18. Initial classifications of widespread Broad Habitats have shown that, in principle, the Broad Habitat classification can be achieved. Overall success will only become clearly apparent once validation, based on check polygons, provides an early measure of success.
19. It is recommended that developments in use of the OSNI vector data continue through spring 1999; in early summer, field reconnaissance will take place in Northern Ireland; a decision on the best images should be made after summer 1999; processing (images permitting) will be scheduled for winter 1999-00.
20. Thus original timetable for LCM2000 will apply with the inclusion of Northern Ireland. However, more intense activity will be needed to ensure completion by November 2000.

1. INTRODUCTION

LCM2000 updates and upgrades the *Land Cover Map of Great Britain* (LCMGB), made in 1990-92 (Fuller *et al.* 1994). Refinements are:

- Inclusion of Northern Ireland to cover the entire United Kingdom,
- Improved accuracy of classification,
- Added thematic detail,
- Compatibility with other systems of environmental survey and evaluation,
- Closer integration between field and satellite data.

The Land Cover Map of Northern Ireland (LCM-NI) is being funded by a Consortium of five organisations. The Northern Ireland contributors (asterisked in Table 1) join the existing GB Consortium to give a membership of 11 Government Departments and Agencies funding Land Cover Map 2000 (Table 1), covering the United Kingdom.

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

Countryside Council for Wales
Department of Agriculture for Northern Ireland*
Department of the Environment, Transport and the Regions*
Environment Agency
Environment and Heritage Service*
Ministry of Agriculture, Fisheries and Foods
Natural Environment Research Council*
Ordnance Survey of Northern Ireland (contributing data)*
Scottish Natural Heritage
Scottish Office
Welsh Office

BACKGROUND

The Land Cover Map of Northern Ireland (LCM-NI) will relate to the Northern Ireland Countryside Survey and will be co-ordinated with the parallel programme of work (Countryside Survey 2000 (CS2000)) in Great Britain. The programme will thus provide integrated information for the United Kingdom, as a whole. The Countryside Surveys give a major audit of the habitats, plants, landscape features and land types of the UK countryside at the end of the Millennium.

In broad terms, the aims in Northern Ireland will be the same as those outlined in the Specification for Land Cover Map 2000. However, there is the intention, if possible, to refine the methodology, using OSNI vector data, to undertake parcel-based CLEVER-Mapping. To ensure that this objective is possible, within the timescale and budget required, ITE have undertaken a pilot exercise, using a sample of OSNI data to test the generalisation procedures needed to bring the data into a suitable resolution for satellite mapping. It has also been an opportunity to demonstrate a variety of outputs to OSNI, so that they might ensure that the integrity of their full resolution data is adequately protected when the Consortium distribute the outputs of LCM-NI.

AIMS

General

The proposed aims for LCM-NI will be:

- To undertake a census survey of the land cover / widespread Broad Habitats of Northern Ireland 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,
- To calibrate and validate satellite-derived classifications against ground reference data, publish results of the correspondence analyses, and provide a guide to their interpretation.

The proposed outputs are essentially unchanged from those in GB, except in that they extend to cover Northern Ireland. In fact, the maps and classified data will include Northern Ireland catchments, in their entirety, even where these in part overlap into Eire.

The overall duration of the project is unchanged, with planned completion by November 2000. Outputs are, in brief:

- A vector GIS recording the dominant land cover in land parcels,
- A raster-based GIS recording land cover on a 25 m grid,
- Integration of these datasets,
- Summary 1 km data,
- Validation/calibration statistics,
- Summary statistics by administrative and environmental regions,
- An assessment of widespread Broad Habitats.

This Report

This Preliminary Report aims to extend the LCM2000 Second Interim Report (Fuller *et al.* 1999b), which covers LCM2000 work done up to 19 February 1999 (and has been supplied to the Northern Ireland Consortium). The Preliminary Report adds details on the Pilot Exercise in Northern Ireland:

- Outlining developments in LCM2000 methodology which will be applicable to Northern Ireland mapping;
- Reporting on image acquisitions for Northern Ireland;
- Testing the generalisation procedures on a sample of OSNI data to generate a suitable resolution for satellite mapping;
- Demonstrating a variety of outputs to OSNI;
- Recommending an ongoing strategy for incorporation of Northern Ireland into LCM2000.

It should be recognised that the developments reported here on the use of OSNI data, are at an early stage: ITE have only had these data for two weeks. Work will continue to develop and

refine OSNI map-based procedures which will be operational before image analyses commence.

This Report is a supplement to earlier LCM2000 reports, adding detail which is specific to Northern Ireland. The other Reports describe more fully many of the issues which are applicable to LCM2000 mapping throughout the UK. Copies of those Reports which are therefore provided to the Northern Ireland Consortium and should be viewed as complementary to this Report. They are:

- The *First Progress Reports* (Fuller *et al.* 1998b) to the LCM2000 Consortium
- The *First Interim Report incorporating the Second Quarterly Progress Report* (Fuller *et al.* 1998c)
- The *CS2000 Joint Management Team Reports* (Fuller *et al.* 1998d & 1998e, the latter of which supplants the Third Progress Report),
- The *Second Interim Report incorporating the Fourth Quarterly Progress Report* (Fuller *et al.* 1999b).
- The *Countryside Survey 2000 Integrated Progress Reports* (see Fuller et al. 1998f & 1999a).

All future Reports on LCM2000 will cover the UK: there will not be separate reports on Northern Ireland.

IMAGES SEARCHES – NORTHERN IRELAND

Landsat Thematic Mapper (TM) images are the preferred choice (Fuller *et al.* 1994); the Indian Research Satellite (IRS) LISS sensor offers similar data with a lower spatial resolution in middle infrared and are thus second choice. A review of 'quick look' satellite overviews (NB with limited resolution and detail) suggests that the hydrological catchments which cross the border will be covered in their entirety by the NI images. If necessary, it will be possible to buy additional part scenes of satellite data. The target date for images was summer 1998, matched by winter images of winter 1997-98. The definitions of 'winter' and 'summer' periods appear in the First Interim Report (Fuller *et al.* 1998c): broadly, winter runs from the first frosts, when deciduous vegetation senesces, to early spring, prior to leaf emergence on deciduous trees (roughly October to April); summer would ideally be the period from full leaf emergence (mid-May) to arable cropping (end of July). Images from 1998, plus or minus one year, and within these target seasons have been sought.

1996-7

Winter 1996-97 showed no TM images worth purchasing (see Figure 1 - note especially path 206, row 022 and 207-022), except maybe to fill any gaps which might remain after purchase of other data. Summer 1997 recorded a useable scene in path 207 row 022, but still with a significant cloud cover (*c.* 15%). Data from this period would best be avoided unless crucial to the completion of the LCM-NI.

1997-8

Winter 1997-98 offered an excellent TM image of path 206, row 022 (Figure 1) but no corresponding data to westward (207-022). Acquisitions of TM images in summer 1998 were poor (Figure 2): speckled cloud over even the very best of scenes, plus the confusion of shadows on the ground, render the summer 1998 acquisitions almost unusable. LISS data record the western half of Northern Ireland with about 5-10% cloud plus their shadows (Figure 3, path 008, row 029 and 008-030).

