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Countryside Survey 2000

Module 8: Airborne Scanner Applications

Classification of airborne CASI and LIDAR data of selected CS2000 sample squares

Final Report

CSCL/Final

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1. EXECUTIVE SUMMARY

- This project evaluates the use of airborne remote sensing data acquired by a Compact Airborne Spectrographic Imager (CASI) and an Airborne Laser Terrain Mapper (ALTM) in Countryside Survey 2000. The focus is on environmental monitoring at an extent and scale that is intermediate to the field and satellite surveys.
- The overall project aim was to assess how the airborne sensors may be used in conjunction with field survey and satellite sensors in future Countryside Surveys.
- Pairs of example survey squares were studied in each of the Arable, Pastural, Marginal and Upland Landscapes of Britain - as defined in Countryside Survey 1990. Each pair was divided into a trial and a check square, to allow the development, refinement, and validation of methods and their subsequent ‘blind’ testing.
- Analysis focussed on 1 km squares using airborne digital data acquired during summer 1999. These data posed two sets of limitations. First, the independent acquisition of the CASI and ALTM data meant that integration was not an automated process. Second, the affects of atmospheric attenuation, and differences in viewing geometry and solar illumination angle restricted the transfer of spectral training data across and between sites.
- A data processing flow-line was developed for the four trial squares. For the ALTM data, pre-processing involved creating a Digital Surface Model from the point-sample elevation data, and subsequently separating the terrain and vegetation canopy height information. For the CASI data, pre-processing involved: image normalisation, geometric correction, flight-line mosaicking, and spectral segmentation. The integrated CASI and ALTM data were then used for per-parcel classification and knowledge-based correction.
- The final product of classification was a vector data-base in which each parcel contained information on land-cover, canopy relative height and terrain context.
- Many of the data processing methods developed for the trial squares were semi or fully automated and were thus directly transferable to the check squares. These can broadly be considered as operational.
- Because the classification of trial squares was restricted to 1 x 1 km areas, spectral training data were identified for an insufficient number of land-cover types to represent those present in the check squares. It was therefore not possible to assess fully the ‘blind’ classification of check squares using only the spectral training data from the trial squares.
- Mapping CS squares by the ‘blind’ classification of airborne remotely sensed data would need libraries of spectral signatures for land-cover types to be developed. This could only become operational if more complex methods of image spectral normalisation than used in this project were developed. This may be addressed in future Research and Development by the EA and NERC airborne remote sensing facilities.
- The data processing flow-line for trial squares was shown to be applicable for the classification of a 3 x 3 km site, setting the core CS square into a wider landscape setting.
- The product of airborne data classification was not directly comparable with field survey or Land Cover Map 2000. Each survey approach differed in: spatial detail; extent of coverage; landscape features and land-cover types mapped; variables recorded; and cost.
- For the farmed Landscape types (Arable, Pastural, Marginal) correspondence of the classified airborne data with edited field survey data (at Broad Habitat level) was 80-89% for the trial squares and 69-80% for the check squares.
- Non-correspondence related to: differences in the reported size and boundary location of land-cover parcels; mis-registration between the two data-sets; a greater subdivision of landscape parcels in the airborne data; distinctions between land-cover mapped from the airborne images and land-use mapped in the field survey; and errors in airborne data classification and in the field survey.

- For the two Upland squares correspondence between classified airborne data and field survey was 69-72%. The discrepancies related to registration and classification errors, and to the classification of a finer spatial mosaic of habitats in the airborne data than the field survey parcel boundaries portrayed.
- Classification of land-cover in the Arable trial square using 1998 and 1999 CASI data demonstrated the repeatability of Broad Habitat mapping from airborne digital data, with an 89% correspondence.
- The correspondence between the classified airborne data and LCM2000 varied between 23% and 74%. Although the process of classifying the airborne digital data largely followed the methods developed for LCM2000, differences between the two data products exist (e.g. in the dates and spatial resolution of the imagery, in the use of generalised soil sensitivity and drift maps for LCM2000).
- Neither LCM2000 nor the classified airborne data represent the absolute ground truth; both contain errors in land-cover identification, and these had a direct influence on the correspondence statistics.
- The cost of using airborne digital data to supply land-cover information for individual 1 km CS squares is prohibitive compared with field survey. This is because the spatial dispersion of CS squares is too great for the operational logistics of airborne data acquisition to be cost-effective for 1 km squares.
- A greater economy of scale exists for airborne survey compared with field survey when acquiring data for CS squares in their wider landscape context. The restrictions imposed by the operational logistics of airborne survey, which prohibit the cost-effective data capture for 1 km squares, are significantly reduced for 3 x 3 km squares and removed for 5 x 5 km squares.
- Airborne data thus offers the potential for mapping land-cover and landscape 3-dimensional structure (at a spatial resolution of 3 m or better), placing the core CS square into a wider landscape context.
- Single-date airborne data cannot, however, supply information on land-use, species composition, woodland type or age. Airborne survey could not easily give national coverage (either census or sample) in a single target year.
- If the emphasis of future Countryside Surveys remains on data acquisition in a single year, then the recommended use of integrated airborne data is to provide landscape-scale information for a sub-sample of key target sites. If a higher proportion of CS squares are to be surveyed in high spatial detail by remote sensing, high resolution satellite data may represent an alternative to airborne digital data.
- National coverage of CS squares in their wider landscape context could be achieved by integrated airborne and field survey on an annual rolling basis.

2. INTRODUCTION

This project evaluates the use of airborne scanner applications in the context of Countryside Survey 2000 (CS2000). In CS1990, information was collected at two spatial scales: (i) a field survey, conducted in 1990, provided detailed information on 508 1 km sample squares; and (ii) the Land Cover Map of Great Britain provided a national satellite census, but at a much coarser spatial resolution and with data collected over several years (mostly 1988-89). Airborne scanners, such as the Compact Airborne Spectrographic Imager (CASI) and the Airborne Laser Terrain Mapper (ALTM) (which operates on a principle of LIght Detection And Ranging - LIDAR) have considerable potential for environmental monitoring at an intermediate extent and scale of survey (see Appendix I). The technique may help improve the quality, utility and cost-effectiveness of future Countryside Surveys.

This is the Final Report, drawing together methodological developments and results presented in the five Interim Reports (Fuller *et al.* 1998, Hill *et al.* 1998, 1999, 2000a, 2000b) and giving a project overview and conclusions. The issues covered will include:

- methods and information derived;
- integration with field survey data and satellite data;
- efficiency and effectiveness of the analytical procedures, including differences in relative costs and quality of information collected by airborne scanners compared with other sources of information;
- the extent to which airborne digital data can be used to monitor landscape change within and around CS2000 sample squares;
- the feasibility of using such data in future Countryside Surveys.

This project was funded by the Department of the Environment, Transport and the Regions (DETR), the Natural Environmental Research Council (NERC), and the Environment Agency (EA).

3. OBJECTIVES

The focus of this work has been on identifying the extent and spatial patterns of linear and aerial landscape features defined by land-cover (more particularly widespread Broad Habitats) in sample CS squares using airborne remote sensing data. Pairs of example survey squares were studied in each of the Arable, Pastural, Marginal and Upland Landscapes of Britain - as defined in Countryside Survey 1990 (Barr *et al.* 1993). The criteria used for field site selection are outlined in Appendix II. Each pair of survey squares has been divided into a *trial* and a *check* square, to allow the development, refinement, and validation of methods and their subsequent ‘blind testing’. Analysis focussed on 1 km squares using integrated multi-spectral CASI and LIDAR ALTM data acquired in summer 1999 (Figures 1-2, see also Appendix III).

The overall aim was to assess how the airborne sensors may be used in conjunction with field survey and satellite sensors in future Countryside Surveys. The objectives (revised in January 2000) for the four 1 km x 1 km trial squares were to:

- evaluate the use of airborne remotely sensed data to measure the extent and identify the spatial patterns of land-cover, linear landscape features and widespread habitats;

- derive accurate height information, using LIDAR, which would allow definition of slope, run-off patterns, identification and measurement of individual trees, hedgerows and ditches and help in the textural identification of areas of semi-natural vegetation;
- compare the airborne imagery with the satellite data and resulting products, to assess the value that the higher spatial resolution can contribute to synoptic surveys of the countryside;
- evaluate the accuracy of methods and above products in the survey of independent examples of squares (for which ground reference data are unseen).

Additional objectives for one site only were to:

- Assess the repeatability of the methods developed and the feasibility of detecting landscape change using airborne digital data from consecutive years.
- Assess the extent to which airborne digital data be used to supplement the CS2000 field survey for the landscapes surrounding the example squares so that patterns observed within the squares can be placed in their wider landscape context.

4. OVERVIEW

The airborne digital data used in this project were acquired and supplied by the Environment Agency in 1999. The first stage in the image processing flow-line involved pre-processing the CASI and ALTM data to achieve integration. Each of the trial squares were then divided into land parcels by the spectral segmentation of CASI data. This enabled parcel-based classification and knowledge-based correction procedures to be carried out. In the resultant vector GIS, the land parcels contained information on land-cover and 3-dimensional data relating to form and terrain context.

The transferability of image processing methods developed using the trial squares was then tested on the check squares. In addition, for one trial site, the image processing methods were tested for mapping land-cover in a 1 x 1 km and 3 x 3 km area in 1998 CASI data.

Comparisons of land-cover mapped by field, airborne and satellite survey were made for the eight sample CS squares. Direct comparison was, however, complicated by issues of the date, spatial resolution, methods and cost of land-cover data generation.

This report ends with discussions on the issues highlighted by this Research and Development project, and makes recommendations for applications of airborne digital data in future Countryside Surveys. Further details on the field sites, data, methods and results of this project can be found in the Appendices.

5. METHODS DEVELOPED FOR AIRBORNE DATA PROCESSING

The development of a processing flow-line for operational image analysis constituted a major part of this project. Methods development (explained fully in Appendix IV) focussed on the four trial squares. The image analysis flow-line involved the following procedures:

ALTM data pre-processing:
(a) create a Digital Surface Model (DSM) from the ‘first pulse’ ALTM point sample data;

(b) create a Digital 'Terrain' Model (DTM) by the removal of surface height features such as buildings, trees, etc, and interpolation across the resultant data gaps;
(c) derive relative height data for the more prominent surface features by subtracting the DTM from the DSM elevation values;
(d) clean the height data by manual editing to remove residual errors.

CASI image pre-processing:

(a) image normalisation (based on averaging) to reduce atmospheric and view angle effects across and between flight-lines;
(b) geometric correction by the registration of individual CASI flight-lines to the corresponding DSM;
(c) mosaic and trim adjacent registered flight-lines to create 1 km square data-sets;
(d) segment images by a process of edge-detection and region-growing.

Image classification:

(a) create a vector data-base of the land-cover parcels derived by image segmentation;
(b) train the classification on known examples of individual land-cover types;
(c) organise the training data into spectral sub-classes;
(d) classify each vector land parcel, based on mean spectral statistics from a shrunken area in all 12 CASI wavebands.

Knowledge-Based Corrections (KBC):

(a) operate on a per-parcel basis using rules based on context, height, class probabilities, and road and railway information (from CS 1990 reporting codes);
(b) operate on a per-pixel basis (after vector-to-raster conversion) using only height and road/railway information;
(c) repeat the per-parcel rules after raster-to-vector conversion (i.e. with the original parcels amalgamated where contiguous and of the same land-cover type).

6. DATA PRODUCTS GENERATED FROM AIRBORNE DATA PROCESSING

The ALTM data processing flow-line produced terrain variables such as elevation, slope and aspect, and the height of trees, hedgerows and buildings relative to surrounding grass or crop canopies (Figure 3). In spite of detailed ground-based height measurements of trees and a 150m section of hedgerow, quantitative comments on the precision of height estimation by ALTM data processing are not simple. In places, the ALTM and ground-based estimates of tree or hedgerow height correspond within 0.05m (which is within the instrument operating specifications). However, the ALTM data can under-estimate feature heights and even fail to identify sections of hedgerow. This occurred because the ALTM data provide point-sample information, and this will not necessarily relate to the highest point of a tree or be guaranteed to hit continuously along the line of a hedgerow. It should be remembered that the Digital Surface Models generated from the ALTM data were interpolated at 1 m spatial resolution from points that fell up to 4 m apart.

The CASI processing flow-line generated geo-registered images of the 1 km CS2000 squares, which were subsequently divided into land-cover parcels according to spectral variations. Whilst these parcels had meaning in terms of subtle changes in the nature or condition of land-cover, landscape features such as fields or hedgerows were identified as being sub-divided into several parcels.

The processes of image classification and knowledge-based correction identified land-cover at a level of spectral sub-classes, which were amalgamated to give the widespread Broad Habitats. For example, individual crops were identified for each Arable square (typically with numerous spectral sub-variants) and these were later merged to give BH 4 (Arable and horticulture). It should be noted, that the classification gave land-cover rather than land-use, and that the Broad Habitats were rendered as closely as possible by the process of land-cover class amalgamation. In the final classification product each land-cover parcel contained 3-dimensional data relating to form and terrain context (Figure 4). This database therefore supplies landscape-scale information not just on 2-dimensional spatial pattern and connectivity, but also on how this relates to underlying terrain and creates its own unique surface 3-dimensional character.

7. TRANSFERABILITY OF AIRBORNE DATA PROCESSING METHODS

7.1 Application of methods to the check squares

Having established a data processing flow-line using the trial squares, the test of its operational capabilities was in its application to the check squares. Of interest was the wider applicability of the techniques in general and of the selected variables, such as segmentation thresholds, classification training data, and KBC rules. The applicability of individual processing stages is shown in Table 1, and discussed in Appendix V.

	Manual Process	Automated Process	Operational for repeat application
ALTM data pre-processing:			
Create a Digital Surface Model*	-	✔	✔
Remove surface height features	-	✔	✔
Interpolate across terrain gaps	-	✔	✔
Derive relative height data	-	✔	✔
Clean the height data	✔	-	na
CASI image pre-processing:			
Image normalisation	-	?	na
Geometric correction	✔	-	na
Mosaic registered flight-lines	✔	-	✔
Segment images	-	✔	✔
Image classification:			
Raster-to-vector conversion	-	✔	✔
Train the classification	✔	-	✔
Roll over existing training data	-	✔	**?**
Sort training data into spectral sub-classes	✔	-	✔
Classify each vector land parcel	-	✔	✔
Knowledge-Based Corrections:			
Train the per-parcel KBC	✔	-	✔
Apply / transfer per-parcel KBC	-	✔	✔
Apply per-pixel KBC	-	✔	

Table 1 – Applicability of data processing methods to the check squares and for repeat surveys

* This can be supplied as a standard product by the EA.

Procedures for image spectral normalisation are being investigated by the EA. If implemented, this would help facilitate the roll over of training data.

Many of the methods developed for the trial squares were semi or fully automated and were thus directly transferable to the check squares. These can broadly be considered as operational. The current EA airborne data acquisition system and planned future developments should minimise the manual processes required to clean the ALTM height data, and register and mosaic the CASI imagery. Software developments for LCM2000 have rendered the manual processes of per-parcel training and identifying spectral classes extremely efficient. The restricted size of this trial meant that there was insufficient variation in land-cover types to perform and assess truly ‘blind tests’ of image classification. In addition, more complex methods of spectral normalisation would be needed for developing libraries of spectral signatures that could potentially allow the ‘blind’ mapping of Countryside Survey squares by airborne data classification. Under such circumstances, the KBC rules applied after classification would need to be much more generic (and thus automated) than those applied in this trial.

7.2 Application of methods to 1998 CASI data

Due to the time constraints imposed on the project by the earlier data quality issues, many of the additional topics for study were examined only for the Arable trial square. This site was selected by virtue of having the highest quality 1998 CASI data. The 1998 ALTM data failed quality checks and so analyses were performed using 1999 ALTM data. Classifications were performed for the core CS square and for a 3 x 3 km area, using the methods outlined in section 4.1 and treating the site as a trial square (i.e. developing independent training data and KBC rules). For the 3 x 3 km classification, however, only a per-parcel KBC procedure was performed, which involved limited shadow removal.

No problems were encountered in applying the data processing methods to the 1 km CS square. For the 3 x 3 km area data pre-processing represented as much effort as for all nine previous 1 km squares together. Developing the image classification and KBC rules, were however much quicker tasks, although both represented a more substantial effort than for a single 1 km square. Additional training was required to extend the classification from the central square as not all land-cover types, or their spectral variants, were present in the core CS square. In total 12 crop types were identified, along with improved and neutral grassland, bare ground, built surface, water bodies, and woody vegetation. Time constraints precluded converting parcels labelled as shaded into the most likely underlying vegetation type.

8. COMPARISON OF CLASSIFIED AIRBORNE DATA WITH FIELD SURVEY

A number of issues were concerned in the comparison between the classified airborne data and the field survey data (see Appendix VI). The most significant issue was rendering the two digital data sets on land-cover more relevantly comparable. The correspondence analysis was performed by per-pixel comparison of land-cover at the Broad Habitat level, after both vector data sets were converted to raster grids with a 1 m spatial resolution.

8.1 Arable, Pastural and Marginal trial squares

Correspondence between the field survey data and the classified airborne images at the Broad Habitat level was high for the Arable, Pastural, and Marginal trial squares (Table 2, Figure 5). The correspondence level increased notably with KBC; from 82% to 89%, for the Arable square, 76% to 87% for the Pastural square, and from 64% to 81% for the Marginal square. The remaining differences in land-cover classification between the field survey data and the classified airborne data can be accounted for by:

- residual mis-registration between the two data-sets:

- real differences in the reported size and boundary location of land-cover parcels;
- differences in detail resulting from the greater subdivision of landscape parcels in the airborne data;
- distinctions between land-cover mapped from the airborne images and land-use mapped in the field survey (particularly in ‘urban’ areas);
- classification error not corrected in the KBC procedure (e.g. roadside hedgerows can be mapped poorly due to shadow problems);
- the field survey has been shown to have a repeatability level of 88% in identifying primary land-cover codes (Prosser and Wallace 1999), which are used objectively to derive most of the widespread Broad Habitats.

The influence of parcel boundaries affecting correspondence is underlined by the land-cover area estimates for these three trial squares (see Appendix VII). The estimates of percentage cover for all Broad Habitat types across the Arable, Pastural and Marginal trial squares differ by less than 5 percentage points between the classified airborne data and the field survey data.

