ENVIRONMENTAL MONITORING AND MAP REVISION USING INTEGRATED LANDSAT AND DIGITAL CARTOGRAPHIC DATA SETS.

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1.0 INTRODUCTION

1.1 THE ENVIRONMENTAL PROBLEM PRESENTED

The character of Broadland pasture was established before the eighteenth century by the artificial drainage of silt-based marshes found in some Norfolk and Suffolk rivers (4). Land management remained unchanged for centuries, and a distinctive pastoral landscape emerged. Recently, movement from pastoral to arable farming has been encouraged by the EEC's Common Agricultural Policy. Important plant and animal communities (whose habitats are the pastures and their drainage ditches) are under threat. These ecological reservoirs need to be protected.

1.2 TOWARDS A SOLUTION OF THE ENVIRONMENTAL PROBLEM

To protect plant and animal communities some knowledge of their location is required. For plants this can be achieved by vegetation mapping. For animals a means must be devised for mapping habitats. Habitat identification procedures differ, and the significant landscape characteristics vary for each animal (7), but the location and dimension of vegetation zones are among the significant characteristics when assessing animal habitat. A first step in the solution of this environmental problem is thus the production of vegetation maps.

Many threatened areas have a protection agency associated with them. In this case it is the Broads Authority (BA), created in 1979, and having a requirement "to define the problems of Broadland, (and) solutions to them, and to secure implementation of these solutions" (2). The BA perceived that part of the solution could be achieved by:

1) acquiring up-to-date 1:10 000 vegetation maps of the area of concern;
2) using these maps to derive acreages of the vegetation zones, and to generate inexpensive cartographic documents for field workers;
3) devising a means of detecting changes in the vegetation cover; and,
4) devising a means of using recent records to derive the rate of vegetation change.

These four steps can be labelled the spatial data aspects of the solution.

1.3 THE SPATIAL DATA ASPECTS OF THE SOLUTION

The UK Natural Environment Research Council (NERC) was approached to assist BA with these aspects of the solution. A Research Contract between BA and NERC enabled completion of the first two steps. An internal research project in NERC enabled completion of the third and fourth steps.

More specifically, vegetation zones were identified by photointerpreting 1980 1:10 000 panchromatic aerial photography, and thirty-eight monochrome 1:10 000 vegetation maps were produced on clear bases. These allowed cheap reproduction for field use. Map production was entirely by computer assisted methods, so a digital data set of the vegetation zones was created which could be accessed to derive zone dimensions, and which could be updated once a suitable method of change detection had been developed.

Landsat multispectral scanner (MSS) data contemporaneous with the photography was analysed and shown to produce data corresponding closely to vegetation cover information derived from the photography. Similar techniques applied to 1982 MSS imagery again provided information agreeing closely with "ground-truth", thereby convincing BA that MSS data provided sufficient detail for both updating the 1980 data set, and studying changes in the 1970's. It is the purpose of this paper to outline the mapping and remote sensing techniques developed within NERC to detect, record, and quantify the movement from pastoral to arable farming in the Broadland area of Eastern England.

2.0 PHOTOINTERPRETATION

As indicated, vegetation zones and classes were identified on 1:10 000 photography flown in January 1980. This was performed by a member of NERC's Institute of Terrestrial Ecology. Observation was on a Bausch and Lomb Stereo Zoom Transferscope and, utilizing its zoom and tilt facilities, a view of the stereoimage was fitted to the relevant 1:10 000 UK Ordnance Survey (OS) map. Vegetation boundaries were transferred to overlays on the 1:10 000 maps, and a coded centroid placed in each polygon showing its class. The thirty-one classes used are listed in TABLE 1. The brown shades of winter vegetation aided class intepretation(4).

TABLE 1

THE 31 LAND-USE CLASSES OF THE BROADLAND MAPPING PROJECT.

LANDUSE: Natural and semi-natural
HABITATS: woodland, carr, scrub, carr/fen, bracken, rough grassland, marsh/fen grassland, rough grazing, marsh/fen grazing, mown fen, mixed herbaceous fen, marsh/fen - cut reed, marsh/fen - uncut reed, reed swamp, intertidal saltmarsh.

LANDUSE: Water
HABITATS: drainage ditches, lakes, rivers, ponds.

LANDUSE: Constructions
HABITATS: railways, roads, tracks, footpaths, residential and service structures, commercial buildings, agricultural buildings, boatyards, embankments, piling, floodplain limit.

LANDUSE: Agriculture and Forestry
HABITATS: arable, pasture, plantation.

LANDUSE: Disturbed Ground.
HABITATS: bare ground.