1998-99

Winter 1998-99 added a 10 October scene (Figure 4) but with substantial cloud cover. Acquisitions since December are not yet in archive for quick-look assessments. A LISS image of 008-029 (Figure 3) has cloud and haze, the latter probably removable by atmospheric correction, so the image may be a useful contribution to the analysis. Late winter 1998-99 and Summer 1999 still remain crucial periods for LCM-NI data acquisitions.

Other images

Autumn 1998 added several valuable images: an excellent full scene of 207-022 (Figure 5) is potentially very useful: it has some haze, probably largely correctable, and very little dense cloud. This image was recorded 20 September and is only of marginal acceptability as a winter scene. But it would nonetheless very usefully complement cloudier scenes of perhaps better winter dates. An excellent TM image of 10 September 1997 might provide late 'summer' infill for the west of Northern Ireland; again the date is marginal.

Overall assessment

Image acquisitions for Northern Ireland in winter 1997-98 and summer 1998 have been poor. This shortage can be made good by various means:

- Use of summer 1997 data,
- Compromises in the definition of 'summer' and 'winter' periods,
- The greater use of IRS LISS 1998 data,
- The generation of mosaics of multiple part-clouded 1998 images,
- Acquisitions of new images in 1999
- Use of imagery acquired in 2000.

Figure 6 shows that compilation of the 'summer' coverage for LCM-NI is already possible using a mixture of summer 1997 data, summer 1998 data, and a very small area of early September 1997 data as extended 'summer' coverage. Figure 7 shows that completion of the winter coverage can also be achieved using winter 1998 data, plus a late September scene of 1997. The compromise on image-dates using early September data as 'summer' and late September data as 'winter' may cause some problems. However, these could to a large extent be overcome by adding the best substitute examples of true summer or winter imagery with partial cloud coverage; alternatively, by adding a third image from a contrasting date (e.g. spring) to offer the extra spectral dimension needed for improved class separability. Price agreements with Eurimage, the suppliers, allow purchase of substitute data at half price; the costings quoted by ITE allow for purchase of substitute data, thereby making this an affordable option. The use of 1997 data will clearly mean that the map spans 2+ years, but Broad Habitats are not transient and a one-year span will make little difference to the overall results. Mixture of summer-winter data from 2 different years might also prove slightly problematic. However, this need only arises in about 20% of Northern Ireland, the rest being covered by summer-winter images recorded within less than a year of each other.

While the choice of images is by no means ideal, the important news is that complete two-date coverage will be available within the 1998± 1 year timespan. This ensures that the LCM-NI is already feasible. Late winter 1999 and summer 1999 will add to these datasets and should be considered. There is even the option, if needs be, of using winter 1999-00 coverage and perhaps even summer 2000 images. The poor rate of image acquisitions will not in itself prevent the production of LCM-NI. A decision on the best way forward should be made after summer 1999.