Landscape type	Square type	No KBC	Full KBC
Arable	Trial	82.1%	89.0%
Arable	Check	60.1%	77.4%
Pastural	Trial	76.2%	86.7%
Pastural	Check	53.8%	80.1%
Marginal	Trial	64.1%	80.9%
Marginal	Check	54.2%	68.7%
Upland	Trial	72.0%	-
Upland	Check	69.1%	-

Table 2. Correspondence between classified airborne data and field survey data.

8.2 Arable, Pastural and Marginal check squares

The classification of the Arable, Pastural and Marginal check squares was notably worse than the trial squares (Figure 6). This was not surprising, given the simplistic nature of the normalisation procedure applied to the check squares and the use of ‘rolled over’ training data. For the Arable, Pastural and Marginal sites the correspondence between the classified airborne imagery (before KBC) and the field survey data was an average of 18 percentage points lower for the check squares than for the trial squares. The need for post-classification KBC was therefore greater for the check squares, and indeed gave a more significant increase in correspondence between the classified airborne imagery and the field survey data (Table 2). Thus, for the Arable check square correspondence rose from 60% to 77%, for the Pastural check square from 54% to 80%, and for the Marginal check square from 54% to 69%. However, the correspondence with field survey data for the check squares remained lower than for the trial squares by an average of 10 percentage points. This extra level of non-correspondence was related mostly to land-cover mis-classification: e.g. confusion between improved grassland and young crops (such as rape or lucerne); improved *versus* neutral grassland; arable harvested and hay fields; deciduous and coniferous woodland; arable bare and built surfaces. This was also borne out in the comparison of land-cover area estimates from the classified airborne data and field survey data. Unlike the trial squares, the check squares were notable for under-estimates of the coverage of BH 5 (Improved grassland), and over-estimates of BH 1 (Broadleaved, mixed and yew woodland), BH 4 (Arable and horticulture), and BH 6 (Neutral grassland). In the case of the Marginal check square, the estimated coverage of BH 5 in the classified airborne data was lower than that of the field survey data by 22 percentage points.

8.3 Upland squares

Classification of the two Upland sites was performed independently (i.e. without rolling over training data), and no KBC rules were applied. Correspondence statistics in the Upland trial square were complicated by the complex mosaic of semi-natural vegetation types (Figure 7). One-third of the field survey data for this site was labelled as mosaic at the Broad Habitat level. Excluding these areas from the correspondence measures gave a value of 68%. Treating a parcel as correct if assigned to one of the Broad Habitat classes constituting a mosaic gave a correspondence of 72%. The level of correspondence with the field survey Broad Habitat data was very similar for the trial and check squares (72% and 69% respectively). The discrepancies in Upland land-cover classification relate, in part, to image mis-registration and mis-classification, but also to the classification of a finer spatial mosaic of habitats than the field survey parcel boundaries portray. It should be remembered that the field survey trials in 1997 showed that ground-survey could not repeatably record boundaries in the heterogeneous and continuously variable vegetation of semi-natural uplands and it was agreed to adopt 1990 boundaries (themselves subject to the same errors) unless changes were clearly evident. It was felt that proportional cover was determined reasonably accurately, but not the exact distributions. To characterise the complexity of vegetation mosaics the field surveyors placed emphasis on recording plant quadrats. Indeed, the estimated proportional cover of the Upland check square derived from the classified airborne data and the field survey tally within 5 percentage points for all the Broad Habitat types present (Appendix VII). Thus it seems likely that the differences between field and airborne surveys in the Upland Landscape may relate largely to the problem of boundary location and that the airborne survey might be the better record of spatial patterns. However, it should be borne in mind that whilst the airborne data can supply detailed spatial information on land-cover, it is not always straight-forward to assign this to a widespread Broad Habitat. An example is heather, which can easily be identified as a land-cover based on spectral characteristics, but can be assigned to either BH 10 (Dwarf shrub heath) or BH 12 (Bog) depending on the under-lying soil conditions. The presence of surface water can detectably influence the spectral response of heather, but soil saturation is probably better assessed on the ground and can be variable temporally.

8.4 Identification of linear features

Linear features present in the British landscape include roads, railways, hedgerows, ditches, canals, and rivers. In the field survey, these features were classified into several different Broad Habitats. For example, roads, railways and hedgerows constituted BH 3 (Boundary and linear features); ditches and canals contributed to BH 13 (Standing open water and canals); rivers were classified in BH 14 (Rivers and streams).

Linear features were only identifiable in the airborne digital data if they were viewed unobstructed from above (i.e. were exposed to the airborne sensor), were not shaded by neighbouring features or relief, and were above the sensor spatial resolution (in this case *ca* 3 m). Drainage ditches in the CS squares were not identified in the land-cover classification derived from airborne data. This was because of their narrow width and the processing method used to separate ‘terrain’ and vegetation canopy height in the ALTM data. Roads bounded on both sides by hedgerows were often obscured by over-hanging trees and by shadow, and so were difficult to identify as single linear features. Rivers also often appeared to be divided into sections by over-hanging trees. Hedgerows separating arable or pastural fields were identified much more readily. However, mis-alignment resulting from the manual process of CASI and ALTM co-registration created problems during KBC as any land parcel classified as woodland or hedgerow was only considered correct if the canopy had a height above the surrounding grass or crop vegetation cover.

In general, it was easier to see linear features in the airborne data (and thus identify by visual image interpretation) than to map them by semi-automated procedures. Broad Habitats 13 and 14 were both inland water classes, and these were impossible to separate from each other based on spectral characteristics. Conversely, BH 3 was composed of several land-cover types, but roads and railways showed spectral similarity with other built surfaces in BH 17 (Built up areas and gardens) and hedgerows had spectral overlap with the woodland vegetation of BH 1 (Broadleaved, mixed and yew) and BH 2 (Coniferous). However, an additional KBC procedure (developed as a demonstration for one CS square only) used width and context to identify the linear features of BH 3 (see Appendix VI, section 4.3). The presence or absence of trees in hedgerows was also identified (Figure 8).

9. CLASSIFICATION RESULTS FOR THE 1998 CASI DATA

9.1 Comparison of 1 km classifications in 1998 and 1999 data

For the 1998 CASI data of the 1 km Arable trial square, classification and correspondence with the 1998 field survey data were performed using the methods developed for the 1999 classifications. The robustness of the image classification procedure and the repeatability of Broad Habitat mapping from airborne digital data is highlighted by the correspondence with field survey of 86% and 89% respectively for the 1998 and 1999 CASI classifications of the Arable trial square (Figure 9).

The correspondence between the 1998 and 1999 classifications at the Broad Habitat level was 89%; about the same as the repeatability level of the field survey. Of the 11% apparent land-cover difference between 1998 and 1999, approximately one-third was genuine with the conversion of a grass field to arable (wheat). The remainder was spread throughout the CS square and related to slight registration differences and classification errors. The percentage cover statistics for the six Broad Habitat types present are within 2 percent of each other for the 1998 and 1999 data (accounting for known land-cover changes) (Table 3). The mapping of Broad Habitats by the semi-automated classification of airborne digital data can thus be achieved with a high level of precision, spatial detail and repeatability. However, as a tool for mapping landscape change, small-scale differences between sample years may easily be lost in the margin of error.

Broad Habitat type	**1998 CASI classification**	**1999 CASI classification**
Broadleaved, mixed and yew woodland	24.1%	22.2%
Arable and horticulture	56.6%	60.3%
Improved grassland	15.8%	13.7%
Neutral grassland	1.6%	0.7%
Water (inland)	0.0%	0.0%
Built up areas and gardens	1.9%	3.0%

Table 3. Comparison of land-cover statistics for the Arable trial square classified with 1998 and 1999 CASI data.

9.2 Comparison of 1 km and 3x3 km classifications

Without detailed independent field data for comparison, it is difficult to comment on the quality of image classification for the 3x3 km area, although this appears to be consistent throughout (Figure 10) and a comparison of land-cover statistics is possible (Table 4). Interestingly, the less common land-covers (e.g. neutral grassland, built surface) show a consistent proportional cover between the central square and its surrounding landscape. However, a notable increase in the proportional coverage of improved grassland is evident at the wider landscape level, and this is at the expense of woody vegetation and arable crops.

Land-cover type	1x1 km	3x3 km
Woody vegetation	24.1%	17.1%
Arable crops	56.6%	51.8%
Improved grassland	15.8%	26.1%
Neutral grassland	1.6%	1.8%
Built surface	1.9%	3.3%
Water bodies	0.0%	0.0%

Table 4. Land-cover comparison between a CS square and its surrounding landscape.

10. COMPARISON OF THE CLASSIFIED AIRBORNE DATA WITH LCM2000

Correspondence between the classified airborne data and LCM2000 was calculated per-pixel, at a 25 m spatial resolution (after re-sampling the airborne data), at the Broad Habitat level. Shifts in the geographical placement of the CS squares in LCM2000 of up to 2 pixels were made, where necessary, to achieve a better overlay of the two data sets.

The level of correspondence between the classified airborne data and LCM2000 varied between 23% and 74% (Table 5). The most notable differences in land-cover classification occurred between BH 5 (Improved grassland) and both BH 4 (Arable and horticulture) and BH 6 (Neutral grassland) in the farmed Landscapes (Figures 11-12). In addition, LCM2000 sometimes over-estimated the area under BH 1 (Deciduous, mixed and yew woodland). The most consistent correspondence occurred in the Upland squares. However, the use of generalised drift and soil sensitivity maps for KBC in LCM2000 caused the designation of large areas as BH 12 (Bog), whereas the classified airborne data suggest a wider range of land-cover types. In all of the CS squares, land-cover below the minimum mappable unit of LCM2000 was not identified.

The comparisons of classified airborne data with LCM2000 show both good and bad features of the national product. To understand the results, however, they need to be placed in context. Neither LCM2000 nor the classified airborne data represent the absolute ground truth; both contain errors in land-cover identification. These will have a direct influence on the correspondence statistics:

- LCM2000 achieves 90% accuracy in the labelling of its parcels at target class level (scores for Broad Habitats are about 4% less);
- the airborne data probably generates Broad Habitat labels with 85-90% success in trial squares and 75-85% in check squares.

Thus, per-parcel correspondence at the Broad Habitat level is likely to be in the range 65-77%. In addition, per-pixel correspondence has been shown to be about 10% lower (Fuller *et al*. 2001). Values in the sixty-percent-plus range are probably acceptable therefore.

Landscape type	Square type	Correspondence
Arable	Trial	63.3%
Arable	Check	54.2%
Pastural	Trial	34.0%
Pastural	Check	66.9%
Marginal	Trial	22.9%
Marginal	Check	49.6%
Upland	Trial	68.8%
Upland	Check	73.5%

Table 5. Correspondence between classified airborne data and LCM2000.

The results do not represent LCM2000 validation statistics, as these will be calculated for all 569 CS2000 squares using the field survey BH data. Although the process of classifying the airborne digital data largely followed the methods developed for LCM2000, differences between the two data products exist and they are not directly comparable. The minimum mappable unit in LCM2000 is 0.5 ha, which would be covered by *ca* 24 x 24 pixels in the airborne data (at the original 3 m spatial resolution). The comparisons between classified airborne data and LCM2000 must consider:

- differences in the dates of imagery (see Table 6);
- effects of image spatial resolution (nominal pixel size of 3 m *versus* 25 m);
- intentional generalisation of satellite segments (with 0.5 ha minimum mappable units);
- spectral confusions, especially of related types (e.g. between grasslands);
- generalisation of external data used in KBC (e.g. drift maps used to distinguish bogs from heaths).

Although obvious differences occur between the classified airborne data and LCM2000 the persistence of the landscape structure is apparent in all but the Upland sites (Figures 11-12). Many of the structural differences can be related to the sampling issues of 3 m and 25 m rasters, and the generalisation which occurs when producing a land parcel data-set with a minimum mappable unit of 0.5 ha. The generalisation of fine-scale detail is particularly apparent in the Upland trial site where LCM2000 virtually provides a single class. Thematic differences are strongly influenced by the timing of image acquisitions. The summer images for the LCM2000 results were acquired for all but one of the CS squares in early May 1998. With this image date arable / grassland confusion is not unlikely as cereal crops and grass swards will have similar spectral signatures and canopy structures. Furthermore, with winter dates of 1996 and 1997 it is hardly surprising that LCM2000 incorporates inter-changes between rotation grass and arable.

Landscape type	Square type	CASI date	LCM image dates	
			Summer	Winter
Arable	Trial	25/06/99	19/05/98	21/11/96
Arable	Check	25/06/99	19/05/98	21/11/96
Pastural	Trial	25/06/99	19/05/98	21/11/96
Pastural	Check	25/06/99	19/05/98	21/11/96
Marginal	Trial	26/07/99	19/05/98	21/09/97
Marginal	Check	26/07/99	01/08/99	01/12/97
Upland	Trial	26/07/99	19/05/98	21/09/97
Upland	Check	26/07/99	19/05/98	21/09/97

Table 6. Image dates for airborne data classification and LCM2000

11. DISCUSSION

This project has involved a strong element of research and development, and has posed a unique set of challenges. The most significant challenge has undoubtedly been attempting to make operational use of airborne remotely sensed data before image acquisition systems were supplying integrated or fully pre-processed data. The consequence of this has been that a disproportionate percentage of the project time and money has been spent on image acquisition and data pre-processing. The manual integration of the multi-spectral CASI and LIDAR ALTM data clearly influenced the quality of the results acquired for the 8 CS squares examined in this study. However, the focus of this discussion is not on the results for the 8 test sites, but on the broader implications for Countryside Survey.

11.1 Data acquisition and integration

The integration of ALTM elevation data with CASI reflected radiance imagery literally adds an extra dimension to the study of landscapes with airborne imaging (Figure 13). This brings the possibility of modelling the 3-dimensional characteristics of vegetation and understanding the terrain context of landscape features. However, the nature of the image acquisition systems at the time of data supply resulted in airborne data that posed two sets of limitations for the issues discussed in this project. Firstly, the independent acquisition of the CASI and ALTM data meant that integration was not an automated process. Secondly, the affects of atmospheric attenuation, viewing geometry and solar illumination angle need to be corrected if spectral training data are to be transferable across and between sites. This project has highlighted the requirements for integrated CASI and ALTM data in operational applications, such as Countryside Survey. Recent developments by the EA have incorporated the simultaneous acquisition of CASI and dual-pulse ALTM data and an integrated processing system. The EA are currently generating geo-registered CASI and ALTM data, thus reducing the lengthy process of manual CASI image registration. Studying CS squares in a wider landscape setting then becomes a more realistic proposition. With dual-pulse ALTM data, deriving a Digital Terrain Model and vegetation canopy height becomes an easier and more accurate process. In addition to EA image acquisition system, the NERC Airborne Remote Sensing Facility is developing a CASI pre-processing system (for completion by March 2002) that will involve geometric and radiometric correction (removing geometric distortions and compensating for illumination conditions, viewing geometry and atmospheric attenuation). This would enable the immediate integration of CASI imagery with ALTM data and remove problems of spectral normalisation across flight-lines and study sites. The transfer of spectral training data between CS squares (possibly developing libraries of spectral signatures) could then become part of an operational process.

11.2 Development of airborne data processing methods

Multi-spectral CASI and LIDAR ALTM data have potential for supplying landscape information with integrated operational data supply. Even with the restrictions of data supplied in this project, many of the methods of data pre-processing and analysis developed for the 4 trial squares were shown to be directly transferable to the check squares. Operational methods have been developed to render a Digital Surface Model from the point sample ALTM first pulse data, and to separate out the terrain from the vegetation canopy and building height. The methods developed for CASI pre-processing are also operational, particularly the segmentation procedure for deriving land-cover parcels that are used in classification. By performing the classification per-parcel, and by employing the operational procedures developed in the production of LCM2000, the process of selecting and reviewing training data to classify a 1 km square can be completed in a matter of hours. Better classification results were shown for the trial squares (which provided training data) than for the check squares (which ‘rolled over’ training data from the trial squares). The KBC rules developed for the trial squares were shown to be generic enough to transfer to the check squares and bring about considerable improvement in classification output. The KBC rules utilised context, canopy/building height, and CS1990 reporting codes on roads and railways. Although not used in this work, it could be possible to use all the digital data from previous Countryside Surveys to steer the classification output.

11.3 Classification products

The result of classification for the eight CS squares was a vector product in which the parcels related to land-cover and contained 3-dimensional data on elevation and vegetation / building height. Additional processing (for one trial site) created parcels that related mostly to landscape features, such as hedgerows, fields or woodland (see Appendix IV). It should be noted that the classified airborne digital data gives land-cover information, from which the widespread Broad Habitats have to be inferred. By using only single date imagery it is not possible to separate BH 1 (Broadleaved, mixed and yew woodland) from BH 2 (Coniferous woodland) as these have overlapping spectral ranges. Broad Habitats 3 and 17 (Boundary and linear features, Built up areas and gardens) are both amalgamations of several land-cover types, which tend to be identified as individual classes in the airborne data. Conversely, Broad Habitats 13 and 14 (Standing open water and canals, Rivers and streams) can only be identified as water bodies from the airborne data. The spectral distinction between the four grassland Broad Habitat types (BH 5-8) may not always be clear enough to enable their correct classification in airborne digital data, whilst heather cover types can belong to either BH 10 (Dwarf shrub heath) or BH 12 (Bog).

11.4 Visual image analysis

This project has made use of semi-automated methods of image classification. However, in the farmland Landscape types visual interpretation of the airborne imagery may be sufficient to provide the landscape information required. For example, semi-automated classification sometimes gave poor results for roadside hedgerows because of shadowing. By a visual inspection of the imagery it would be possible to identify (and digitise) all linear woody features. Labels could then be attached to the linework supplying each individual feature with a code depending on average height, the presence of trees or gaps, and whether it represents a complete or fragmented feature. It would also be possible to give a habitat quality score based on the above features and the level of connectivity with other hedgerow or woodland parcels.