Figure 1. Landsat Thematic Mapper images, growing season 1996-1997

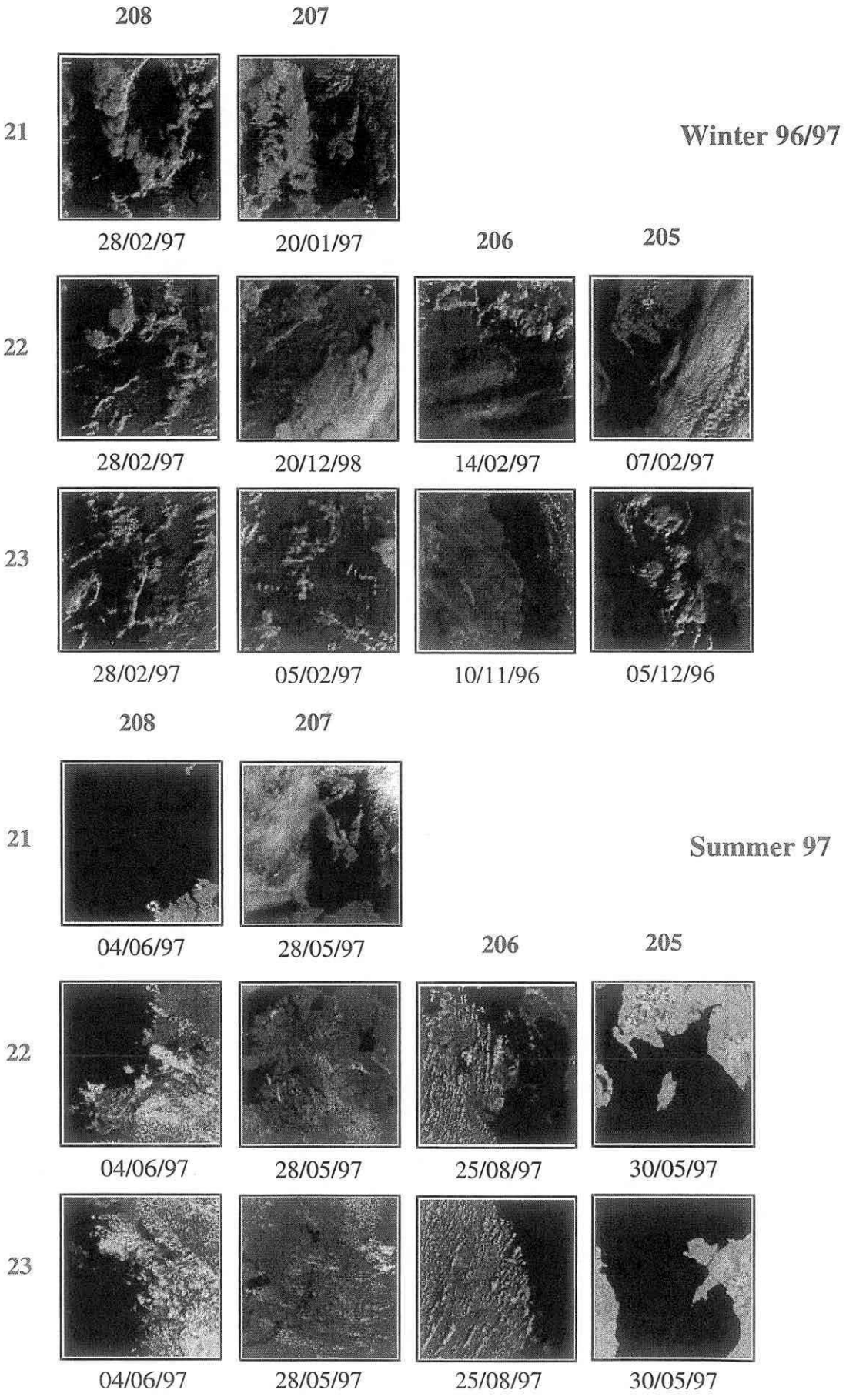


Figure 2. Landsat Thematic Mapper images, growing season 1997-1998

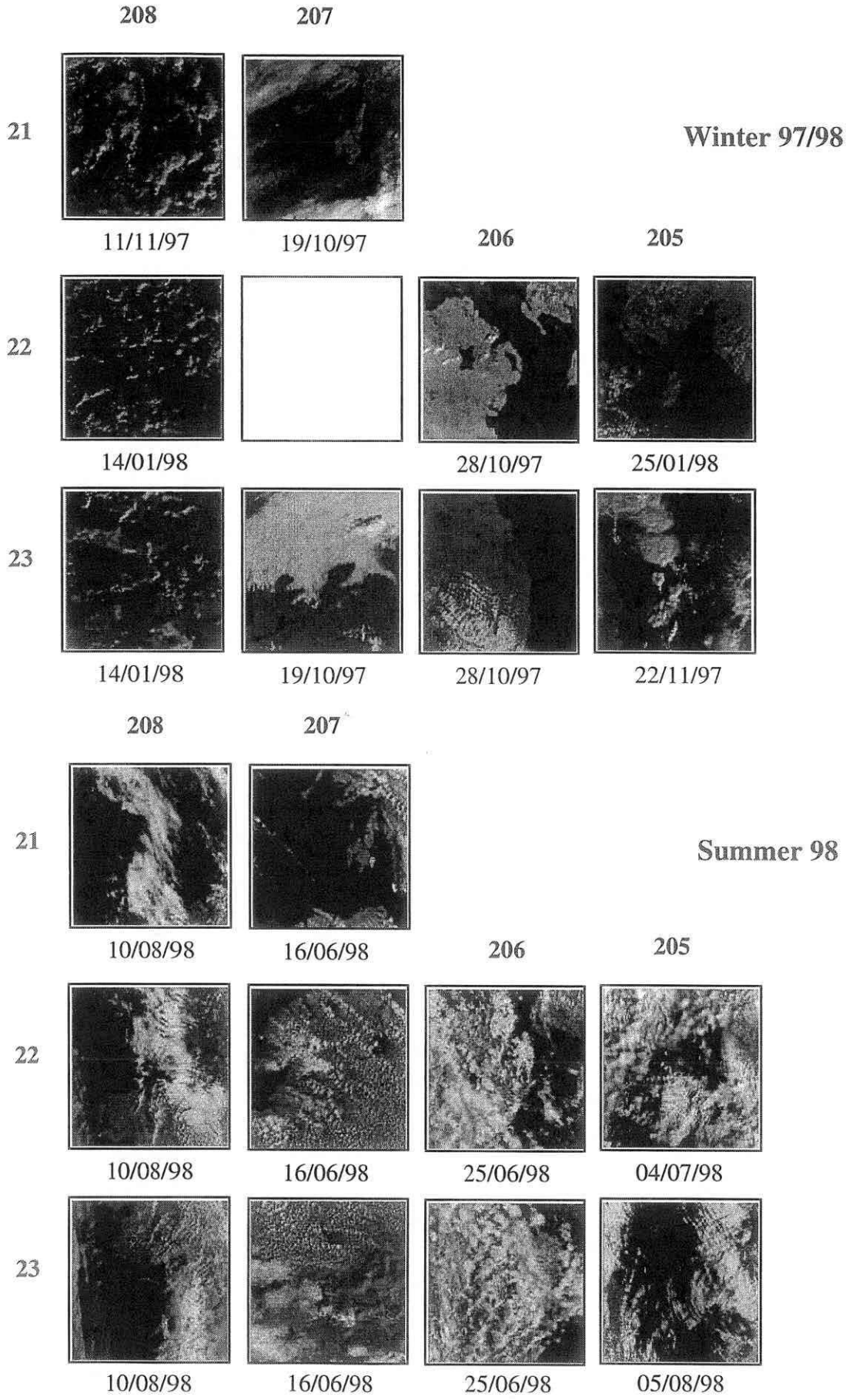
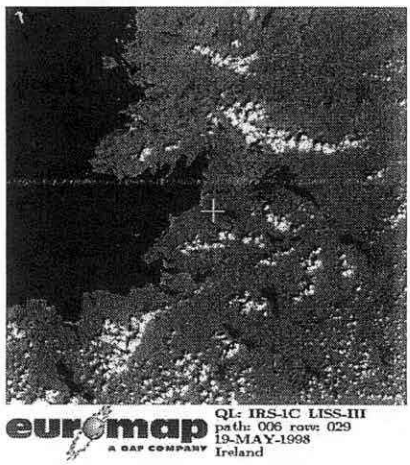


Figure 3. Selected IRS LISSimages of winter 1997-98 and summer 1998

Path 007 row 027
17 June 1998 (below)



Path 006 row 029
19 May 1998 (above)

Path 008 row 029
22 February1998 (below)