These kinds of decision can be made easily by a trained image interpreter, but are extremely difficult to replicate by semi-automated procedures. Similarly, it would be easy to identify and digitise fields of arable crops or improved grassland and to supply each with a label on land-cover, the presence of a prominent field margin, scattered trees, a pond, etc. It would also be significantly easier to digitise the boundaries of an urban area and supply a label of BH 17 (Built up area and gardens).

11.5 Comparison of land-cover classification from airborne data and field survey

Airborne digital data can supply useful landscape information for Countryside Survey, whether acquired by semi-automated or manual image interpretation techniques. In comparing the products generated by field survey and by the classification of airborne digital data it is clear that the two approaches offer something different. Airborne imagery provides complete and simultaneous coverage of an entire CS square. Furthermore, the potential exists to survey the surrounding countryside giving a landscape context, and allowing a more meaningful assessment of feature connectivity within the core square since many landscape features extend beyond the 1 km square boundaries. The level of spatial detail present within the airborne imagery is greater than field surveyors could reasonably be expected to map, and this is of particular significance in the continuously variable vegetation of semi-natural Upland Landscapes where field survey boundaries are known to be approximations. In addition, the airborne imagery provides detailed height data for surface features and landscape topographic information. Whilst field surveyors could supply a higher level of spatial detail or vegetation canopy measurements, these are areas where airborne data can contribute most. It should be remembered, however, that the airborne imagery provides land-cover rather than land-use information, and will always have difficulties in separating those land-cover types that require botanical examination for identification, such as grassland types. Furthermore, airborne data cannot supply information on woodland type, composition, age, management, or on hedgerow shape, composition or type. Airborne digital data can only supply information on the surface vegetation type as seen from above; it can say nothing about under-storey vegetation. The airborne data were poor for identifying walls, ditches and roadside hedgerows (where shadow was a problem). Lastly it should be remembered that mapping land-cover and landscape features only represents about one-third of the work of field surveyors, and that field data are needed to train the classification of airborne digital data. Nevertheless, field survey would be greatly facilitated if surveyors had hard-copy prints of CASI data as a guide. Airborne imagery should thus be seen as providing information to complement the work of field survey (particularly for larger area mapping), but not to replace surveyors.

11.6 Comparison of classified airborne data and LCM2000

Comparisons between classified airborne data and LCM2000 are somewhat misleading, especially for just eight squares, since the strength of the satellite survey is as a national-scale land-cover census. Focussing in on the detail of a 1 km square in the LCM2000 overlooks the issues concerned in its production and its primary value as a means of providing a spatial framework within which to understand the extrapolations made from the field survey data. It is clear that airborne digital data provides much greater within-field and field boundary information for restricted landscape areas and gives far more accurate and detailed context to the CS squares.

11.7 Cost comparisons for land-cover mapping by field, airborne and satellite survey

In comparing the cost of deriving land-cover information from field, airborne and satellite survey the above discussions on the extent, detail and context of data recording must be borne in mind.

The field survey was an integrated approach providing a wider collection of data than land-cover alone (e.g. additional land parcel information such as land-use and species composition, detailed vegetation plots). The terrestrial field survey component of CS2000 cost about £1.3 million at Full Economic Cost (FEC). This equated to *ca* £2 300 per 1 km sample square. An estimated maximum of 30% of the costs of the terrestrial field survey were associated with mapping data on land-cover and landscape features (C. Barr, *pers. comm.*). Thus a more accurate reflection of the cost associated with land-cover mapping in each 1 km square, as part of the CS2000 programme, might be *ca* £700. This includes project planning, a share of training, the field survey itself, data entry, data analysis and reporting.

With current EA image acquisition and processing systems the cost of supplying integrated CASI and ALTM data is £400 per 1 km square. There is a minimum flight cost of £10 000 and a restriction of flying sites that are within a 20 km radius of a manned GPS base-station. To be cost-effective, at least 25 1 km squares should be flown. Given that the CS squares are positioned on a 15 x 15 km grid, within a radius of *ca* 20 km a maximum of nine 1 km CS squares could be encountered. Therefore, it would not be cost-effective to fly individual 1 km squares. However, cost-effectiveness could be achieved by acquiring data in a 20 km radius for three 3 x 3 km sites (costing £10 800) or one 5 x 5 km site (costing £10 000).

Repeating the data processing flow-line to derive land-cover classification from the CASI and ALTM data used in this project would take 6 days for a trial square and 5 days for a check square. The Full Economic Cost at SO grade for processing trial and check 1 km squares would thus be *ca* £1300 and *ca* £1100 respectively. Processing the 3 x 3 km trial square took 18 days, and so the FEC of repeating this process for the remaining trial squares would be *ca* £3900. (Note these costs are excluding airborne data acquisition and the collection of 'ground truth' data to train the classification of trial squares).

Recent developments by the EA that have incorporated the simultaneous acquisition of CASI and dual-pulse ALTM data and an integrated processing system are likely to reduce the data processing times (and therefore costs) outlined above. The most significant of these is the integrated acquisition of the CASI and ALTM data, as the process of manual integration consumed *ca* one-third of the total data processing time for the 1 km trial squares and over one-half of the processing time for the 3 x 3 km trial square. Given the current developments in the EA image acquisition and processing system, and the further possible upgrades it is difficult to speculate on likely future costs of processing airborne digital data. Nevertheless, even with the effects of inflation the costs are likely to fall in the foreseeable future.

The estimated cost of LCM2000 generating nation-wide land-cover data is £725 000, which translates into a cost per 1 km square of £3. This figure includes project Research and Development costs, and so a true implementation cost would be approximately half.

It can therefore be seen that even with probable future developments in airborne data acquisition and processing systems, the cost of deriving land-cover information from airborne digital data is notably higher than satellite census or field survey for individual CS squares. However, increasing the spatial coverage to a wider landscape setting gives a greater economy of scale in the costs of image acquisition and processing than of field survey. This represents the potential strength of airborne data acquisition if future Countryside Surveys.

11.8 Recommended CASI and ALTM applications in future Countryside Surveys

The field survey and LCM2000 provide nation-wide information, whilst the logistics of airborne data supply are such that it would not be possible to provide information for all, or even a significant proportion of the CS squares in a single year. Thus, if the emphasis of future Countryside Surveys remains on data acquisition in a single year, the strength of airborne survey would be to provide landscape-scale information for a sub-sample of key target sites. This could include: CS squares that fall in SSSIs, AONBs and other designated areas, sites with a history of scientific research; or areas for which field survey is difficult, dangerous or prohibited, such as remote Upland areas, inter-tidal zones, military or private land. Within these areas, airborne digital data could provide landscape-level information on spatial pattern, connectivity, terrain, and surface 3-d structure. Through these landscape metrics it may be possible to derive an indication of habitat quality.

Complete national coverage of all CS squares could be achieved in a structured rolling programme of integrated data acquisition and field survey. For example, an annual survey of 71 CS squares (recording a 3 x 3 km area) would give national coverage in 8 years. A product useable to field surveyors could be supplied within 2 weeks of data acquisition. Analysis of the field survey and airborne data could be undertaken throughout the year.

11.9 Alternative remote sensing data sources

It is important to consider other alternative sources of detailed remotely sensed data. Options include:

- air photography - with stereo capability and options for digital scanning and automated analysis);
- space photography - e.g. from Shuttle missions);
- very high resolution satellite data – e.g. IKONOS, with four spectral bands (4m resolution) and a panchromatic band (1m resolution);
- high resolution satellite data - e.g. IRS LISS-III, SPOT HRV and Landsat ETM which have panchromatic bands with 5.6 m, 10 m and 15 m resolutions respectively.

The first of these is potentially operational, with a 3-dimensional capability close to LIDAR, but with spectral limitations which would severely limit thematic classifications. Space photography and very high resolution systems may offer scope, but would need testing. The high resolution satellite systems offer the advantage of routine and comprehensive data collection and might even be used for full national coverage in future LCM updates. Whether the spatial improvements would match scales of pattern in the landscape needs assessment. High resolution satellite data would not record smaller linear features such as hedgerows, but the vector structure of landscape boundaries with attribute data on parcel-contents might offer an elaborate framework on which to extrapolate field survey estimates of hedgerow types and densities. The project on ‘integration’ will investigate the principles of such a procedure.

It was beyond the scope of this research to assess the operational potential for these techniques. Nonetheless, if future Countryside Surveys seek to expand the number of sites sampled, provide context for the samples or extend the spatial detail captured in national survey, all such options should be reviewed. It is suggested: first, that the user community should identify needs; second, that a literature assessment should identify potential; third, that a desk study should assess costs and logistics of various options; and fourth, that candidate techniques should be assessed in further trials.

12. CONCLUSIONS

- Operational procedures have been developed for processing ALTM first pulse data; generating a Digital Surface Model, ‘terrain’ elevation, and canopy height for trees and hedgerows relative to surrounding grass and crop canopies.
- Current ALTM sensors routinely supply first and last pulse LIDAR data, enabling the more accurate generation of Digital Terrain Models and vegetation canopy height.
- Operational methods have been demonstrated for the spectral segmentation, raster-to-vector conversion, training and classification of CASI data.
- The integration of CASI and ALTM data enables feature height to be used in knowledge-based correction and gives a final classification product in which land-cover parcels contain 3-dimensional data on terrain and surface features.
- On-going developments in CASI data acquisition and pre-processing systems may operationalise image registration and normalisation. The study of CS squares in a wider landscape setting and the transfer of training data between sites for ‘blind’ classification would then become part of an operational process.
- The product of airborne data classification is not directly comparable with field survey or LCM2000. Each survey approach differs in: spatial detail and extent of coverage; landscape features and land-cover types mapped; variables recorded; and cost.
- Airborne data offers the potential for mapping land-cover and landscape 3-dimensional structure at a 3 m spatial resolution, placing the core CS square into a wider landscape context.
- Field survey would be facilitated if surveyors had hard-copy prints of CASI data as a guide.
- Airborne data cannot supply information on land-use, species composition, woodland type or age, and could not easily give national coverage (either census or sample) in a single target year.
- The cost of using airborne digital data to supply land-cover information for individual CS squares is prohibitive compared with field survey. However, increasing the spatial coverage to a wider landscape setting gives a greater economy of scale in the costs of image acquisition and processing than of field survey.
- If the emphasis of future Countryside Surveys remains on data acquisition in a single year, then the recommended use of integrated airborne data is to provide landscape-scale information for a sub-sample of key target sites.
- If a higher proportion of CS squares are to be surveyed in high spatial detail by remote sensing in a target year, high resolution satellite data may represent the best alternative to airborne digital data.
- National coverage of CS squares in their wider landscape context could be achieved by integrated airborne and field survey on an annual rolling basis.

13. REFERENCES

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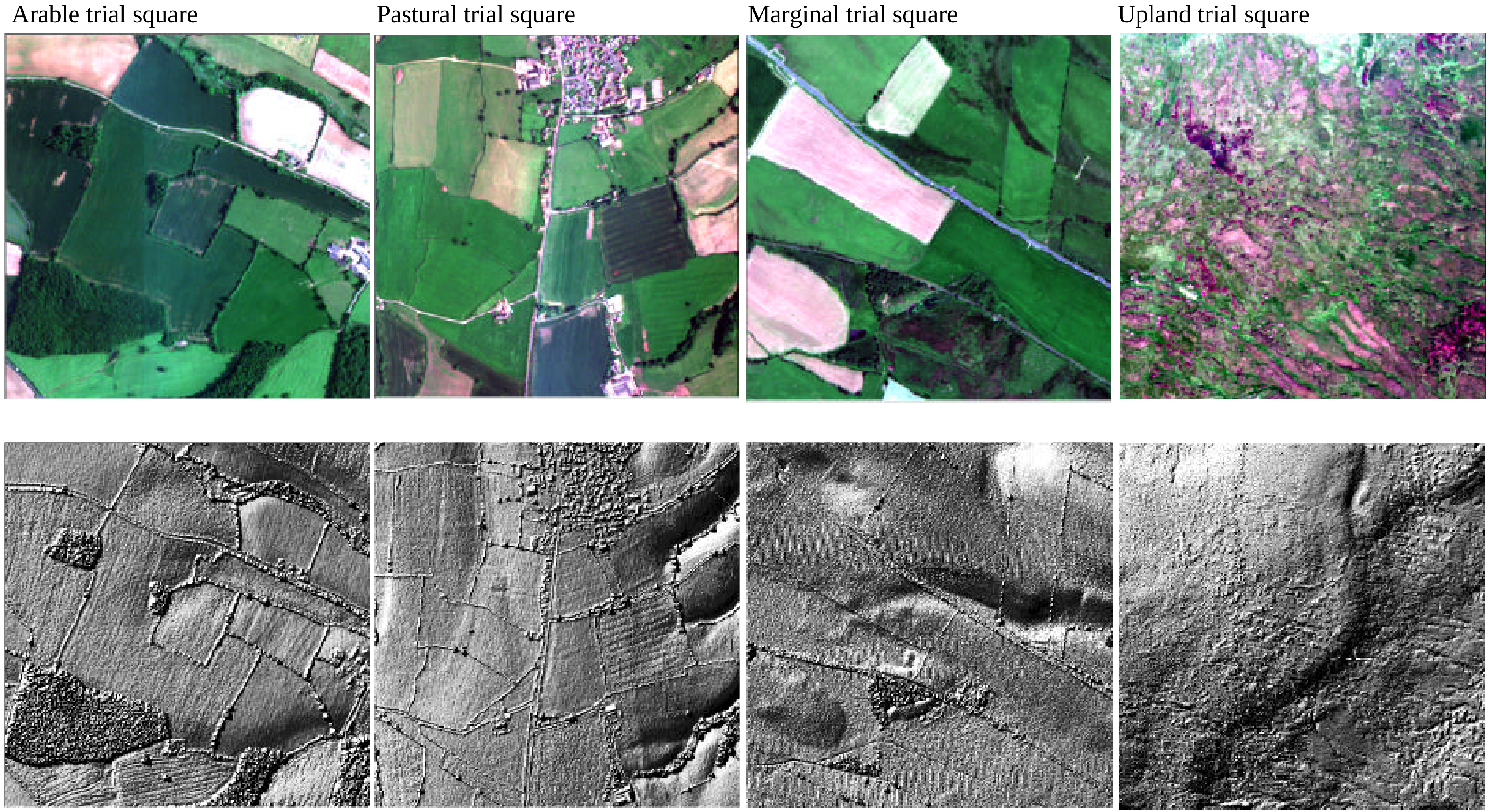


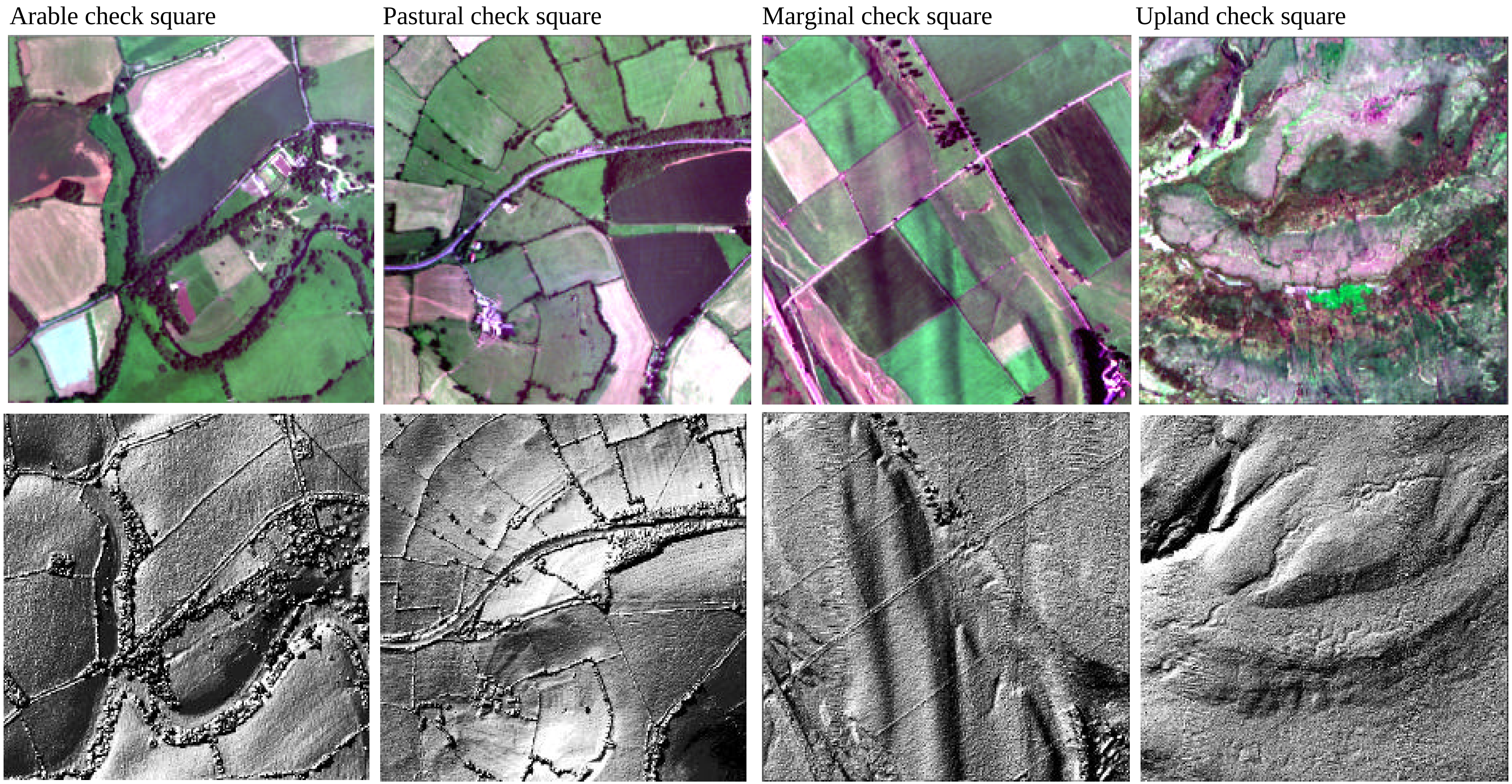
Arable trial square

Pastural trial square

Marginal trial square

Upland trial square

Figure 1. Multi-spectral CASI imagery (top) and LIDAR ALTM data (below) for the trial squares.
CASI images are shown as true colour composites, ALTM data as hillshaded Digital Surface Models.