Figure 4. Landsat Thematic Mapper images, growing season 1998-1999

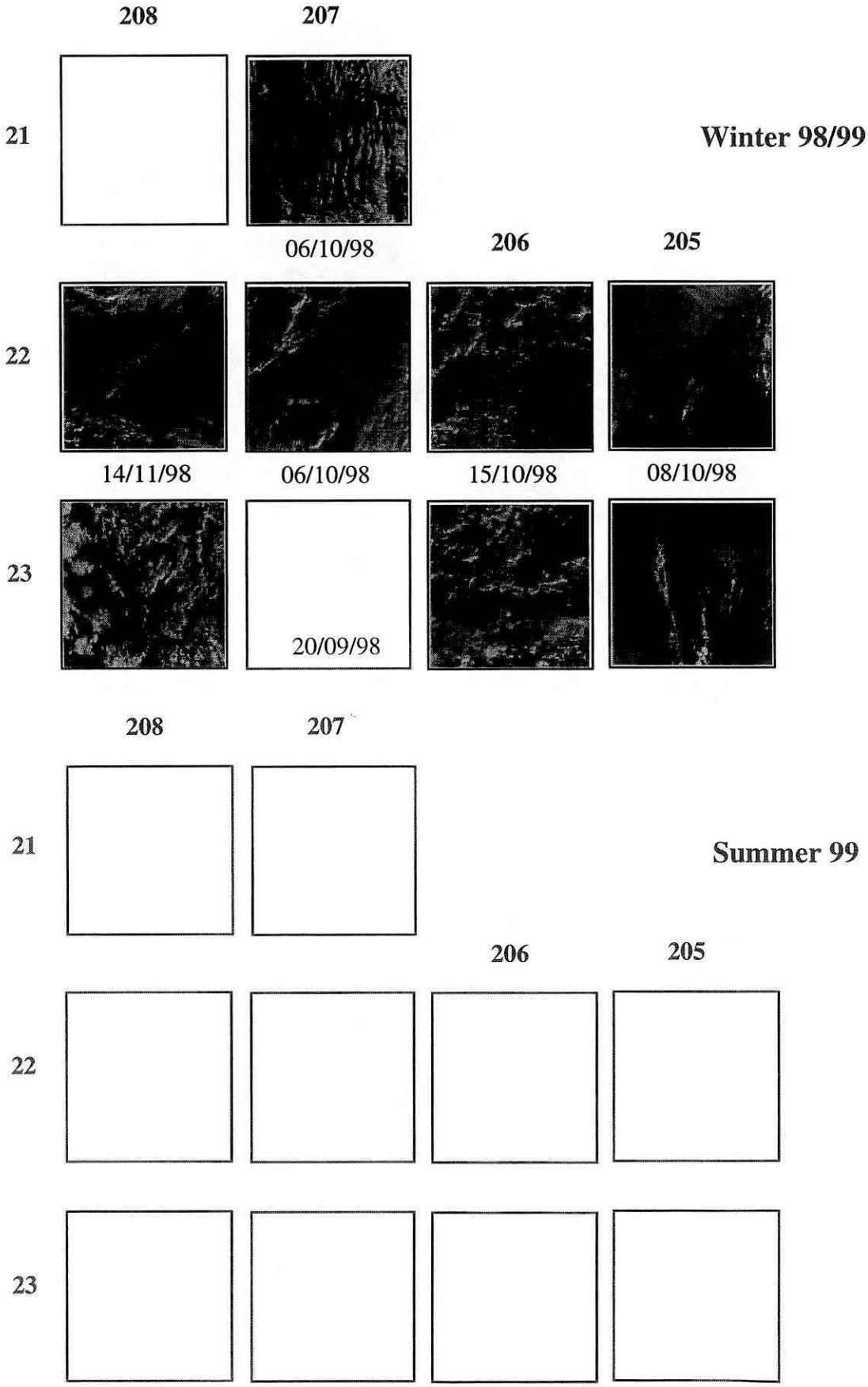
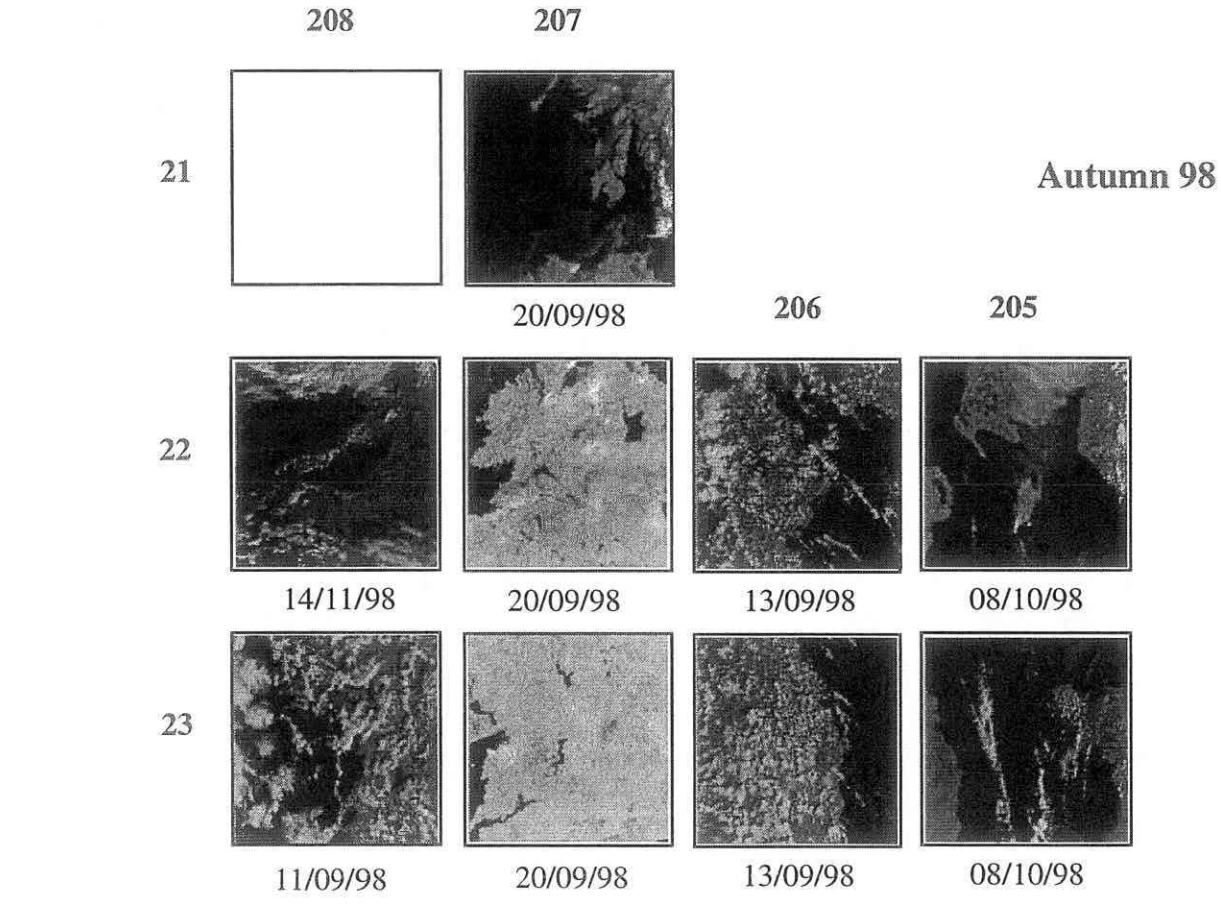
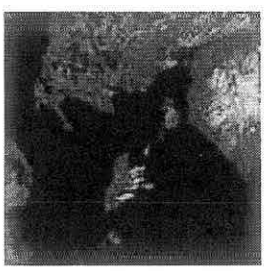
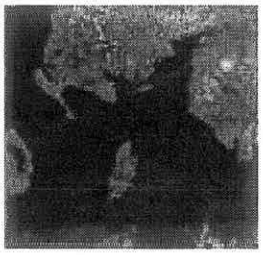


Figure 5. Landsat Thematic Mapper images, recorded outside target summer-winter dates





205 22 12/4/97



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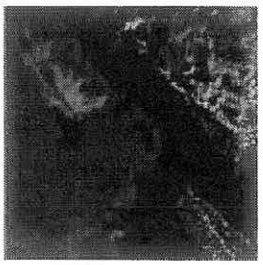
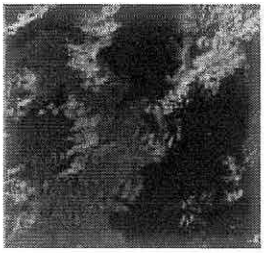
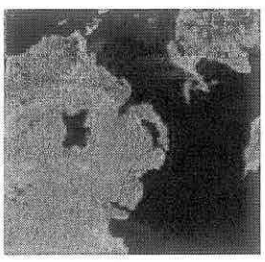