Arable check square

Pastural check square

Marginal check square

Upland check square

Figure 2. Multi-spectral CASI imagery (top) and LIDAR ALTM data (below) for the check squares.
CASI images are shown as true colour composites, ALTM data as hillshaded Digital Surface Models.

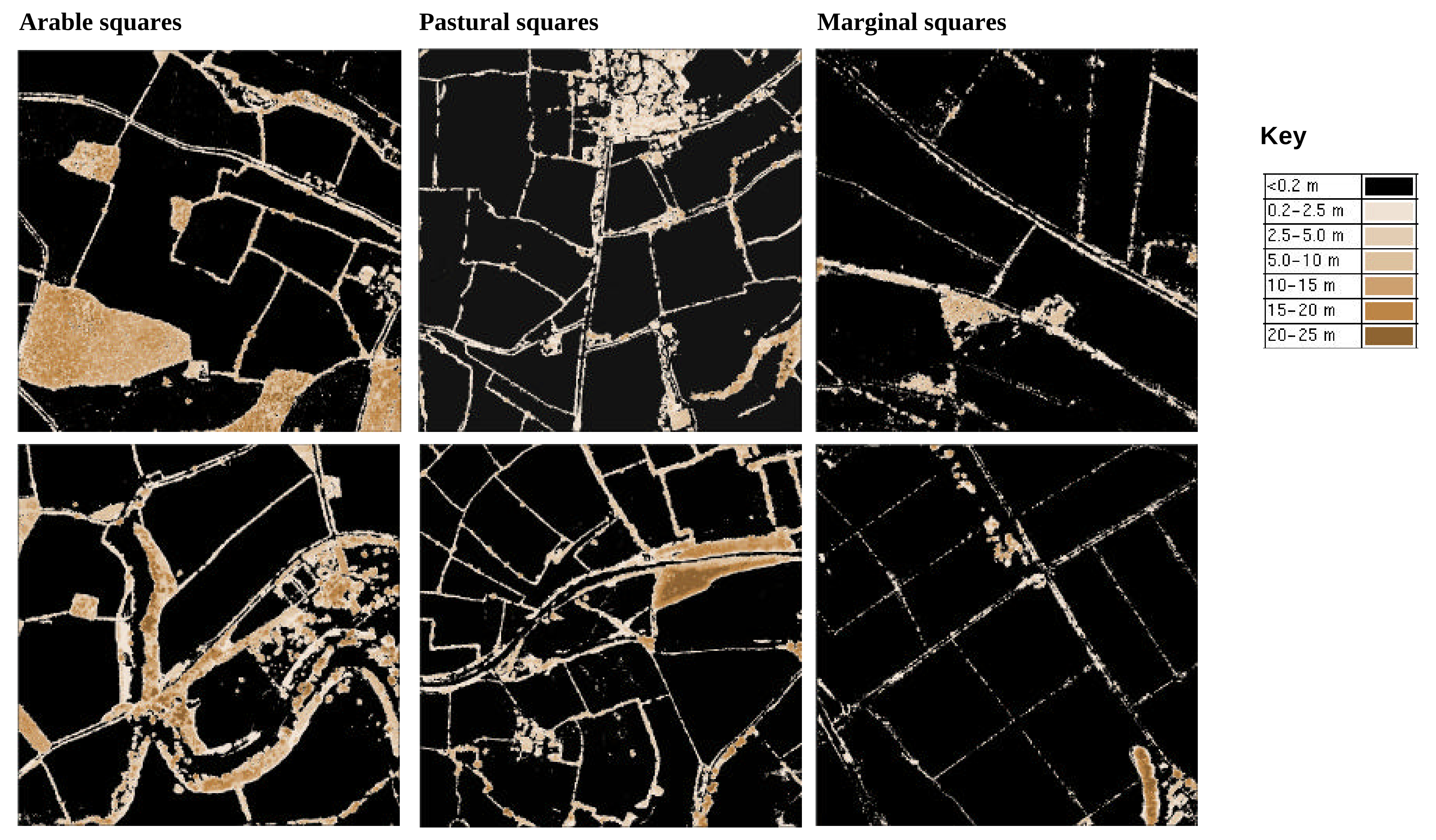
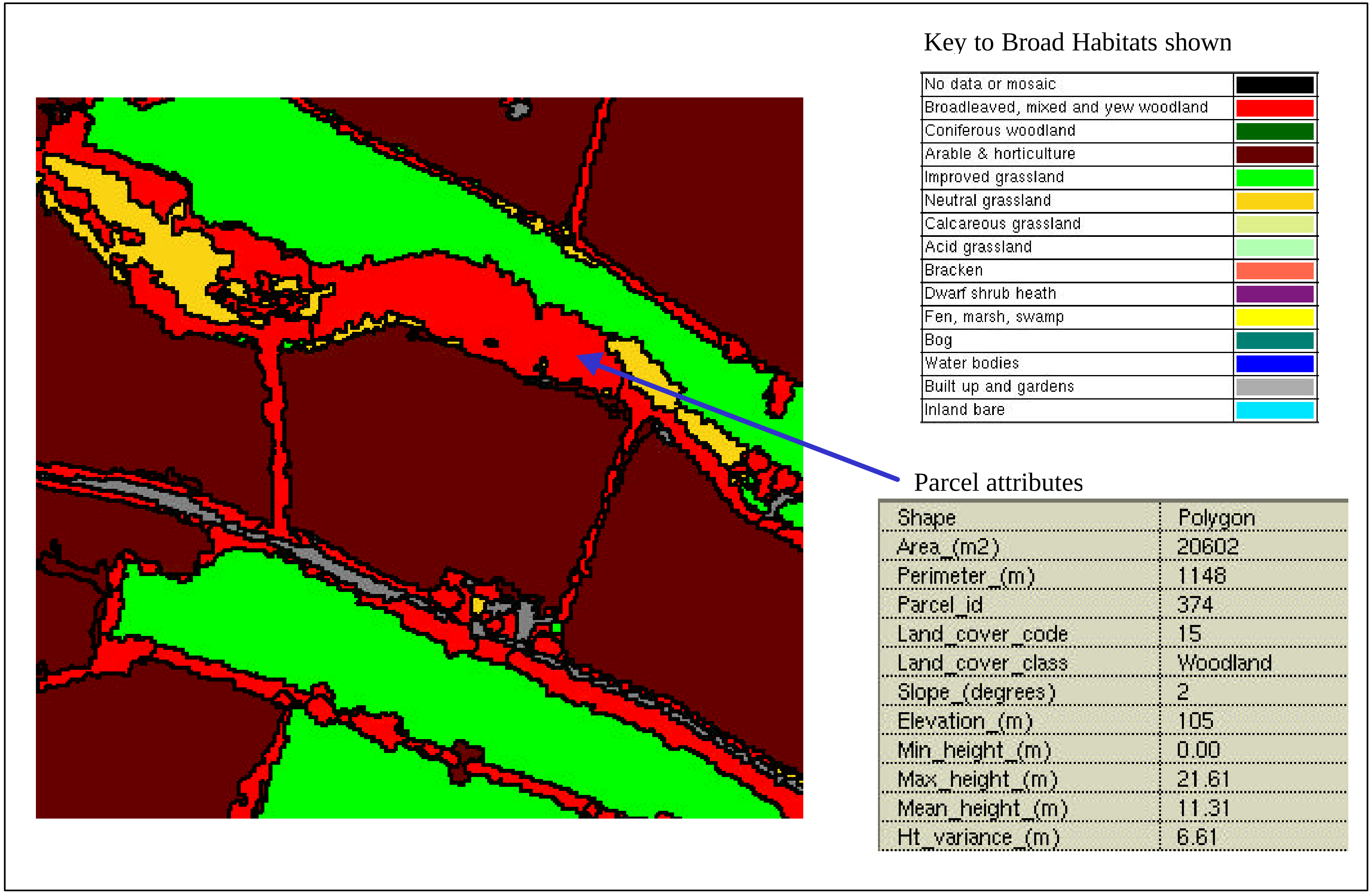


Figure 3. Relative height for trees, hedges and buildings derived from the ALTM data.



Key to Broad Habitats shown

No data or mosaic	⬛
Broadleaved, mixed and yew woodland	🟥
Coniferous woodland	🟩
Arable & horticulture	🟫
Improved grassland	🟩
Neutral grassland	🟨
Calcareous grassland	🟨
Acid grassland	🟩
Bracken	🟧
Dwarf shrub heath	🟪
Fen, marsh, swamp	🟨
Bog	🟩
Water bodies	🟦
Built up and gardens	⬜
Inland bare	🟦

Parcel attributes

Shape	Polygon
Area_(m2)	20602
Perimeter_(m)	1148
Parcel_id	374
Land_cover_code	15
Land_cover_class	Woodland
Slope_(degrees)	2
Elevation_(m)	105
Min_height_(m)	0.00
Max_height_(m)	21.61
Mean_height_(m)	11.31
Ht_variance_(m)	6.61

Figure 4. Section of a vector data-base derived from classified airborne data (showing parcel attributes).

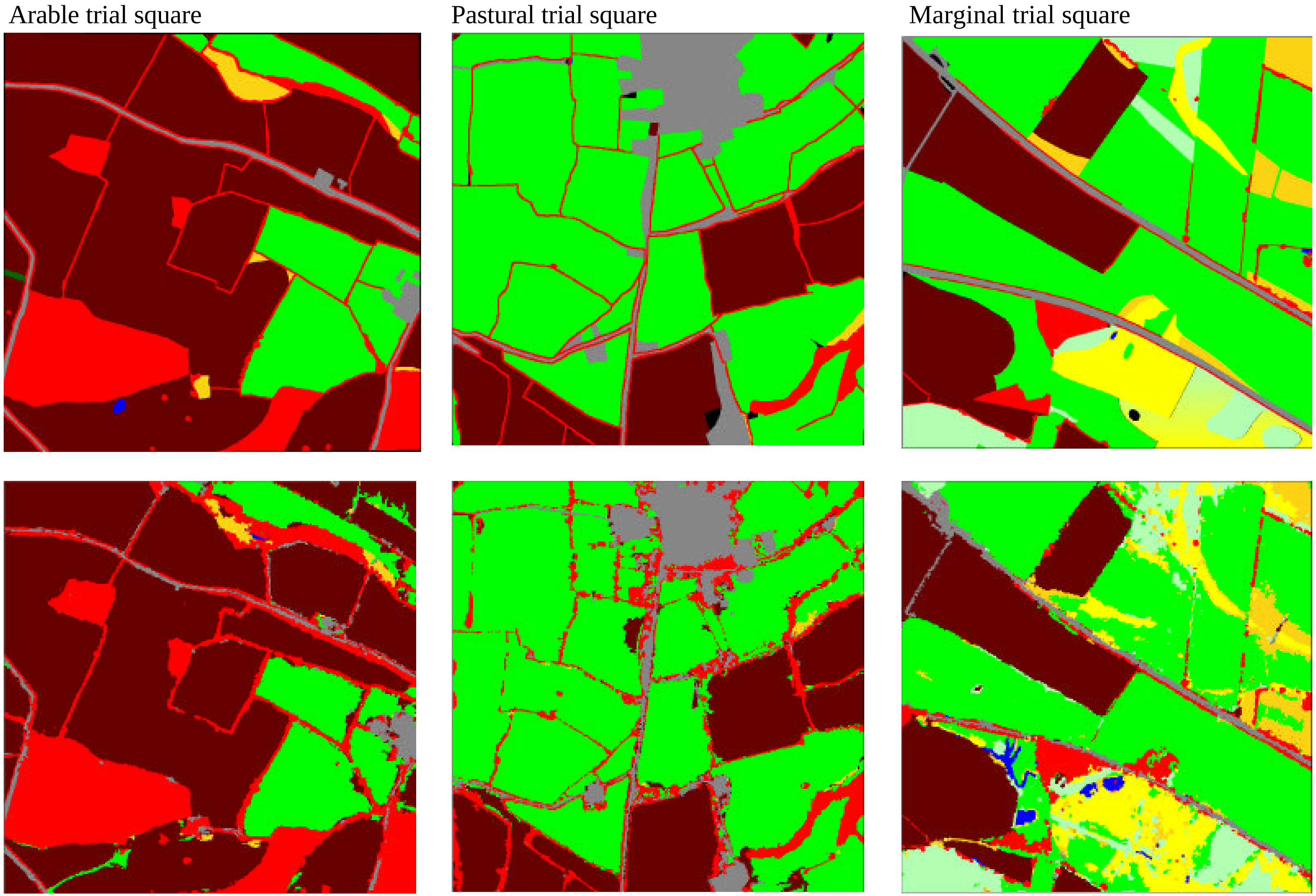
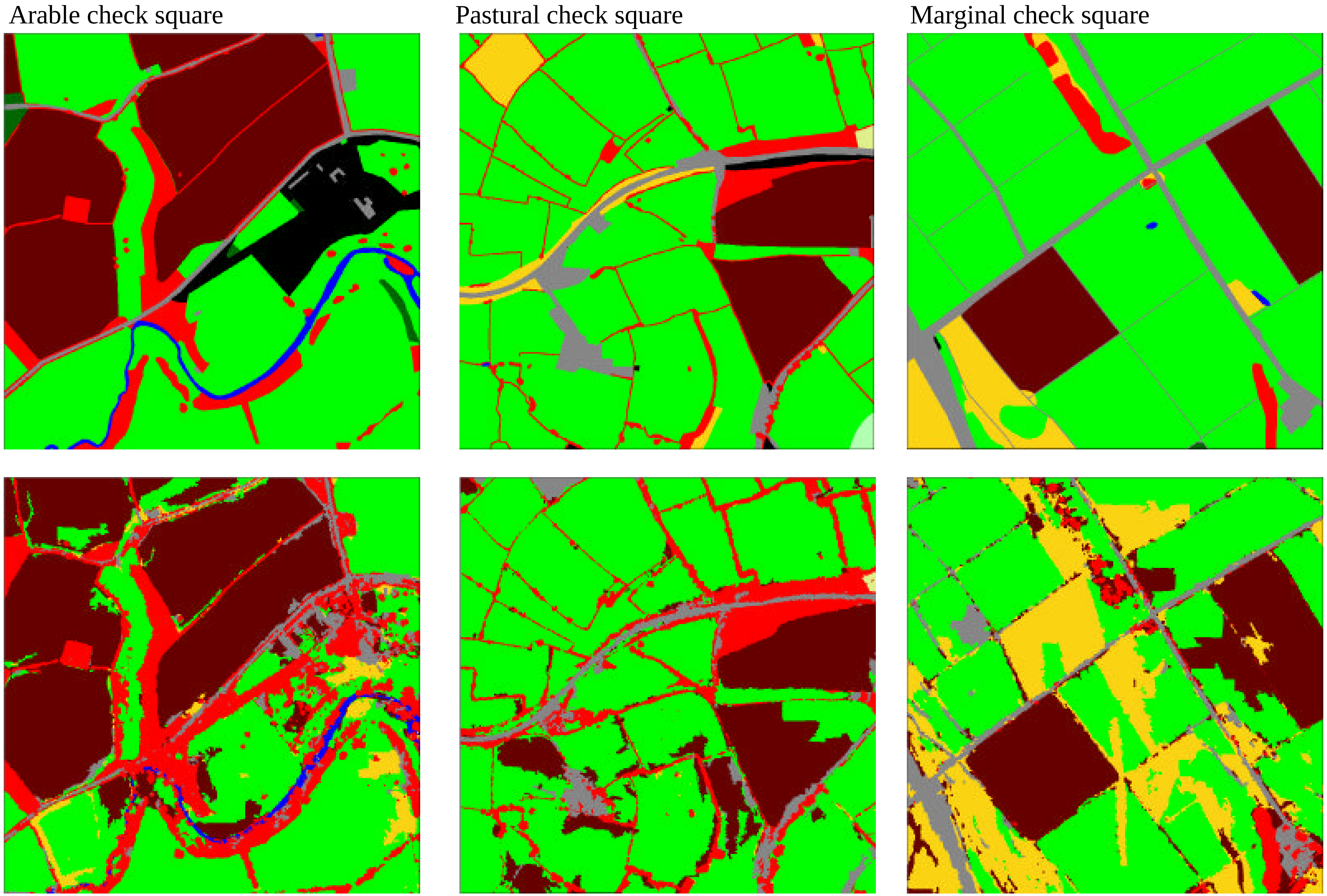


Figure 5. Comparison between field survey (top) and classified airborne data (below) at the widespread Broad Habitat level. (For key see Figure 4)


Arable check square

Pastural check square

Marginal check square

Figure 6. Comparison between field survey (top) and classified airborne data (below) at the widespread Broad Habitat level. (For key see Figure 4)

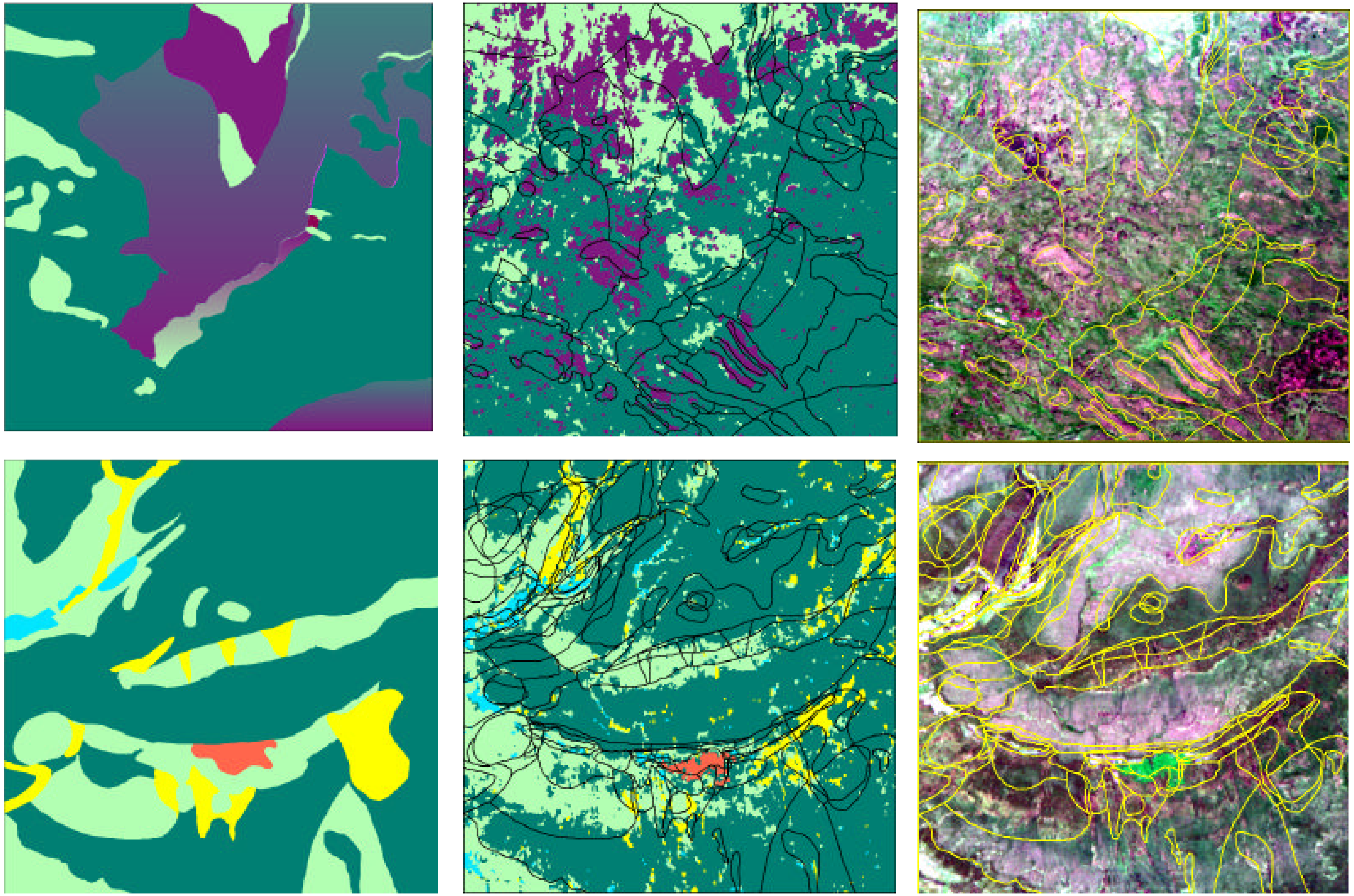
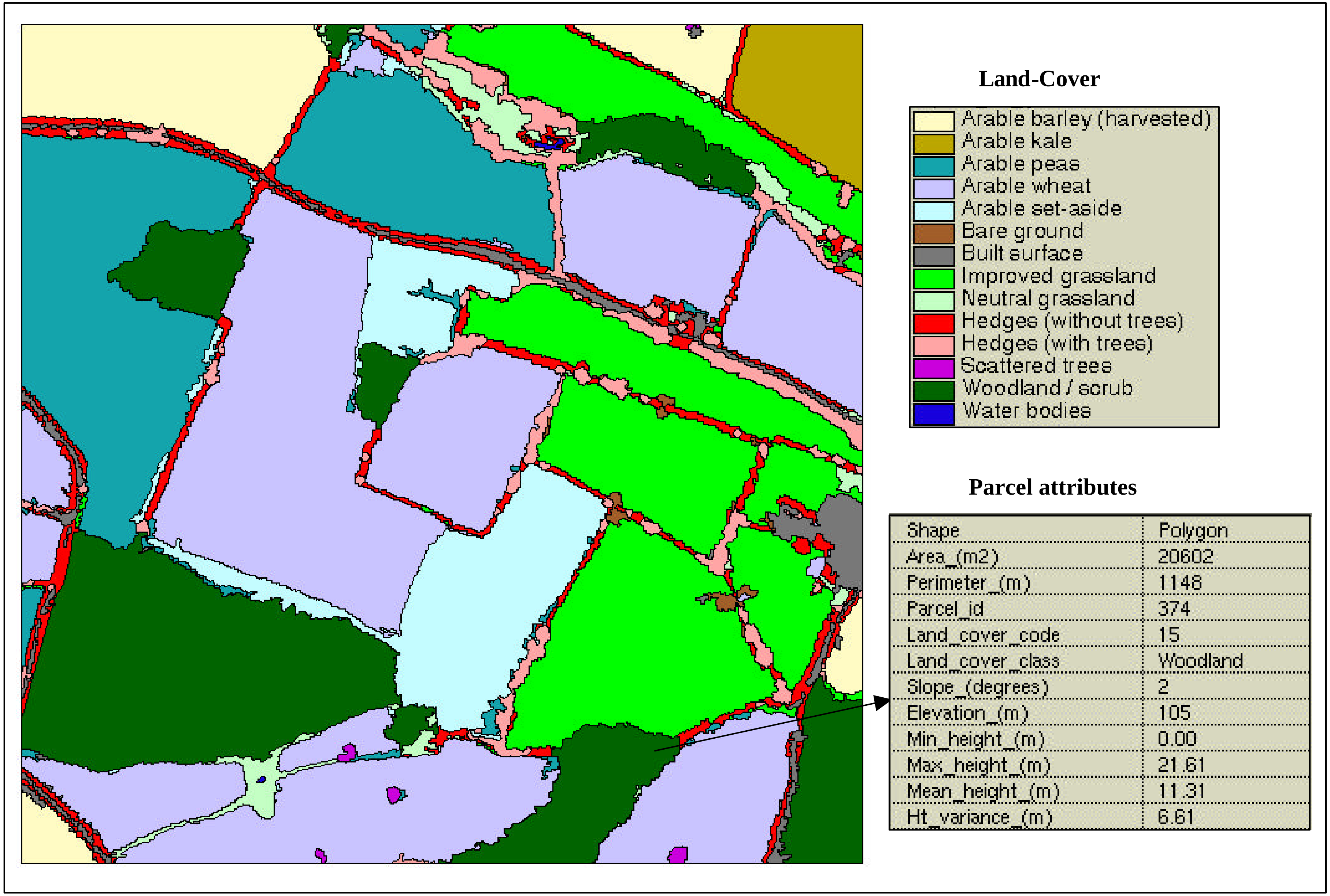


Figure 7. Classification results for the Upland squares. Images show field surveyed land-cover, (left) classified airborne data with field survey parcels overlaid (middle); and CASI data with field survey parcels overlaid (right). (For key see Figure 4).



Shape	Polygon
Area_(m2)	20602
Perimeter_(m)	1148
Parcel_id	374
Land_cover_code	15
Land_cover_class	Woodland
Slope_(degrees)	2
Elevation_(m)	105
Min_height_(m)	0.00
Max_height_(m)	21.61
Mean_height_(m)	11.31
Ht_variance_(m)	6.61

Figure 8. Detail of land-cover beyond the widespread Broad Habitats. Hedgerow classification derived by an additional process of KBC.

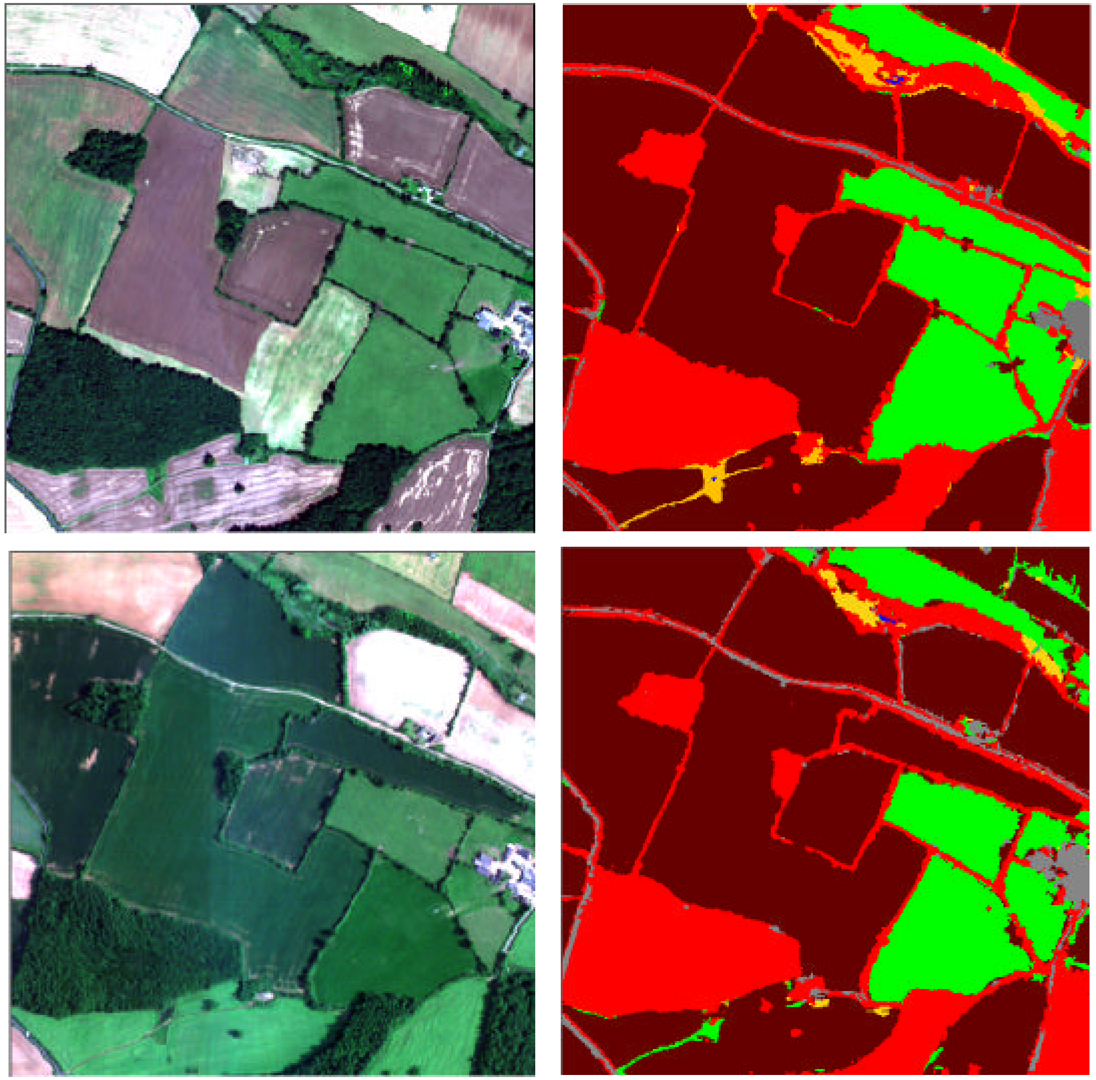


Figure 9. Classification of 1998 CASI data (top) and 1999 CASI data (below) for the Arable trial square. (For key see Figure 10).

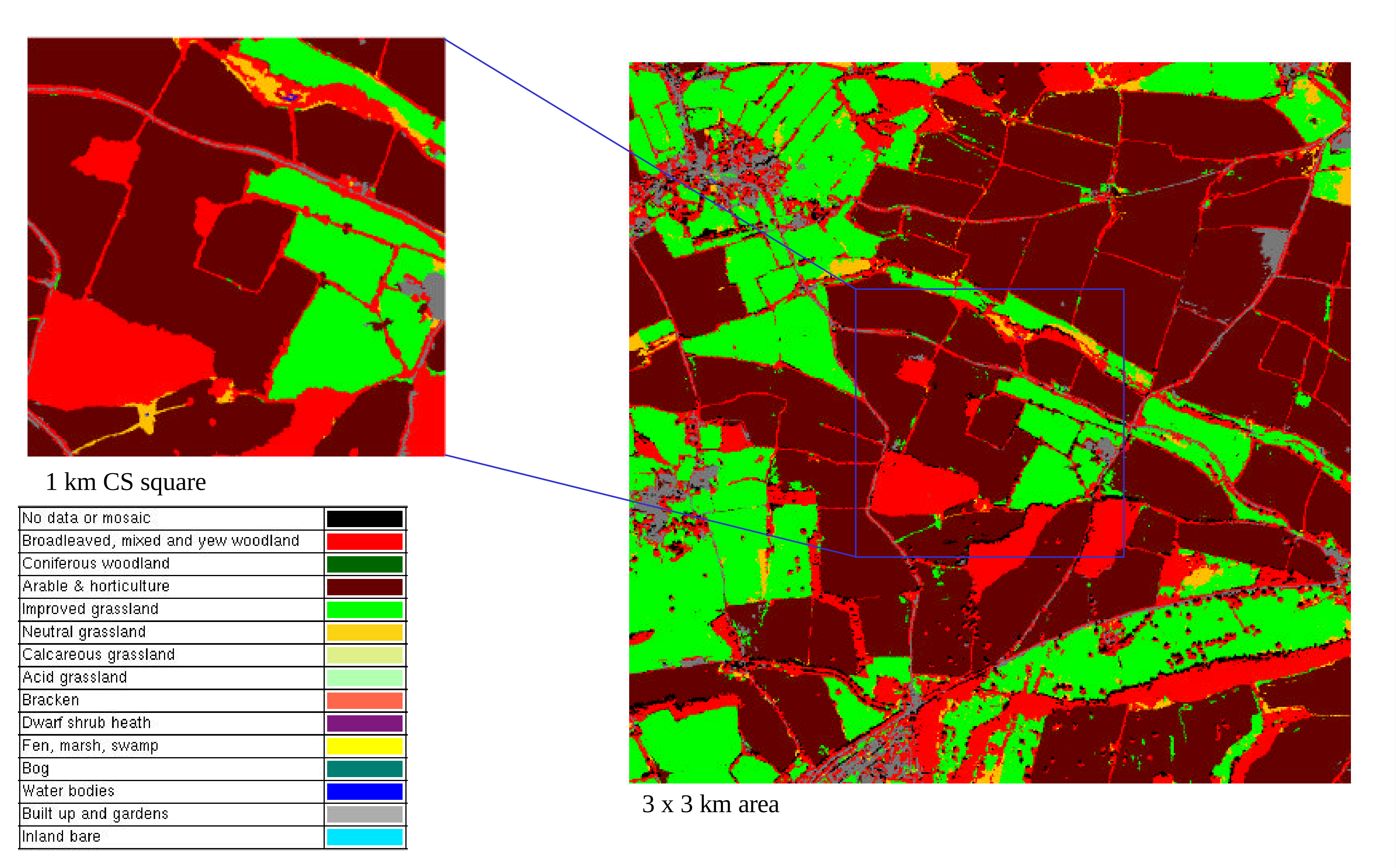


Figure 10. Classification of airborne data of the Arable trial square and surrounding 3 x 3 km area

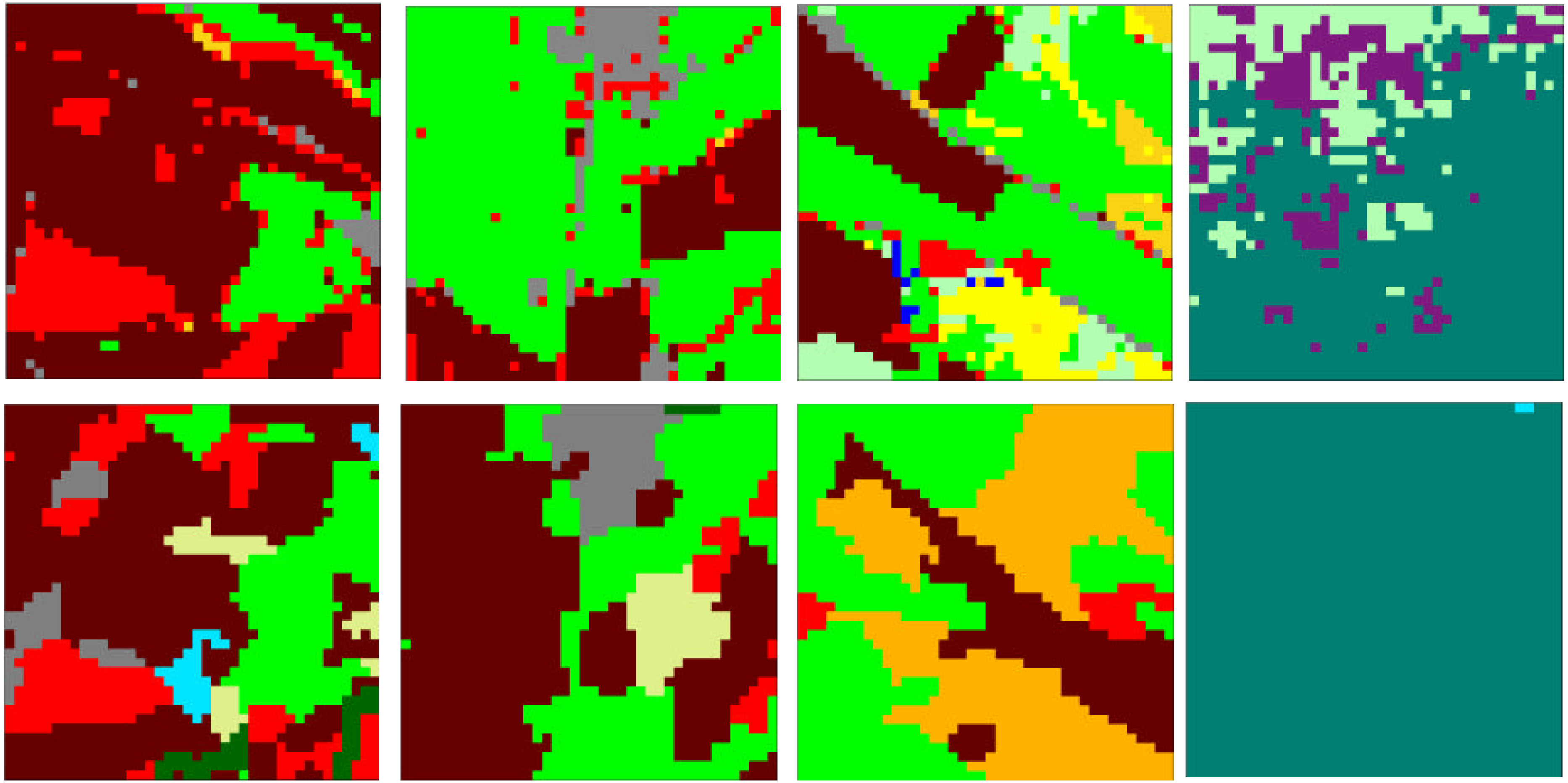


Figure 11. Comparison of classified airborne data at 25 m spatial resolution (top) and LCM2000 (below) for the trial squares.
(For key see Figure 10).