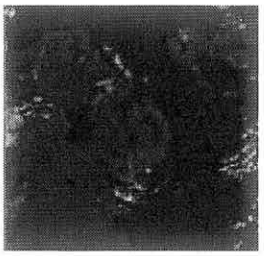
206 22 10/11/96



206 22 02/03/97



206 22 10/09/97



206 22 21/12/97

208 21 17/4/97

208 22 17/04/97

Figure 6. Possible complete winter coverage

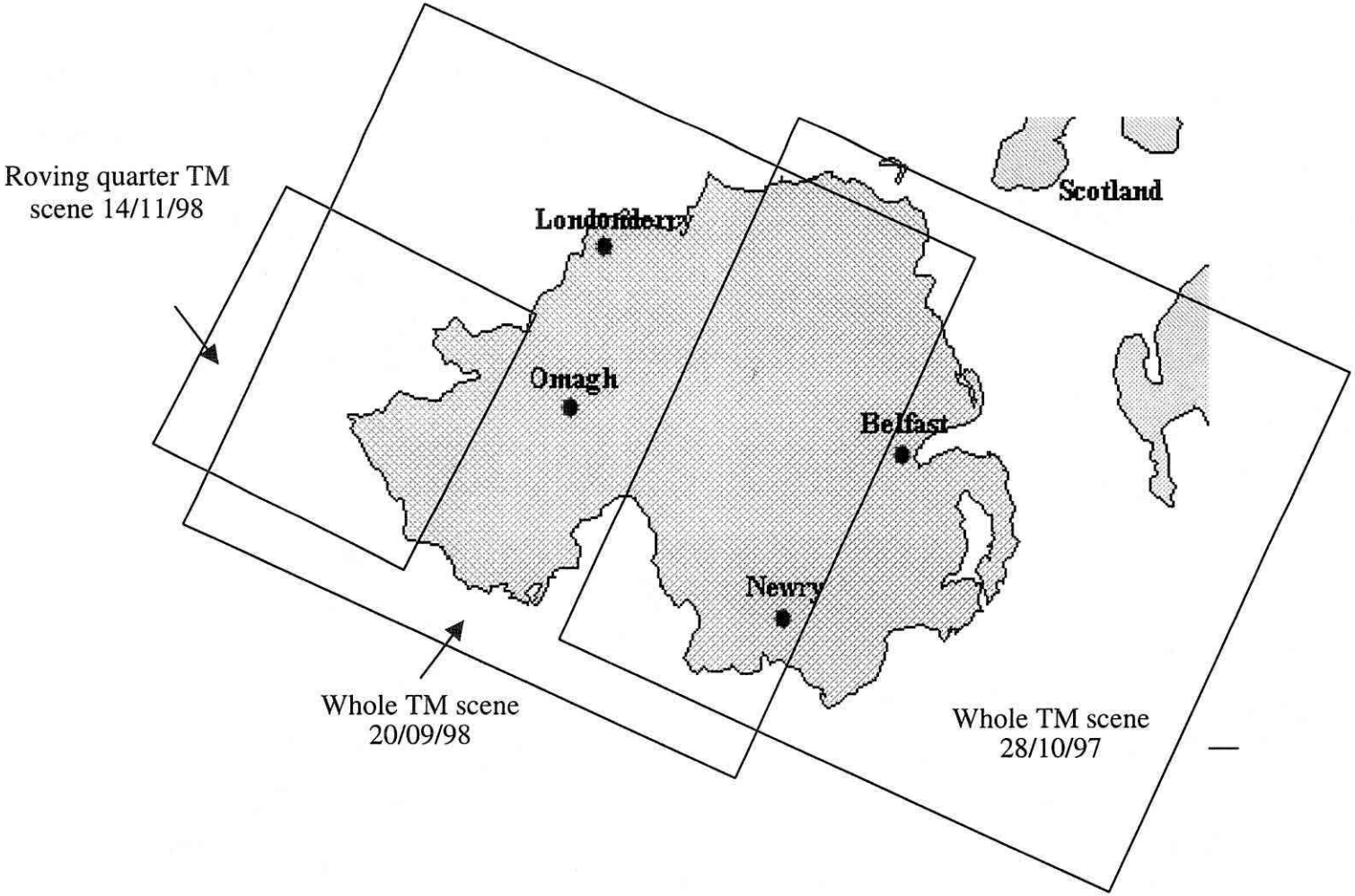
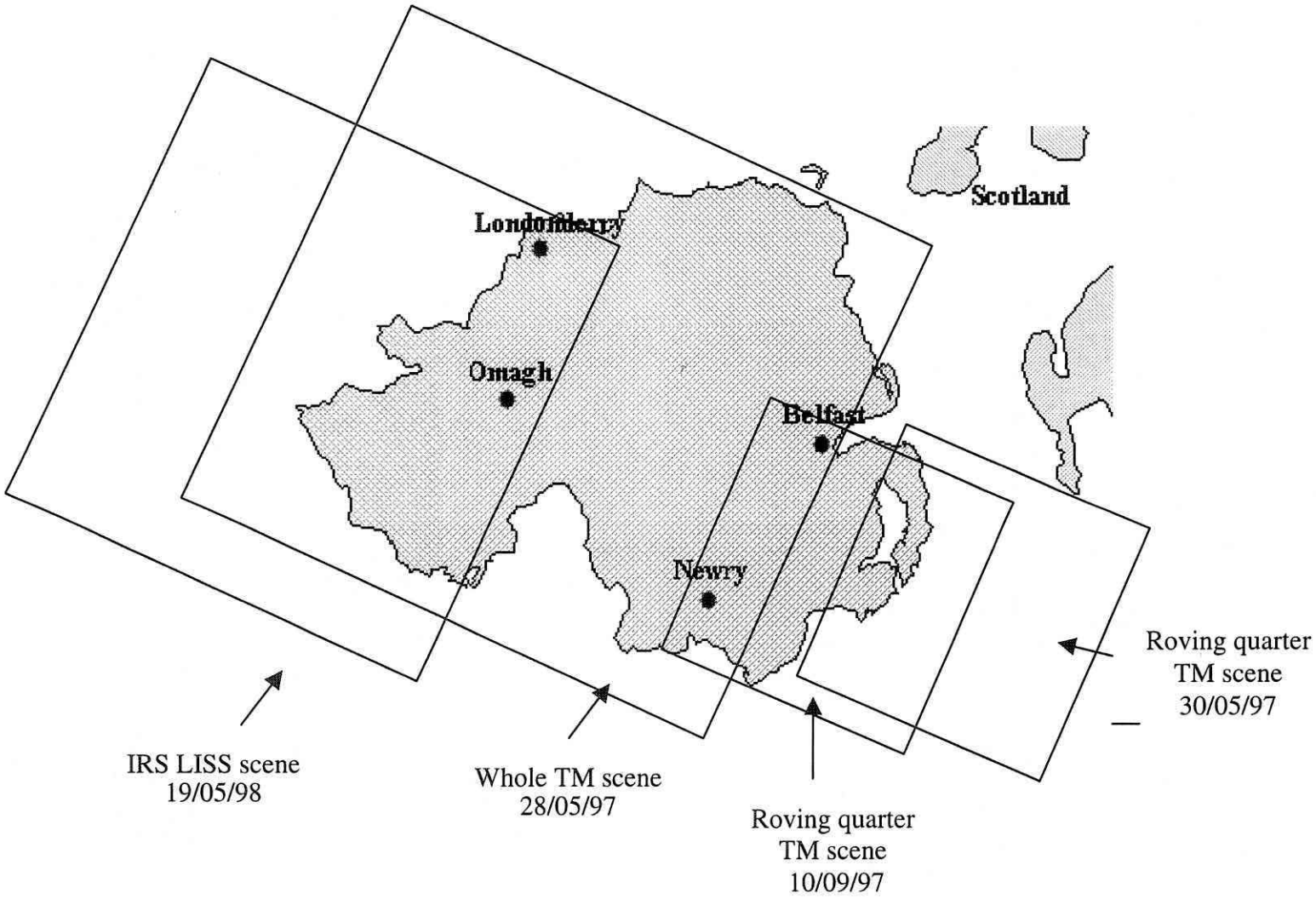


Figure 7. Possible complete summer coverage



OSNI VECTOR DATA

CLEVER-Mapping in Northern Ireland will aim to use vector-based CLEVER-Mapping built upon OSNI vector map data - similar procedures have been used in Jersey (Smith & Fuller 1997, 1998). OSNI are naturally concerned that the LCM-NI might offer a detailed land-parcel structure for Northern Ireland and thus become a 'cheap' source of OSNI linework. Thus, the trials have not only considered the suitability of OSNI linework for CLEVER-Mapping but they have also presented a range of possible outputs which provide detail commensurate with satellite mapping but which also protect OSNI's commercial interests. The output options will allow OSNI the chance to agree their final detail and format, prior to commencement of production mapping.