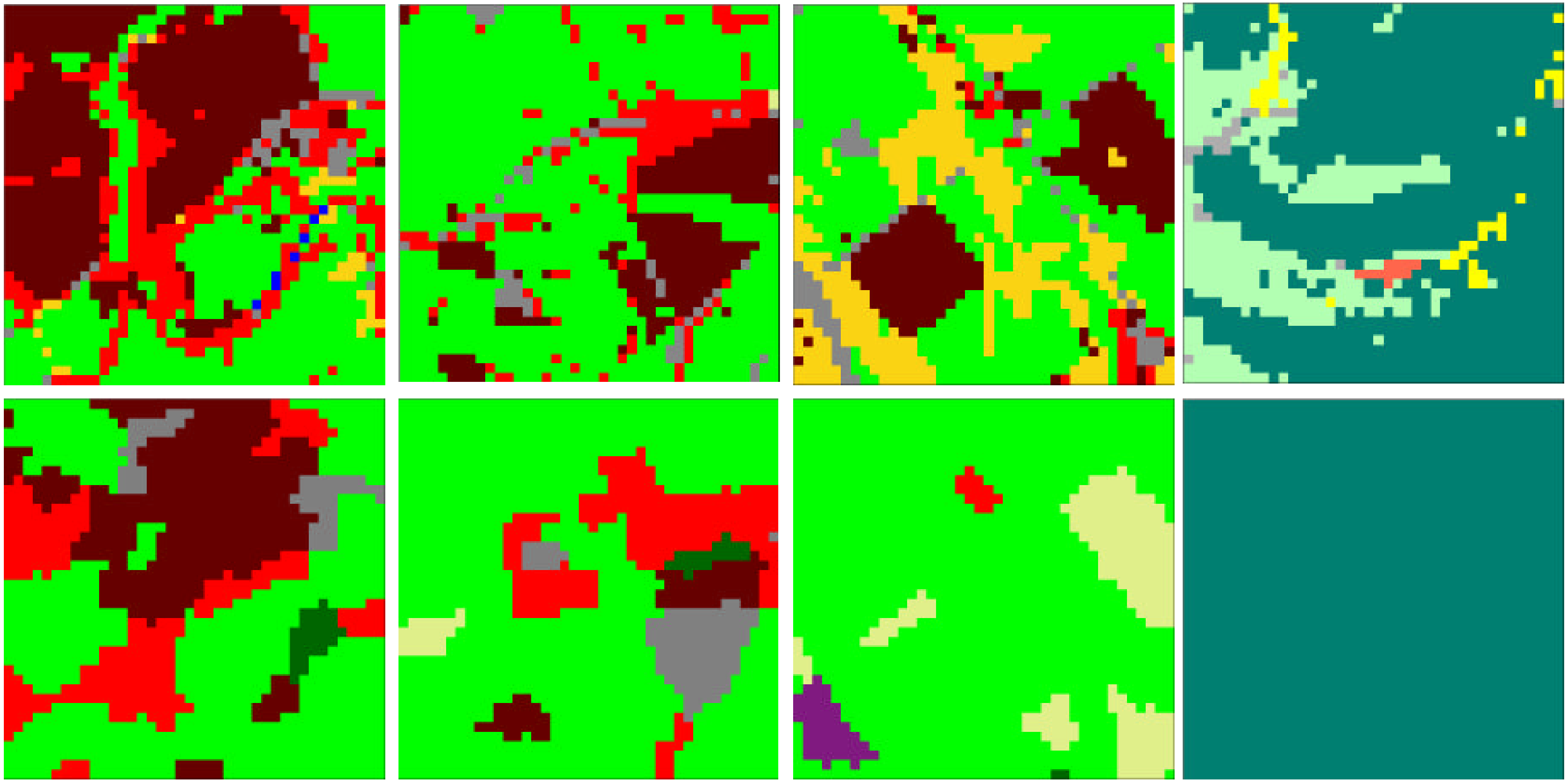


Figure 12. Comparison of classified airborne data at 25 m spatial resolution (top) and LCM2000 (below) for the check squares.
(For key see Figure 10).

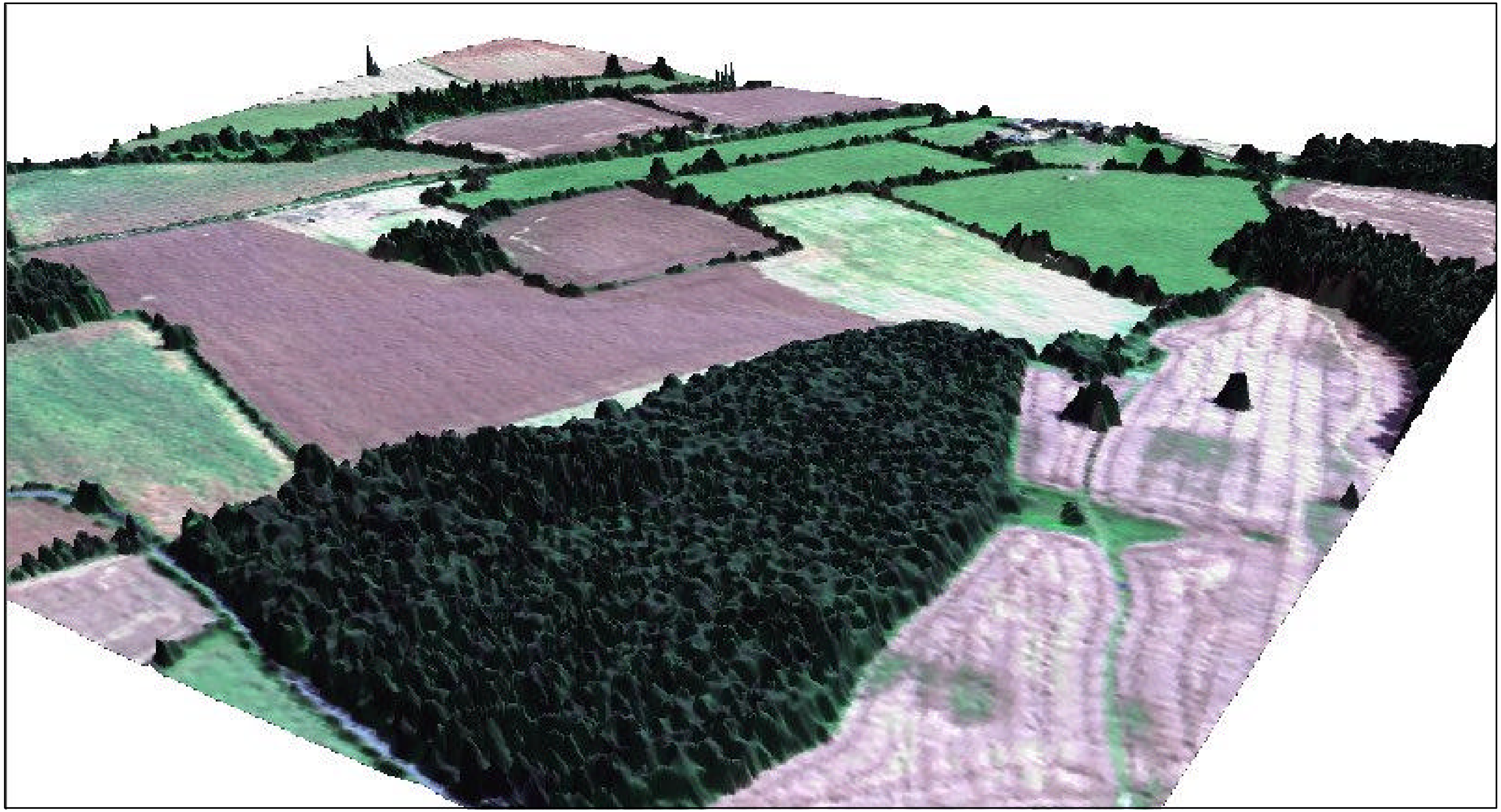


Figure 13. Three-dimensional visualisation of a Countryside Survey square from integrated CASI and ALTM data.

APPENDICES

APPENDIX I – INTRODUCTION TO CASI AND ALTM DATA

CASI (Compact Airborne Spectrographic Imager) is a passive sensor recording reflected radiance in visible and near-infrared wavelengths (400-915nm). Operating in 'spatial mode', CASI records continuous coverage across a 512 pixel swath in up to 19 bands of selected spectral location and width (Babey and Anger 1993). The spatial resolution of CASI imagery (i.e. pixel size) depends on lens optics and aircraft altitude during image acquisition. A 3m spatial resolution was agreed for the CASI data in this project, as this would enable detection of linear and point features (such as hedges and trees) while allowing coverage at a modest data rate commensurate with later potential operations. With mosaic-coverage, a 3m pixel size required 4 flight-lines to cover each target site. The configuration of the sensor adopted the narrowest possible lens to minimise off-nadir viewing affects which would otherwise cause adverse geometric distortions, topographic displacements and illumination differences when illumination was across-track. The chosen wavebands were those of the VEG bandset (Table 7), used in earlier work for the then National Rivers Authority (Fuller *et al.* 1995a & b). It was based on the 14 waveband BIOTA bandset adopted by CEH for coastal work (Thomson *et al.* 1998), modified for inland use to give more data around the red-infrared boundary that could be used for red-edge modelling in biomass estimations of vegetation.

Ch.	Centre/Width (nm)		Start nm (Ch No.)		End nm (Ch No.)
1.	450	20	441.53 (264)	-	459.17 (254)
2.	490	20	480.37 (242)	-	499.84 (231)
3.	552	10	547.74 (204)	-	556.63 (199)
4.	670	10	665.57 (138)	-	674.54 (133)
5.	700	10	694.28 (122)	-	703.27 (117)
6.	710	10	705.07 (116)	-	711.06 (111)
7.	740	10	735.66 (99)	-	744.67 (94)
8.	750	7	746.47 (93)	-	753.68 (89)
9.	762	5	760.90 (85)	-	764.51 (83)
10.	780	10	775.34 (77)	-	784.37 (72)
11.	820	10	815.13 (55)	-	824.18 (50)
12.	865	10	860.46 (30)	-	869.54 (25)

Table 7. The selected CASI bandsets

The ALTM (Airborne Laser Terrain Mapper) uses a pulsed laser to provide a ranging measurement by determining the time-of-flight between an emitted and received pulse following diffusion and reflection from a feature on the earth surface (Flood and Gutelius 1997). To identify the 3-D position of each ranged point, the LIDAR is supported by an integrated position and orientation system (POS) consisting of a differential global positioning system and an inertial measurement unit (Wehr and Lohr 1999). The ALTM scans across the swath generating a saw-toothed pattern of spot heights whose spacing is dictated by the laser pulse repetition rate, scan angle, aircraft speed and height, and terrain topography (Ackermann 1999). Each incident laser pulse supplies the altitude for the ground surface or objects on it. Any vegetated surface will return a multiple echo, as the laser pulse can penetrate into and possibly through the vegetation cover. Typically the first significant echo pulse records information from the vegetation canopy surface, whilst the last significant echo pulse records ground or within-canopy information, depending on the canopy density

(Ackermann 1999, Davenport *et al.* 2000). The ALTM 1020 supplies only 'first' or 'last' pulse data, and so for the purposes of this project 'first' pulse data were recorded to supply vegetation canopy information. An average point distribution of 2.5m was selected to achieve a level of spatial detail commensurate with the CASI data. The laser pulse 'footprint' was *ca*. 0.2m at nadir.

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APPENDIX II - FIELD SITE SELECTION

The original criteria which determined the selection of field sites were:

- There will be 4 trial squares plus 4 check squares, a pair of each in Arable, Pastural, Marginal and Upland Landscapes.
- Each site must cover 3 km x 3 km, centred on a 1 km field survey square.
- The squares should be located close together to be within 20 km of a GPS base station.
- The majority of each 3 km x 3 km site (not just the central square) should be representative of the chosen Landscape.

To select squares, we first interrogated the Countryside Information System database using a 5 km x 5 km potential study site, to determine the number of neighbouring 1 km squares, out of 24 possibles, which shared the same Landscape class as the core field survey square. We then plotted those sites where over 15 representative squares would be found out of 25. Inspection showed that it was not possible for one 40 km circle to encompass all 4 Landscapes; but it was possible to select examples, each with *ca* 20 representative squares per site, if we used TWO general study areas. One group of squares in east Cumbria represented Upland and Marginal land (each with 2 sites): none had significant content of urban land. There were three options for combined Arable and Pastural areas; in Berkshire, Gloucestershire and Wiltshire/Avon: the first two contained high contents of urban/suburban (perhaps averaging 25-30%); the Wiltshire/Avon urban cover was 0-20% with an average of *ca* <10%. The selected squares are shown in Table 8.

Landscape type	**CS 2000 number**	**County**	**No. of squares in same Landscape**		**Trial / Check square**
Arable	180	Wiltshire	9/9	22/25	T
Arable	209	Wiltshire	9/9	25/25	C
Pastural	208	Avon	9/9	25/25	T
Pastural	179	Avon	7/9	19/25	C
Marginal	692	Cumbria	9/9	24/25	T
Marginal	691	Cumbria	9/9	25/25	C
Upland	708	Cumbria	9/9	25/25	T
Upland	1214	North Yorks	9/9	25/25	C

Table 8. The Countryside Survey squares chosen as representative of their Landscape types.

APPENDIX III – DATA COLLECTION

1. Airborne remotely sensed data

The CASI and ALTM data were acquired initially during summer 1998, to coincide with the field survey. However, data quality problems arose because of poor weather conditions and instrument failure during summer 1998. Also the required data standards of this project exceeded those for normal operational purposes of the EA. After consultation with the EA all eight sites were re-flown with both CASI and ALTM during summer 1999. Flying dates for the CASI data were 25th June for the Arable and Pastural sites, and 26th July for the Marginal and Upland sites. The ALTM was flown on 8th and 17th June for the Arable/Pastural and Marginal/Upland sites respectively. The specifications for airborne data retrieval were that at least a 3 x 3 km area was recorded for each site, from which the central CS2000 square could be extracted. The ALTM recorded first pulse only, capturing height information for the tops of vegetation canopies. A slight edge-of-flight-line z-displacement was detected in the ALTM data, particularly of the Marginal/Upland sites. The CASI recorded twelve wavebands, which focused particularly on the red and near infrared spectral boundary, with a pixel size of 3 m. The atmospheric quality was excellent and the geometric quality was as good as the EA systems would allow.

Pre-processing of the 1999 CASI data at the EA involved roll-correction only for flight-lines covering the Arable, Pastural, and Marginal squares. This was because of a problem in their Itres 'geocor' software, which generated erroneous data shifts if applied to the CASI imagery for geometric correction. For the Arable, Pastural, and Marginal sites, the CASI data supplied by the EA thus contained residual geometric distortions where aircraft roll had been either under- or over-compensated. In addition, geometric distortions also resulted from underlying topography, which was not accounted for in the pre-processing. The two Upland squares, however, were given higher order geometric conversion, as conventional geometric correction of imagery can be a near impossible process in upland areas, where fewer prominent landmarks (e.g. field boundaries, crossroads) are found.

2. Field reconnaissance

Field visits were made to all eight sites during summer 1998 to coincide with the timetables of the CS 2000 field surveyors. Thus, these took place in the weeks beginning 13th July for the Marginal and Upland sites and 14th September for the Arable and Pastural sites. At both locations the field visits were contemporaneous with CS 2000 surveying for three of the four CS squares. This minimised the level of disturbance to land owners resulting from this study, and enabled first-hand experience to be gained on the issues and problems faced by field surveyors in all four landscape types. The field visits were designed to complement the field survey, providing additional information. The focus at all sites was thus on identifying land-cover patterns and features in the eight 1 km squares surrounding the CS square, so as to identify additional cover types not present in the central 1 km square. (Although acquired for all 8 sites, subsequent limitations on airborne data processing resulted in only 3x3 km field data being used for only one site).

In addition to the land-cover information, hedgerow and tree height measurements were recorded at one site to provide comparison with the airborne height data. A detailed 150m hedge profile was recorded, with height and width at 3m intervals and the dimensions of gaps and trees also recorded.

Repeat field visits were made to the Arable and Pastural sites during the week beginning 19th July 1999 to acquire ground reference information for the replacement airborne data. This field work focussed primarily on the central 1km square to identify any land-cover change from 1998. The Marginal and Upland sites were not re-surveyed owing to time constraints since it was considered that only arable land-cover types were likely to show significant changes.

APPENDIX IV – IMAGE PROCESSING METHODS

A processing flow-line has been developed at CEH that involves: elevation and height data generation from ALTM point sample data; CASI normalisation, geometric correction and segmentation; image classification; and knowledge-based correction. The methods, training statistics and correction rules were developed using the trial squares (CS Squares 180, 208, 692, and 708) which were selected by virtue of image data quality and land-cover diversity. The test of the operational capabilities of the processing flow-line was in its application to the check squares. Of interest was the wider applicability of the techniques and of variables such as segmentation thresholds, classification training data, and KBC rules.

1. ALTM data pre-processing

1.1 Creating a Digital Surface Model

The ALTM data were supplied by the EA as ascii files of x, y, z point information. The point sample information formed a zig-zag pattern with distribution varying, but typically falling *c.* 3-4 m apart. The ALTM swath width was approximately 750 m, and the flight-lines were flown to overlap. A 1 km square contained around 165000-175000 sample points.

The first stage of the ALTM pre-processing was to interpolate a continuous surface from the point sample information. This was achieved by the creation of an irregular triangular mesh (Triangulated Irregular Network) from the sample points. This was then transformed into a lattice with a rectangular array of mesh points with a chosen constant sampling interval in the x- and y- direction of 1m. Because the ALTM data were first response only, this 1 m spatial resolution interpolated grid was a Digital Surface Model (DSM), as trees, buildings, etc, were present in the data with height expressed in metres above OS Datum (OSGB 1936).

1.2 Creating a Digital Elevation Model

The second, and more complicated phase of ALTM pre-processing, was the generation of a Digital Elevation Model (DEM) in which all prominent superficial features (e.g. trees, hedges, buildings) were removed to give landscape elevation. To achieve this, all superficial features had to be removed from the DSM to allow re-interpolation of surface elevation across the gaps generated. Various methods of feature removal were investigated including: the use of surface variance filters; and the mean filtering and statistical approach recommended by Jaafar *et al*. (1999). These approaches identified variance in surface height and in mean surface height respectively, over a specified area using a spatial filter. The size of the spatial filter had to be determined statistically for each image, depending on the nature of landscape and surface feature variance. Once the appropriate filter size had been decided, a threshold was identified to distinguish between pixels representing the 'ground' and those which represent unwanted features such as buildings. In the approach using height variance filters, the threshold was applied directly to the resultant image, whilst in the approach using mean filtering, the threshold was applied to the product of subtracting the filtered image from the DSM. In general, the variance filtering approach identified the edges of features such as hedges or buildings, whilst the mean filtering approach masked the centre of features. An additional stage was to 'grow' a mask outwards to capture a greater proportion of the unwanted surface features, or to use the two methods together to identify both the centre and edges of features. However, these approaches were found to achieve the complete removal of surface features (such as hedges and buildings) at the expense of removing considerable areas of near-ground hits in areas of low growth vegetation. This influenced the potential accuracy of the surface interpolation across the masked areas, especially large blocks of woodland that contain areas of near-ground sampling in glades and rides.

Interpolation of heavily masked ALTM data did, however, give a rough indication of the ground surface. This was used to put surface elevation information back into the original masked image, where the difference between the original DSM and interpolated surface were within a specified limit (e.g. + or - 0.5 metres). This enabled the creation of a mask which removed virtually all unwanted surface features (such as hedges and buildings) but considerably fewer true ground samples.

The method of interpolating across the masked off data gaps was selected from an operational standpoint. Possible procedures included: triangulation, splining, kriging and inverse distance weighted methods of interpolation. Of these, surface triangulation was the preferred choice since it represented a continuation of the method used to create the original DSM from the ALTM point sample data. In addition, the other interpolation methods proved highly intensive on computer and analyst time to identify the optimum input parameters, which varied spatially depending on the nature of the landscape.

1.3 Creating a surface height model and other products

Once the Digital Surface and Elevation Models were complete, it was a simple task to create relative height data for surface features by subtracting the two data-sets. In addition, slope and aspect data were generated directly from the DEM.

Height data were generated only for Arable, Pastural and Marginal squares, since no features with significant above ground height occurred in the Upland sites. The accuracy of the surface height data was examined in Square 208 by comparing tree height estimates, derived using the 1999 ALTM data and measurements taken in the field in 1998. Correspondence in height estimates was found to vary between 5 cm and 90 cm. It should be noted that because of the slight z-displacement in the ALTM data, a degree of manual editing was necessary to ‘clean’ the surface height imagery.

2. CASI image pre-processing

2.1 Image normalisation

In optical imagery, the spectral signal recorded for surface features will be ‘distorted’ by atmospheric effects of scattering and absorption. The degree of atmospheric distortion in an image will vary with atmospheric conditions, and with both view and sun angle. Atmospheric attenuation needs to be accounted for to achieve comparability in spectral reflectance of features across image flight-lines, or of areas sampled at different times or dates. Achieving this by detailed atmospheric modelling is far beyond the scope and time-frame of this project and, to-date, no generalised atmospheric correction model exists for airborne imagery. For operational purposes (in the absence of atmospheric correction models), it would be necessary to visit each site at the time of airborne data acquisition to record calibration reflectance data for target surface features. Given the spatial coverage of these trial data-sets, it is virtually impossible to find surface features within or between sites that should have identical surface reflectance spectra, since building materials, crop maturity, grassland nutrient status, and semi-natural land-cover mosaics, will all vary spatially.

It was possible, however, to perform some basic normalisation procedures. For example, a procedure for correcting view angle differences across the swath has been devised at CEH based on mean nadir values. In this procedure normalised pixel values were calculated as follows:

$$x'_{ij} = x_{ij} - (\overline{x}_j - \overline{x}_{nadir})$$

where x_{ij} was the original pixel value at row i and column j, $\overline{x}_j$ was the average of column j after smoothing using a moving average (100 pixels) and $\overline{x}_{nadir}$ was the average of the nadir column after smoothing. The radiance values of adjacent flight lines could be made comparable by normalising each to the mean scene values of the central flight line for each site, and the same approach could be used to normalise between sites of the same Landscape type. However, since an inherent assumption in this procedure was that the type and proportions of land-cover were similar between flight-lines and different sites, there was a limit to the degree to which normalisation could be performed. This restricted the assumed transferability of identified spectral characteristics. Thus, the 1999 CASI data of the Arable and Pastural sites (which have a mixture of grassland and agriculture land-covers) were normalised to enable their combined training and classification. For the Marginal sites, however, the check square was normalised to the trial square, whilst for the Upland sites the land-cover was too distinct to allow the normalisation of the check to the trial square.

2.2 Geometric correction

Correction of the CASI imagery was necessary to remove geometric distortions remaining in the data following pre-processing by the EA. This was achieved by registering the required sections of each CASI flight-line to the matching DSM by identifying ground control points (GCPs) and performing ‘rubber sheeting’ to warp the image around those identified points. This was an extremely labour intensive process, requiring anything up-to 200 GCPs to correct a 1 km square. Furthermore, because only the specified control points were guaranteed to link the ALTM and registered CASI imagery, it was virtually impossible to achieve a perfect correspondence. Registration was performed using a nearest neighbour algorithm, resampling the CASI imagery to match the 1 m spatial resolution of the elevation data. This method had the advantage of maintaining the original spectral value of pixels whilst achieving a more detailed spatial matching by sub-dividing each 3 m CASI pixel. It must be remembered, however, that the minimum mappable unit will not be reduced in size by this apparent increase in image spatial resolution.

For many of the sites (Squares 179, 180, 208, 209 and 691), the central 1 km square did not fall entirely within one flight-line but was split across two adjacent runs. In these circumstances, the registered flight-line sections had to be mosaicked to generate a single data-set.

2.3 Topographic-illumination correction

An additional stage in the processing flow-line was investigated during the check square analysis. Topographic variation influences the spectral response of ground features recorded in CASI imagery. This is because undulating terrain is illuminated differentially according to whether facets of terrain are horizontal, face the sun, or face away from the sun (potentially shaded from direct solar illumination). Only in the case of the Marginal check square was the nature of relief in the central 1 km square considered significant enough to warrant attempted topographic-illumination correction. This was carried out using software developed by Cambridge University Geography Department and used operationally in creating the Land Cover Map 2000 (Fuller *et al.* 1999a). Differential illumination across the landscape, and its consequent effects on the radiation recorded by the CASI sensor, were modelled using a smoothed version of the DTM and compensated for in the topographic correction software.

2.4 Image segmentation

The image segmentation procedure was based on the same software package being used in LCM2000 (Fuller *et al.* 1999b). Written originally in the Microsoft Windows environment by the Cambridge University Geography Department, Laser-Scan has now implemented a fully operational version of the segmentation software, in a Unix environment.

Important methodological issues for image segmentation include:

- band selection for edge-detection and segmentation,
- setting thresholds to identify edges and generate segments,
- post-segmentation boundary rejection and generalisation.

It was only possible to use three bands for the edge-detection / segmentation process and so the optimum choice of wavebands was investigated using the four trail 1 km squares of 1999 CASI data. Principle Components Analysis of the 12-band CASI images, demonstrated these data to be two-dimensional (with at least 96% of variance contained in PCs 1 and 2). The two dimensions related to the visible and near infrared (NIR) part of the spectrum. Correlation analysis supported these findings, with strong positive correlations within, but not between, the visible and NIR wavebands. In spite of the strong 2-dimensionality of the data-set, it was decided that out of the 12 available wavebands, the three bands which made the strongest contribution to PCs 1-3 and which were the least correlated were Bands 4, 6, and 10. These occupy a point of maximum red absorption by vegetation (670 nm), a point along the so-called ‘red-edge’ (708 nm) between the red absorption trough and NIR reflectance peak, and a point in the NIR vegetation reflectance maximum (780 nm). The segmentation algorithm was tested using PCs 1-3 and CASI Bands 4, 6 and 10, in the four Landscape types. This demonstrated the use of individual wavebands to give a better result, with more ‘meaningful’ parcels created.

The segmentation procedure builds parcels around ‘seed-points’ that have been selected as within a segment or a land parcel; an edge detector is used to ensure that the appropriate seed-points are selected away from parcel-edges. There is potential in the software to dictate the degree of region merging by setting segmentation thresholds for each of the spectral bands and by establishing the number of standard deviations expected to contain the majority of the population of a segment. If the first threshold (entered separately for each band) was set low (i.e. 1 SD) then a higher number of segments was generated initially. If the second threshold was then set high (i.e. 6 SDs in the farmed Landscape types and 3 SDs in the Uplands) a much greater level of region merging took place. This gave a much better end-product than growing bigger parcels initially, as more detail was retained without generating an overly segmented image.

Post-segmentation generalisation involved dissolving parcels of 9 or less pixels (i.e. one pixel of data in the raw CASI image) into the surrounding parcels. Sliver parcels greater than 9 pixels in size occurring at boundaries were, however, retained since linear features were very much a part of the CASI data.

It is important to note that this was a low-level segmentation process (Haralick & Shapiro, 1985) in that the parcels created were not necessarily meaningful entities (such as fields) but merely parts of them. The parcels were identified according to spectral variation which may have related, for example, to crop development, wind damage or unplanted field margins.

Once acceptable segmentations were achieved, vector versions were created in a GIS database. This was a simple procedure of raster-to-vector conversion where the boundaries between segments with different values in the raster images were represented by vector lines. These formed the basis of the vector data-base used in the classification procedure.

3. Airborne data classification

The classification approach was a per-parcel procedure based on CLEVER-Mapping (Smith & Fuller 1998, 2001), using the vector boundaries derived from the segmentation procedure and the full 12-band CASI images. Due to restrictions of the software package, a 16-bit to 12-bit conversion of the imagery was required. This reduced the dynamic range of the spectral values recorded, but maintained the relative differences between landscape features.

The classification was trained by assigning a class value to selected parcels of known land-cover types (Table 9). For the trial squares, this made use of detailed data from the Field Assessment Booklets and from personal visits to the sites during 1998 and 1999. Training was carried out separately for the following 1 km CASI data-sets: Arable trial square (1998 CASI data); Arable and Pastural trial squares (1999 CASI data); Marginal trial square (1999 CASI data); and Upland trial square (1999 CASI data). Only in the case of the Arable and Pastural squares in 1999 CASI data, was land-cover distribution considered similar enough to enable between-site spectral normalisation. The total array of spectral sub-classes identified across the 1km squares is shown in Table 10. These could be readily amalgamated into Broad Habitats, with the one exception of BH 3 (Boundary and linear features) which was trained for classification into its constituent parts of hedges and built surfaces.

The basic aim of the training procedure was to identify as much spectral variance within the image as possible, and to achieve this for each land-cover type present (i.e. to achieve a full and accurate sub-division of the spectral feature space). Because of the nature of the segmentation process, the parcels available for training varied in size, but were reasonably consistent in spectral variance. The important consideration in creating a training data-set was therefore not achieving an equal distribution of parcel size, but achieving an even distribution of training parcels throughout the spectral feature space.

Having identified a series of training parcels, it was then necessary to review the training data to decide on the spectral sub-classes to be used for classification. A refinement built into IGIS operation (as part of the LCM2000) allowed ‘image chips’, representing the remotely sensed data for each training area, to be displayed side-by-side on the screen, almost like a colour-chart. This enabled the training parcels to be compared and labelled to give a series of different spectral sub-classes where necessary (Kershaw and Fuller, 1992). The training areas were reviewed in what was considered to be the two most useful 3-band combinations (Bands 4, 3, 2 and Bands 10, 6, 4) to ensure that the spectral sub-classes were not mixed. When deciding on the aggregation of training parcels, the general rule applied was that the narrower range of spectral variance allowed in each spectral sub-class, the less likely would be confusion in classification at the aggregate level. For example, 11 sub-variants of bog were identified in the classification of the Upland trial square.

The classification procedure used the Maximum Likelihood algorithm (Schowengerdt 1997) applied to the parcel, using mean statistics to select the most likely class in statistical terms. The parcel statistics were extracted from a shrunken area (by a margin of 3 pixels) to avoid edge pixels with a mixed signature.

Land-cover Class	Arable Trial square		Pastural trial square	Marginal trial square	Upland trial square
	1998 data	1999 data	1999 data	1999 data	1999 data
Arable bare	X	X	X	X	-
Arable barley	X	X	-	-	-
Arable harvested	X	X	-	X	-
Arable kale	X	-	-	-	-
Arable linseed	-	X	-	-	-
Arable maize	-	X	X	-	-
Arable peas	X	-	-	-	-
Arable rape	-	X	-	-	-
Arable set-aside	X	-	-	-	-
Arable turnips	X	-	-	-	-
Arable wheat	X	X	X	-	-
Grassland – improved	X	X	X	X	-
Grassland – neutral	X	X	X	X	-
Grassland – acid	-	-	-	X	X
Coniferous woodland	X	X	-	-	-
Deciduous woodland	X	X	X	X	-
Deciduous hedge	X	X	X	X	-
Dwarf shrub heath	-	-	-	-	X
Fen, marsh, swamp	-	-	-	X	-
Bog	-	-	-	-	X
Built surface	X	X	X	X	-
Water	X	X	-	X	-
Shadow	X	X	X	X	-

Table 9 Land-cover types identified (X) in each trial 1 km square. (Note each of these land-cover types may be composed of several spectral sub-classes)

Landscape type	No. of parcels	No. of spectral sub-classes	No. of land-cover types	No. of Broad Habitats
Arable (1998 data)	103	41	16	7
Arable & Pastural	200	59	15	7
Marginal	139	40	11	8
Upland	63	17	3	3

Table 10. Breakdown of the training data used for the classification of the trial squares. (Note that the Arable and Pastural Squares in 1999 CASI data were trained and classified together.)

4. Knowledge-based correction

A degree of mis-classification of parcels was expected due to spectral similarities between certain land-cover types. Likely inter-class confusion could be estimated prior to classification from the review of training data. For example, the three grassland types in the four trial sites (improved, neutral and acid) showed spectral overlap with each other, and with sunlit aspects of deciduous woodlands / hedges, and with certain crop types (e.g. oilseed rape, peas, maize, barley) depending on crop maturity. The shaded aspects of deciduous woodlands / hedges showed spectral overlap with mature arable wheat, marsh / swamp, water, and shadow; whilst built surfaces showed spectral overlap with the arable classes of bare, harvested, and set-aside. Since shadows can be cast over any land-cover type present within a square, this class had a wider spectral range and showed overlap with more land-cover classes than the other spectral sub-classes.

Knowledge-based correction (KBC) procedures were required to address these classification errors, and have been developed using a combination of context, ALTM height data, CS 1990 codes, and class probabilities. Because the correction procedures operated per-parcel, more subtle internal context rules could be used (e.g. assigning parcels to adjoining or nearby classes).

4.1 Phase-1 KBC procedure

The simplest KBC rules devised were contextual, based on a parcel being surrounded by an unlikely land-cover type (Table 11). To give some examples, an arable parcel surrounded by built surfaces was relabelled as built, whilst a shade parcel surrounded by deciduous woodland was coded as deciduous. It must be remembered that, although the parcels reflect genuine spectral variance from ground features, they do not necessarily represent whole objects. Thus, fields were composed of many parcels, and so the KBC rules operated at the within-field level. Changes to parcel class assignment through the KBC process were applied at the level of land-cover types within the Broad Habitats. Thus in an arable setting, class re-assignment would be to an individual crop type.

The ALTM height data was invaluable at addressing mis-classification between the deciduous woodland / hedge classes and certain grassland and arable classes. It was possible to identify a height threshold, which all parcels classified as hedge or woodland must exceed, and all other parcels (except for built surface) must be under. Conversion to deciduous woodland / hedge classes was a simple matter, but conversion from deciduous woodland / hedge to neighbouring land-cover classes was according to local context and a series of class priority rules.

The CS 1990 reporting codes (and obviously the CS 2000 codes in any repeat exercise) represent an important data source that could be used in the KBC process. However, using these data for full knowledge-based correction would remove any ability to identify change by the classification of airborne imagery. Exceptions to this are the more stable classes such as roads, railways and built up areas, which are highly unlikely to be converted into agricultural use, grassland, forestry or semi-natural vegetation. Thus, a mask of CS 1990 reporting classes 51-52 (Railway and Road) and classes 53-55 (Built on land) was applied to identify and re-assign parcels mis-classified as arable (bare, maize, harvested), shadow, or water. From an operational standpoint, this correction can only be applied to Countryside Survey squares for which previous field survey data exist.