ITE has been supplied with a 2.4 km x 3.2 km sample area of OSNI data. The area incorporates urban land, farmland and semi-natural zones. Prior to supply, ITE and OSNI agreed to cut down the OSNI linework, shortlisting features to be used in the trial and eliminating unecessary information. The NTF Level-2 format was used for export and import to Laser-Scan IGIS. This process was achieved without obvious loss of linework but there have been losses of detail. For example, it has been observed that the original linework, which carried multiple attributes per line, only recorded single attributes upon import from the NTF Level-2 format. So a parcel boundary, which also happens to be a fence-line and a road edge, only carries the first attribute of the list; and this may not necessarily be the important fact that it is a boundary. Thus, features were interpreted as lines not areas; and a validation error was recorded because polygons did not close; the structured topology was lost.

It is not yet clear whether there are better options for transfer formats which OSNI can produce and which IGIS can read and which will retain all the information inherent in the original data. However, it is understood that there is a special OSNI translator for the data which may present difficulties of compatibility. Further consultations with OSNI and Laser-Scan will investigate the matter over the next few weeks.

In addition to the definition of a structured topology, CLEVER-Mapping requires the vector data to be generalised to a level compatible with satellite mapping (and one which also protects OSNI interests):

- Multiple linework (e.g. road edges and centre-lines) should be reduced to single-line features unless the linear feature (e.g. a river) is wider that the pixel size (25 m is the intended output image 'resolution'),
- Small polygons (e.g. <0.5 to perhaps 1 ha) should be dissolved and/or aggregated so as to ensure that all polygons are large enough to contain pure image pixels for classification,
- Total coverage of remaining polygons should add up to 100% of the landscape.

The fact that the OSNI data did not read in as polygons (as had been expected) causes problems for ongoing vector analysis. If vector polygon-formation and generalisation are to be used, it will be necessary to build the structured topology. In doing this, every boundary line of every polygon must join exactly to the other boundaries of the polygon and a complete polygon outline must result for each polygon. There are risks that lines will fail to 'snap' together, polygons will thus fail to close, and that complex or mixed polygons will result; it is

hoped that the linework which has already been cleaned by OSNI to generate a fully structured topology, can do so again without editing: trials will continue. If a full topology cannot be generated, 'intelligent' analyses will have to be developed to rebuild that topology - and that may not be a straightforward procedure. Consultations with OSNI will continue to investigate transfer formats to maximise the information content of imported data and to ensure the cleanest possible topology. Only if this fails will ITE start to investigate rebuilding the topology 'from scratch'.

Vector generalisation will be needed if detailed, vector-based, CLEVER-Mapping is to be used. this task is a demanding one and methods may need to be developed in conjunction with OSNI. It may be that OSNI would still be reluctant to generate a vector product from which much of the original database could be reconstituted. Other options deserve attention.

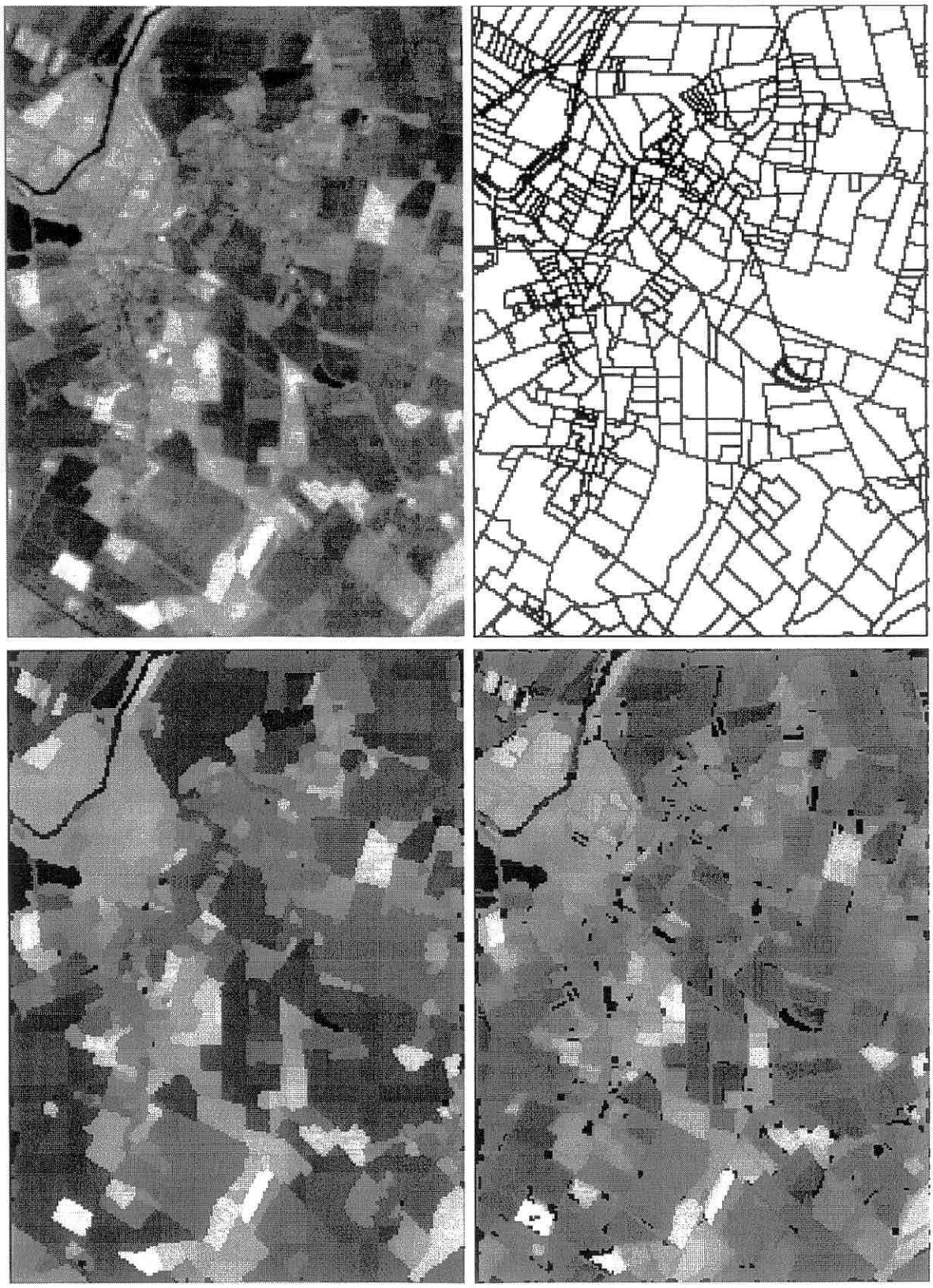
Throughout GB, raster-based segmentation and per-segment classification is being used: use of raster procedures but based upon vector OSNI linework is a compromise solution to the topological problem which will substantially improve results over image-based segmentations, will generate a recognisable parcel structure based upon OSNI mapping of Northern Ireland and will protect OSNI data interests: the solution may also be relatively quick and simple in operation.

One option is to use vector-raster-vector conversion whereby vector lines are converted into lines of raster pixels and the data then converted back again. This has the advantage of closing polygons and offering a much simplified dataset with multiple lines thinned to single pixel linework, except where features are large. If the linework is digitised as, say, 5 m pixels, the resolution easily exceeds that needed for analyses based on images with 25 m pixels. The conversion back to vector produces a vector line down each side of the raster linework and linework takes the form of linear polygons: however, this result is not an illogical format for recording most landscape linear features (e.g. roads, railways, ditches, streams, tree-lines, verges and hedgerows). When the 25 m image is overlaid by this new simplified vector linework, each image-pixel can be labelled as a edge pixel or a within-field pixel and all pixels within a single field might be treated as an entity for CLEVER-Mapping purposes. However, it is not immediately clear how this might be achieved and further tests and developments are needed. The vector-raster-vector procedure has the advantage, from OSNI's point of view, that the original linework is eventually generalised at the image-pixel resolution, protecting the original data and precluding the generation of detailed polygon linework from LCM2000 output products.