Land-cover class	Surrounded by:	Convert to:	In Square(s):
Arable bare	Arable barley	Arable barley	Ar (98)
Arable bare	Arable set-aside	Arable set-aside	Ar (98)
Arable bare	Built surface	Built surface	Ar /Pa (99)
Arable barley	Arable harvested	Arable harvested	Ar (98)
Arable barley	Arable set-aside	Arable set-aside	Ar (98)
Arable barley	Grassland - improved	Grassland – improved	Ar /Pa (99)
Arable harvested	Arable wheat	Arable wheat	Ar (98)
Arable harvested	Built surface	Built surface	Ar /Pa (99)
Arable maize	Built surface	Built surface	Ar /Pa (99)
Arable peas	Arable bare	Arable bare	Ar (98)
Arable peas	Arable harvested	Arable harvested	Ar (98)
Arable peas	Arable wheat	Arable wheat	Ar (98)
Arable rape	Grassland - improved	Grassland – improved	Ar /Pa (99)
Arable turnips	Arable barley	Arable barley	Ar (98)
Arable wheat	Arable harvested	Arable harvested	Ar (98)
Arable wheat	Arable rape	Arable rape	Ar /Pa (99)
Grassland – improved	Arable peas	Arable peas	Ar (98)
Grassland – improved	Arable set-aside	Arable set-aside	Ar (98)
Grassland – improved	Arable rape	Arable rape	Ar /Pa (99)
Grassland – improved	Arable maize	Arable maize	Ar /Pa (99)
Grassland – improved	Grassland – neutral	Grassland – neutral	Ar /Pa (99)
Grassland – improved	Grassland - acid	Grassland – acid	Ma (99)
Grassland – neutral	Grassland – improved	Grassland – improved	Ar /Pa (99)
Grassland - acid	Grassland - improved	Grassland – improved	Ma (99)
Fen, marsh, swamp	Grassland – acid	Grassland – acid	Ma (99)
Fen, marsh, swamp	Grassland - improved	Grassland – improved	Ma (99)
Deciduous hedge	Arable harvested	Arable harvested	Ar (98)
Deciduous hedge	Arable peas	Arable peas	Ar (98)
Deciduous hedge	Arable set-aside	Arable set-aside	Ar (98)
Built surface	Arable set-aside	Arable set-aside	Ar (98)
Built surface	Grassland – improved	Grassland – improved	Ar (98)
Built surface	Grassland	Arable bare	Ar /Pa (99), Ma (99)
Built surface	Arable	Arable bare	Ar /Pa (99), Ma (99)
Shadow	Deciduous woodland	Deciduous woodland	Ar (98), Ar /Pa (99)
Shadow	Arable wheat	Arable wheat	Ar /Pa (99)

Table 11. Contextual knowledge-based correction rules as applied to the Arable, Pastural and Marginal trial squares.

Ar (98) = Arable trial square in 1998 CASI data, Ar /Pa (99) = Arable and Pastural trial squares (1999 CASI data), Ma (99) = Marginal trial square (1999 CASI data).

4.2 Phase-2 KBC procedure

The Phase-1 KBC procedures were applied to the spectrally determined parcels. Additional KBC procedures could be performed on a per-pixel basis and after aggregating all contiguous parcels of the same land-cover class. At the aggregate level, a repeat of the above contextual KBC rules enabled additional cleaning to take place. For example, a patch mis-classified as grass in the middle of an arable field, would not have been converted in the Phase-1 KBC procedure if composed of more than one parcel. In addition, at the aggregate level, it was possible to add a suburban label to parcels of grass or woodland land-cover within an urban setting, thereby placing them into BH 17 (Built up areas and gardens).

At the pixel level, a more spatially detailed knowledge-based conversion was performed to correct deciduous woodland / hedge classification and to remove shadow. Per-pixel KBC was particularly useful for correcting between deciduous woodland / hedge and other classes, since the height data was averaged across spectrally defined parcels in the Phase-1 KBC. The greater spatial detail of per-pixel KBC also enabled the attempted conversion of shade parcels into the likely underlying land-cover types, according to a series of decision rules based on context and class priorities.

Although not used in the above KBC procedures, there is no reason why the elevation, slope and aspect information derived from the ALTM data could not be used to identify parcels assigned to classes outside their natural context. This may prove particularly useful in the Upland Landscape type, for which no KBC rules have yet been developed. The issue of texture variations in the height and elevation data as a means of identifying different land-cover types (especially coniferous and deciduous woodland) was not addressed due to time constraints, but could represent a further stage in KBC.

4.3 Additional KBC applied to Arable trial square in 1998 CASI data

Additional KBC procedures were developed for the classified 1998 CASI data of the Arable trial square which sought to recognising features as objects. The temporary conversion of the classified vector data back to a 1m raster grid removed boundaries between adjacent parcels of the same land-cover class and enabled per-pixel filtering operations to be performed on the woody vegetation class. The component features of this land-cover class were identified in a three stage process. Stage 1 involved first shrinking a mask of the woody vegetation class to a point that removed all scattered trees and linear features, and then re-growing the mask remnants guided by a height threshold. This identified patches of woodland and scrub from scattered trees, hedgerows and treelines. Within these latter woody vegetation types, trees could be discriminated from hedges by a greater width and height. Stage 2 involved calculating a focal sum for the remaining woody vegetation mask and applying thresholds to the sum and relative height data to identify the approximate centroids of trees. These were then buffered outwards within the area covered by the woody vegetation class. Re-vectorising these data (Stage 3) enabled the separation of trees in hedgerows or treelines from scattered individuals or clumps according to the surrounding context. A brief KBC to tidy up any ‘stray’ parcels of woody vegetation not captured by the region-growing filters gave the final arrangement of parcels. The final product consisted of a vector database in which the parcels closely relate to ‘real world’ objects (such as the cropped areas of fields, field margins, woodland patches, hedgerows etc). Fourteen land-cover types were identified, including 5 different crop types, improved grassland, neutral grassland, bare ground, built surfaces, water bodies, woodland patches, scattered trees, and hedgerows / treelines (with the presence of trees identified). At this 14 class level, the correspondence with field survey was 88%. Each parcel contained 3-dimensional data relating to the form and terrain context of the object identified.

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APPENDIX V - APPLICATION OF THE PROCESSING FLOW-LINE TO THE CHECK SQUARES

The processes of creating a DSM from the ALTM first pulse data, and CASI flight-line normalisation involved running a series of automated software applications. The methods developed for the trial squares could thus be applied directly and objectively to the check squares. The extraction of 'terrain' from the DSM and the segmentation of the CASI images were both multi-stage processes involving the running of programs which required operator input of threshold values. Optimal values were derived for the trial squares, and these were found to be directly applicable to the check squares. Cleaning the height data to remove the slight edge-of-flight-line errors and registering the CASI flight-lines to the corresponding DSM were manual processes requiring considerable operator interaction. The techniques were readily transferable from the trial to the check squares, but the cleaning and registering processes were unique to each flight-line and so there was no 'correction algorithm' that could be transferred from one image file to another. Recent developments in the Environment Agency image acquisition system should reduce data quality problems, and therefore reduce these highly interactive pre-processing phases from any repeat exercise.

To investigate the transfer of training data from trial to check squares, it was necessary to normalise the spectral data of each check square to match its corresponding trial square. This was achieved by shifting the mean radiance value in each waveband of the check squares to match those of the trial squares. Since an inherent assumption in this procedure was that the type and proportions of land-cover were similar between sites, the transferability of spectral characteristics between sites was restricted. In the Arable and Pastural sites (which have a mixture of grassland and agricultural land-cover types), it was possible to normalise the check squares to the trial squares. This created a set of four 1km^2 images in which classification was achieved by training the two trial squares and applying these training data to the check squares. Although intended as a 'blind test' the training data were applied to the check squares with minor modifications, inserting three additional land-cover types not present in the trial squares (arable field beans, arable lucerne, and calcareous grassland). The land-cover of the Marginal sites was too distinct to allow their normalisation with the Arable and Pastural sites, but it was possible to normalise the check square to the trial square. This enabled the roll-over of the classification training data from the trial to the check square. However, as the check square contained fewer land-cover types than the trial square, the superfluous training data were not included in the classification. For the Upland sites, the land-cover of the check square was very different to that of the trial square. As a result, these images were not normalised and no attempt was made to transfer training data from the trial square to the check square. Instead the check square was trained independently using known examples of land-cover type (including bracken, bog, fen / marsh / swamp, acid grassland, bare rock).

The KBC rules were also applied directly to the check squares, with only minor alterations required. This involved: slight changes to the height thresholds used for correcting woodland / hedge classification; the addition of extra rules to address problems of water mis-classification in the Arable and Pastural check squares; and the removal of rules relating to classes not present in the Marginal check square. As with the trial square, no KBC rules were applied to the Upland site, since there were insufficient ground data to identify mis-classification. Because the Upland squares were trained for classification independently, there was no need for correction rules to remove incorrectly identified land-cover classes from rolled-over training data. However, if this classification process was repeated over a larger area, the elevation, slope and aspect data supplied by LIDAR would almost certainly be of use in KBC rules.

APPENDIX VI - ISSUES IN THE COMPARISON OF CLASSIFIED AIRBORNE MAGERY WITH FIELD SURVEY DATA

Field survey data were supplied in both paper format (photocopied Field Assessment Booklets) and digital format (a vector GIS in which labels were attached to both the parcels and linework). Correspondence was investigated between the classified airborne data and the digitised field survey widespread Broad Habitat data. Although both data-sets have land-cover data in more detailed classes than the Broad Habitats, this is the only level at which automated validation can be performed readily.

Three potential methods of calculating correspondence were investigated:

1. per-pixel correspondence between the two data-sets at 1 m spatial resolution;
2. labelling the segmented CASI parcels with field survey data and comparing the result with the classified airborne data; and
3. labelling the field survey parcels with the dominant class from the airborne data and comparing the result with the field survey data.

Investigations, as part of the LCM2000 validation work, have shown that rasterising the CS2000 vector data to a 1 m grid alters the spatial area estimates of Broad Habitat classes by an average of just 0.1%. Comparison between the two 1 m spatial resolution grids thus gives a direct correspondence per-pixel between the field survey and airborne image classifications. Attaching the classification of one data-set into the vector boundaries of the other for validation purposes was tested for the Arable trial square in 1998 CASI data. The level of correspondence increased from 86% for method 1, to 88% for method 2, and to 94% for method 3. As these figures suggest, labelling the segmented CASI parcels with field survey data made few changes to the distribution of land-cover as mapped by the field survey. However, labelling the field survey parcels with the dominant class from the airborne data had the effect of generalising land-cover mapped in the airborne data, since the field survey vector had fewer land parcels. As one of the per-parcel approaches made little difference to the per-pixel scores, and the other gave higher scores by generalising detail in the airborne data classification, it was considered best to use a per-pixel approach for calculating correspondence.

Subtle differences exist between the field survey Broad Habitat data and the classified airborne data:

- a one year time difference exists between the 1998 field survey and 1999 airborne imagery;
- a mis-alignment occurs between the two data-sets as the field survey linework, digitised from OS mapsheets, does not meet the 15 cm x-, y-accuracy of the ALTM data (which, here, is considered the baseline for inter-comparisons);
- a distinction occurs between land-use mapped in the field survey and land-cover mapped in the airborne imagery (e.g. BH 3 (Boundary and linear features) is an amalgamation of hedges, roads and railways);
- the field survey does not identify hedges as features having an area, but as boundary features in a separate layer of the GIS database.

To make the two data-sets more comparable, a degree of editing of the field survey data was necessary. The 1999 field reconnaissance data were used, where necessary, to update the land-cover of fields identified as arable or improved grassland in the 1998 field survey data of farmed Landscapes. An object-based classification would have been necessary to achieve the operational identification of BH 3 (Boundary and linear features) in the airborne digital data. Instead, BH 3 is identified in its constituent elements of hedgerows / treelines, walls and built surfaces. To render the CS2000 field data comparable all boundaries identified in the vector linework as hedges or walls were given a nominal width comparable to the airborne data spatial resolution. The inserted hedges were assigned to BH 1 (Broadleaved, mixed and yew woodland), and dry stone walls to Broad Habitat 17 (Built up areas and gardens). Improved registration of the two data sets was necessary since the boundaries in the field survey data were not located with the same geometric precision as with the airborne digital data. The effect of boundary shifting and hedge insertion was to reduce the width of BH 3 (Boundary and linear features) in the field survey digital data and restrict this class to its built surface component. In the correspondence analysis this was regarded along with BH 17 (Built up areas and gardens) as a predominantly built surface. Individual trees that were identified in the field survey were inserted into the vector data-base as BH 1 (Broadleaved, mixed and yew woodland). Finally, BH 13 (standing open water and canals) and BH 14 (rivers and streams) were treated as one water class.

APPENDIX VII – PERCENTAGE COVER ESTIMATES FROM CLASSIFIED AIRBORNE DATA AND FIELD SURVEY

The tables below show percentage cover estimates for 1 km CS squares, calculated from the classified airborne data (1999 CASI and ALTM) and edited field survey data. Edits to the field survey include: the insertion of hedges and treelines as features with width (placed in BH 1); the shifting of boundaries for a better alignment between the two data sets; the placement of the road and railway component of BH 3 into BH 17.

	Airborne data	Field survey
BH 1	22.2%	17.7%
BH 4	60.3%	62.4%
BH 5	13.7%	14.8%
BH 6	0.7%	1.4%
BH 13	0.1%	0.1%
BH 17	3.0%	2.7%

Arable trial square.

	Airborne data	Field survey
UNCLASSIFIED	-	7.2%
BH 1	18.9%	8.7%
BH 2	-	0.8%
BH 4	36.2%	23.9%
BH 5	36.5%	55.0%
BH 6	3.0%	-
BH 14	0.9%	1.7%
BH 17	4.5%	2.7%

Arable check square.

	Airborne data	Field survey
UNCLASSIFIED	-	0.3%
BH 1	10.8%	7.0%
BH 4	20.3%	19.7%
BH 5	59.8%	61.7%
BH 6	0.3%	0.2%
BH 17	8.8%	11.1%

Pastural trial square.

	Airborne data	Field survey
UNCLASSIFIED	-	0.8%
BH 1	13.2%	7.8%
BH 4	16.3%	12.0%
BH 5	65.4%	69.7%
BH 6	0.1%	3.7%
BH 7	0.1%	0.2%
BH 8	-	0.3%
BH 17	4.9%	5.5%

Pastural check square.

	Airborne data	Field survey
UNCLASSIFIED	-	0.2%
BH 1	5.0%	4.4%
BH 4	22.9%	23.1%
BH 5	45.5%	48.8%
BH 6	5.1%	3.7%
BH 8	8.2%	6.3%
BH 11	9.5%	5.9%
BH 13	0.8%	0.0%
BH 17	3.1%	3.9%
BH 8 + 10 mosaic	-	3.5%

Marginal trial square.

	Airborne data	Field survey
UNCLASSIFIED	-	0.2%
BH 1	2.6%	2.0%
BH 4	19.8%	13.4%
BH 5	48.7%	70.7%
BH 6	22.4%	5.7%
BH 17	6.5%	5.2%

Marginal check square.

	Airborne data	Field survey
BH 8	18.4%	7.3%
BH 10	17.5%	5.5%
BH 12	64.1%	48.0%
BH 8 + 10 mosaic	-	1.6%
BH 10 & 12 mosaic	-	37.1%

Upland trial square.

	Airborne data	Field survey
BH 8	23.0%	25.9%
BH 9	0.6%	1.0%
BH 11	4.8%	7.2%
BH 12	69.5%	64.9%
BH 26	2.1%	1.0%

Upland check square.

APPENDIX VIII – COMPARISON OF CLASSIFIED AIRBORNE DATA, LCM2000 AND FIELD SURVEY

The tables below show percentage cover estimates for 1 km CS squares, calculated from the Land Cover Map 2000, classified airborne data, and field survey data. All data sets have a 25 metre spatial resolution (i.e. the airborne and field data have been re-sampled). No edits have been made to the field survey data.

	LCM 2000	Airborne data	Field survey
BH 1	16.25%	20.69%	13.38%
BH 2	-	-	0.06%
BH 3	-	-	2.75%
BH 4	51.31%	62.94%	65.0%
BH 5	18.31%	13.89%	16.44%
BH 6	-	0.69%	1.50%
BH 7	3.69%	-	-
BH 13	-	-	0.06%
BH 17	4.50%	1.81%	0.81%
BH 26	2.50%	-	-

Arable trial square.

	LCM 2000	Airborne data	Field survey
UNCLASSIFIED	-	-	7.13%
BH 1	16.75%	19.38%	7.00%
BH 2	1.81%	-	0.75%
BH 3	-	-	2.56%
BH 4	26.88%	37.75%	32.88%
BH 5	50.50%	37.00%	47.38%
BH 6	-	2.38%	-
BH 13	-	-	-
BH 14	-	0.44%	1.56%
BH 17	4.06%	3.06%	0.75%

Arable check square.

	LCM 2000	Airborne data	Field survey
UNCLASSIFIED	-	-	0.38%
BH 1	3.56%	7.19%	1.50%
BH 2	0.38%	-	-
BH 3	-	-	2.69%
BH 4	53.25%	20.38%	20.69%
BH 5	28.88%	63.88%	64.25%
BH 6	-	0.13%	0.31%
BH 7	6.00%	-	-
BH 17	7.94%	8.44%	10.19%

Pastural trial square.

	LCM 2000	Airborne data	Field survey
UNCLASSIFIED	-	-	0.44%
BH 1	14.19%	10.50%	3.44%
BH 2	1.19%	-	-
BH 3	-	-	3.62%
BH 4	4.50%	15.94%	12.19%
BH 5	72.00%	69.50%	73.31%
BH 6	-	-	4.19%
BH 7	1.44%	0.13%	0.25%
BH 8	-	-	0.31%
BH 17	6.69%	3.94%	2.25%

Pastural check square.

	LCM 2000	Airborne data	Field survey
UNCLASSIFIED	-	-	3.75%
BH 1	3.13%	3.94%	1.81%
BH 3	-	-	4.69%
BH 4	17.94%	23.56%	23.94%
BH 5	37.50%	47.19%	49.00%
BH 6	41.44%	4.25%	4.25%
BH 8	-	7.63%	6.63%
BH 11	-	9.75%	5.94%
BH 13	-	0.75%	-
BH 17	-	2.94%	-

Marginal trial square.

	LCM 2000	Airborne data	Field survey
BH 1	0.88%	2.13%	2.25%
BH 2	0.13%	-	0.06%
BH 3	-	-	5.00%
BH 4	-	17.88%	13.63%
BH 5	82.75%	51.69%	72.38%
BH 6	-	22.94%	6.00%
BH 7	13.38%	-	-
BH 10	2.88%	-	-
BH 13	-	-	0.06%
BH 17	-	5.37%	0.63%

Marginal check square.

	LCM 2000	Airborne data	Field survey
BH 8	-	17.00%	7.56%
BH 10	-	14.25%	5.44%
BH 12	99.88%	68.75%	47.81%
BH 26	0.13%	-	-
BH 8 + 10 mosaic	-	-	1.69%
BH 10 + 12 mosaic	-	-	37.50%

Upland trial square.

	LCM 2000	Airborne data	Field survey
BH 8	79.37%	21.44%	26.63%
BH 9	-	0.69%	0.88%
BH 10	-	-	-
BH 11	-	2.94%	6.81%
BH 12	20.63%	73.50%	64.69%
BH 26	-	1.44%	1.00%

Upland check square.