An even simpler approach, and one which will undoubtedly work, is to convert the linework to 25 m raster cells matching the image resolution, and to use the resultant raster edge map as the primary input to seed the segmentation; this edge-map could replace the normal Sobel edge-detector used in GB (see Second Interim Report, section 6.3). While this procedure will ensure the best possible input to segmentation, it will not necessarily generate a segment for each field, as the growth of segments can cross the edge-image linework where reflectance values are within the threshold set for the segmenter.

There are ways of making the edge-map more 'dominant' in the segmentation process, for example preventing the segmenter from growing across boundaries, even where pixel-values are near-identical. Experiments have shown that the OSNI linework rasterised to 25 m cells, can be 'burnt' into one of the bands used for segmentation. This might be done by subtly or

Figure 8. Map and image based segmentations: a Landsat Thematic mapper summer-winter composite image (top left) of a part of Cambridgeshire; rasterised OS vector linework (top right); an image-based segmentation (bottom left); a segmentation using map linework to direct the segmentation (see text for details).



radically altering the digital numbers in the image, for the OSNI boundaries to have an influential or a dominating effect on the resultant image segments. Because ITE have no image data for Northern Ireland at present, the use of vector data to control segmentation is illustrated using OS GB linework and GB imagery (Figure 8). The results have not gone through the 'cleaning' process to remove 'non-segment' speckle (black on the image), nor the review of small polygons and lines to ascertain whether they should generalised into the neighbouring polygons or retained as features in their own right; these processes are described in the Second Interim report (Fuller *et al.* 1999b). It is therefore clear that improvements are still possible. The fact that this result can be achieved using the unstructured topology of OS GB data means that such an approach will undoubtedly work with OSNI data. Use of OSNI data to seed and perhaps direct the segmentation will completely protect OSNI data interests, in that the outputs will be quantised at the scale of the pixels, that is, based on the 25 m raster. It would, however, be possible to use the classification data to populate the original vector dataset, should OSNI wish to do so.

OSNI vector data only cover Northern Ireland. Contacts in Eire may be able to supply linework for vector-based CLEVER-Mapping in catchments which cross the border. Otherwise, the need to map catchments in Eire will demand use of image segmentation procedures, based upon Sobel edge-detection; while this may not generate the same quality of outputs that are expected in Northern Ireland, the procedures will have been widely tested in GB and should generate adequate data for catchment modelling purposes.

A digital terrain model (DTM) will also be needed for analyses. It will be used to model and compensate for the topographic effects on illumination (eg N- and S-facing slopes). It may also contribute to post-classification, knowledge-based corrections (see Groom & Fuller, 1996). The OSNI terrain data have a similar format to those used in GB. It has therefore not been necessary to evaluate the OSNI data independently. It is understood that the DTM already covers the cross-border catchments.

DEVELOPMENTS IN METHODOLOGY RELEVANT TO NORTHERN IRELAND

The Interim Reports on Land Cover Map 2000 (Fuller *et al.* 1998c, 1999b) give details of developments in methodology. All such developments will apply in Northern Ireland. This section gives only a brief summary of these.

Image pre-processing

The early stages of LCM2000 have involved procedural developments. Some have been software refinements; many have required the development of macros to automate the processes of image analysis; others simply formalise and make objective the complete sequence of activities. Various improvements have made image pre-processing more complex, delaying the start of production mapping; however, the improvements will offer consequent time savings at post-classification correction stages.

Geo-registration of multi-sensor images and resampling algorithms for segmentation outputs have demanded an investment of time in methodological developments. Results will be applicable in Northern Ireland. There the projection will be based on the Irish National Grid but it is believed a conversion to British National Grid can be made if it is needed for integration. Other pre-processing facilities have included automated procedures to identify and mask out clouds and cloud-shadows (an ITE-coded macro). Otherwise, the original specification envisaged limited pre-processing. However, further improvements in the processing stream include atmospheric corrections (new ITE software) and terrain-induced illumination corrections (Cambridge University subcontract).

Laser-Scan has implemented a fully operational, Unix version of the prototype CLEVER-Mapping segmentation software, designed by Cambridge University colleagues. Segmentation consists of two separate stages: edge-detection to identify boundary features; and region growing from seed points. Experiments have examined: band selection for edge-detection and segmentation; the choice of edge-detector; threshold values to identify edges; thresholds to control the degree of segmentation; post-segmentation boundary rejection and polygon generalisation. After segmentation, raster-to-vector conversion draws boundaries between segments.

Broad Habitats

LCM2000 will map, as far as possible, widespread examples of Broad Habitats, as defined under the Biodiversity Action Plan. A list of target cover classes has been defined which generally match widespread Broad Habitats, only excluding small scale features, those which incorporate land use or contextual characteristics and marine types. The classification was reported in detail in the First Interim Report (Fuller *et al.* 1998c) with amendments agreed at a subsequent Consortium Meeting. Further Subclasses and Variants will allow relation to NLUSS and other classifications.

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. A *Key to Vegetation and Land Cover Types*, given in the *Field Handbook*, which identifies vegetation and contextual indicators was used by the LCM2000 reconnaissance team during the collection of ground reference data. The Consortium Meeting of 9 September 1998 raised what members saw as residual problems relating to sites with as little as 25% tree cover, heather- or grass-dominated bog and heath mosaics.

The currently planned classification appears in the Second Interim Report. Uncertainties remain regarding upland bogs, heaths and moors and the LCM2000 team have undertaken to meet in the field with the SNH peatland survey team, the CCW Phase I team and Northern Ireland Countryside Surveyors to clarify definitions and generate a consistent and applicable classification for remote sensing. Support has in principle been agreed to assist ITE reconnaissance visits within Northern Ireland and to ensure the closest possible match to user needs.

The Northern Ireland Consortium members have broadly agreed the LCM2000 classes. However, ITE will investigate a suggestion that the grassland classification should be extended to accommodate the wide variety and extent of grasslands in Northern Ireland. Abandoned / extant peat cuttings may be an additional classes. Any amendments to the classification will refine rather than radical altering plans: none will be allowed to cause inconsistencies in relation to earlier outputs. Clearly, any addition of thematic detail should not preclude the generation of generalised outputs compatible with products for GB.

It is important to remember that the final classification represents an aggregation of spectral subclasses tailored to match the target list: the subclass details will be permanently held in the GIS allowing alternative re-aggregations at any time.

Development of training and classification procedures

Field reconnaissance data, collected in 1998, have focussed on stock-images covering most of England and much of Wales. The data are being used to train the classifier, with field-mapped land parcels being identified on segmented images as training or validation polygons. Training for per-parcel analyses is objectively based on the segments, identified individually by pointing to them, without the need to painstakingly draw the outline. The process of training is probably 20-50 times quicker than per-pixel training, allowing a much larger sample and the definition of spare 'check' parcels for use in validation. A software refinement allows the review of training areas using display image 'chips' to show the quality of the remotely sensed data in each training area. The operator can compare training areas, define spectral subclasses, reject odd examples and flag training or validation polygons. The review facility saves much time in classification.

The object-oriented procedures of CLEVER-Mapping allow a classification of one scene to be 'rolled over' to an overlapping neighbour to extend labelling to polygons on the new image. The training data review procedure ensures that the training set matches standards which an operator would apply.

Classification requires that the training polygons are used to interrogate the image to derive statistical measures for reflectances in each chosen band and for each spectral subclass. CLEVER-Mapping uses a shrinking procedure, when extracting raster data for polygons, to avoid edge pixels and ensure the use of 'pure' core pixels of a cover type. The shrinkage is a dynamic process minimising edge effects while ensuring an adequate sample in smaller polygons.

The classification procedure applies a maximum likelihood algorithm to the polygon mean statistics to select the most likely class in statistical terms. CLEVER-Mapping in IGIS also

records the probabilities for all other subclass options. Per-pixel classifications record the natural heterogeneity associated with polygons.

Proposed validation methods

Validation has been designed as a two-stage process: first, using the check-polygons to validate the results derived from training polygons; second, using field survey data to validate and calibrate results (Fuller *et al.* 1998a). The former will assess how far extrapolation attaches the correct labels to areas of known cover. The latter will offer a method for 'translation' between detailed field classes and the more generalised target classes of LCM2000.

Production of LCM2000

Production has involved processing 5 scenes in parallel from initial atmospheric corrections through geo-registration, illumination correction, co-registration of summer-winter data and segmentation stages. Preliminary classifications will be produced in March 1999.

Initial classifications have shown that, in principle, the Broad Habitat classification can be achieved. Overall success will only become clearly apparent once finalised classifications result. Validation based on check polygons will provide an early and objective measure of success.

Quarterly Progress Reports, six-monthly Interim Reports and a Final Report will be delivered as originally planned, but encompassing the full production of LCM-UK. Five copies of completed reports will be submitted to the each Consortium member by the agreed dates. The survey findings, including those of the LCM-NI, will be published. The results and the Final Report will be presented at a Technical Seminar to be organised towards the end of the project. The CS2000 Web site and newsletter will include details on Northern Ireland. Digital data will be fully compatible with Arc/Info, Arc/View and Erdas, supported by technical documentation.

7. CONCLUSIONS

Imagery of Northern Ireland

1. While the choice of images is by no means ideal, the important news is that complete coverage is available within the 1998±1 year timespan. This ensures that the LCM-NI is already feasible. Late winter 1999 and summer 1999 will potentially add to these datasets. There is even the option of using winter 1999-00 coverage and perhaps even summer 2000 images. Paucity of image acquisitions need not prevent the production of LCM-NI.

CLEVER-Mapping in Northern Ireland

2. In Northern Ireland, where mapping will be based upon OSNI vector map data, trials have considered the suitability of OSNI linework for CLEVER-Mapping and the form of outputs which will protect OSNI's commercial data interests.
3. OSNI have supplied a 2.4 km x 3.2 km sample area of OSNI data imported using NTF Level-2 format. Some of the structured topology was lost in export-import. Further consultations with OSNI and Laser-Scan will investigate improvements.
4. Vector-generalisation would require a rebuild of the vector topology which might prove problematic.
5. Raster generalisation may be simpler. Vector-raster-vector conversion followed by labelling of image-pixels as edge pixels or a within-field pixels for subsequent CLEVER-Mapping looks possible; investigations continue.
6. A simpler and already demonstrable approach would use a raster-converted edge map to seed a segmentation. ITE is investigating ways of making the edge-map 'dominant', preventing the segmenter from crossing boundaries; early and successful results are reported. Mapping into Eire will use segmentation procedures based upon Sobel edge-detection.
7. The OSNI digital terrain model will be suitable for topographic-illumination corrections and knowledge-based corrections.

Procedural developments in GB applicable to Northern Ireland

8. Procedural developments have involved software refinements; macros have been developed to automate the processes of image analysis; other developments have formalised and made objective the sequence of processing activities.
9. Geo-registration and resampling algorithms have demanded methodological testing. Pre-processing facilities have included automated procedures to identify and mask out clouds and cloud-shadows. Improvements in the processing stream include newly operational atmospheric corrections and illumination corrections for terrain-induced effects.
10. The pre-processing improvements will produce time savings at post-classification stages.
11. The Unix version of CLEVER-Mapping segmentation is operational.
12. Bands have been examined and selected for edge-detection and segmentation; the Sobel edge-detector is to be used in GB and for catchments crossing into Eire.

Classification procedures and their application in Northern Ireland

13. In GB, field reconnaissance data have been used to train the classifier, with field-mapped land parcels objectively based on the segments. The process is probably 20-50 times quicker than per-pixel training. The same procedures will apply in Northern Ireland.
14. A review of training data, using display image 'chips', allows the operator to compare training areas, define spectral subclasses, reject odd examples and flag training or validation polygons.

15. The interrogation of the image to derive statistical measures for reflectances in each chosen band and for each spectral subclass uses a dynamic shrinking procedure on polygons to ensure the use of 'pure' core pixels of each cover type.
16. The classification procedure applies a maximum likelihood algorithm to the polygon mean statistics to select the most likely class in statistical terms. However, and uniquely, CLEVER-Mapping in IGIS also records the probabilities for all other subclass options. Per-pixel classifications will record the natural heterogeneity associated with polygons.
17. Validation has been designed as a two-stage process: first, using check-polygons to validate the results per-polygon; second, using field survey data to fully calibrate results, offering a 'translation' between detailed field classes and the generalised target classes of LCM2000.
18. Production has involved processing 5 scenes in parallel, from initial atmospheric corrections through geo-registration, illumination correction, co-registration of summer-winter data and segmentation stages. Preliminary classifications of each will be produced in March 1999. The procedures will all apply in Northern Ireland.
19. Initial classifications of widespread Broad Habitats have shown that, in principle, the Broad Habitat classification can be achieved. Overall success will only become clearly apparent once validation, based on check polygons, provides an early measure of success.

Production in Northern Ireland

20. Complete image coverage is available within the 1998±1 year timespan. This ensures that the LCM-NI is already feasible. There are still opportunities to collect better images, if required, over the next year or more.
21. Early results demonstrate that OSNI data can and should have an important role in CLEVER-Mapping of Northern Ireland. It remains to be seen whether this will be done through generation and use of the vector topology followed by vector generalisation. The experiments on vector-analysis will continue and results will be reported long before operational applications start.
22. Alternatively, the data might contribute through raster-generalisation and raster parcel-formation.
23. The OSNI data might simply be used to seed and perhaps control the image segmentation. Most likely, the OSNI data will be used directly to control the segmentation. This would provide the exact resolution needed for classification purposes while generalising the OSNI detail in a way which best protects OSNI data interests.
24. It remains uncertain whether the logistics and costs of using OSNI vector data in vector-form can be accommodated within the time / cost estimate. However, use as a raster input to direct segmentation is undoubtedly feasible, within the costings, and beneficial.
25. It is recommended that developments in use of the OSNI vector data continue through spring 1999; in early summer, field reconnaissance will take place in Northern Ireland; a decision on the best images should be made after summer 1999; processing (images permitting) will be scheduled for winter 1999-00.
26. Thus, the original timetable for LCM2000 will apply with the inclusion of Northern Ireland. However, more intense activity will be needed to ensure completion by November 2000.

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