3.0 GENERATION OF THE DIGITAL CARTOGRAPHIC DATA SET

The first stage of generating the digital cartographic data set involved digitising the boundary segments of the vegetation zones and their centroids. As the digitised document had been fitted to OS 1:10 000 maps the coordinate system was the British National Grid (BNG). In this particular project digitising was done at ARISTO workstations. The ARISTO System and in-house software permitted, and the project required, multiple attribute coding. Thus a line that was a track, an administration boundary, and separated two vegetation types such as carr and scrub would carry four codes, two online (track and boundary) and two offline (carr and scrub). On completing the digitising of each 1:10 000 sheet a check plot was produced at 1:10 000 on a flat-bed plotter using clear film and a 30 micrometer line weight. Overlaid on the original source document, errors could be identified for subsequent interactive editing.

Once a "clean" data-set was achieved the second stage of creating the data set, polygon generation, commenced. The algorithm used for polygon generation (3) is similar to others widely used, as is the algorithm used for the polygon dimension calculations (4)(8).

The final stage of vector data preparation involved coding the newly generated polygons on the basis of their centroid codes. In-house software also permitted polygon coding on the basis of offline codes but this approach required very "clean" data; as the whole data set comprised about 150,000 lines time did not permit the necessary interactive editing.

The line and centroid data were both used to produce the printed map series. Positive plots for screen masks were based on offline codes. Line symbology was based on online codes; and centroid text on centroid codes. All plotting was done by photohead on NERC'S ARISTO flat-bed plotter, enabling the production of monochromatic maps on clear film. The map product was suitable for Diazo reproduction, and hence fieldwork. A further map - an index map with a code number for each polygon was produced. This code number enabled access to data tables giving dimensional and land-use details for the polygons.

4.0 TRANSFER OF THE DIGITAL CARTOGRAPHIC DATA SET TO THE I2S.

The polygon (as derived looped lines), line, and centroid data held in NERC's PDP 11-45 hosted vector cartographic system, were written to magnetic tape in an exchange format containing a series of xy coordinate pairs together with header records giving details of polygon class and nesting level. The data were imported into NERC's HP 3000-III hosted International Imaging Systems' Image Analysis System (I2S). Although primarily used for satellite image analysis (1), the I2S can also be used as a raster cartographic system (6). During data input a transformation of xy coordinates was carried out to fit the vector data to the lattice used for raster data. Polygons, lines, and centroids were then stored in a vertices file format within the I2S. Next the polygons were rasterised. Particular polygon classes were selected and the data encoded onto one I2S refresh memory channel. The polygon boundary was first drawn on the graphics channel, and the polygon area in the refresh memory infilled line by line with a feature code unique to that polygon class. Once encoded the boundary and polygon class were saved as a raster image for future presentation and to aid the analysis of other imagery. The rasterised polygon data set could also have undergone interactive graphics editing at this stage.

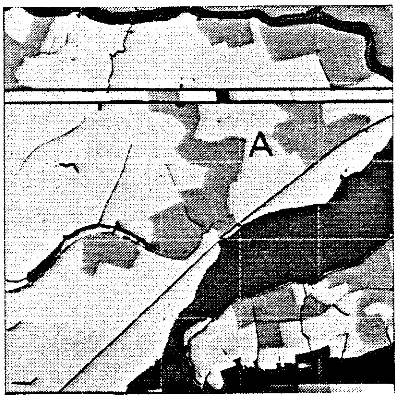
Of the thirty-eight 1:10 000 sheets forming the Broadland data set, one sheet was initially transferred from the vector system to the raster system. The sheet, Sheet 23 of the series, covered a 5x5 Km area, and lay within the 10x10 Km region of interest selected for detailed analysis using MSS data (see below). First, polygons with feature codes corresponding to all habitats within the 5x5 Km area were transferred such that the map filled an entire 512x512 area (Fig.1a). Second, only the polygons having three particular feature codes, open water, arable, and pasture, were transferred to a 250x250 area (Fig.1b). In both cases the resolution was considerably degraded from the original cartographic data set, but the display did immediately show up miscoded areas. Three feature coding errors, which were revealed by a comparison of the original photo-interpretation document with Fig.1a, were corrected in Fig.1b by the raster map editing facilities. Thus the vector based cartographic data was ready for combination with the satellite data, and accessible by the analytical and display software usually used to manipulate this raster data format.

5.0 GENERATION OF THE DIGITAL SATELLITE DATA SET

A multitemporal multispectral data set from Landsat sensors can be employed in two basic ways. First individual data sets acquired in different seasons within one year can be used to refine classification by combining data taken from different stages within the annual growth cycle. Second individual data sets acquired in one season but in different years can be used to study temporal changes in ground cover type.

MSS data sets covering Broadland were inspected for the 1980 growing season - autumn 1979 until summer 1980. Two were selected because they were acquired in spring and early summer in almost ideal conditions. A third was selected, despite some cloud, because it was acquired within a week of the photography taken for the BA project. For 1982 it was possible to select three good scenes with seasonally similar acquisition dates. Scene details are summarised in Table 2.

FIGURE 1



1a. The rasterised polygons transferred such that the area of the map covers a 512x512 array (9.77m pixel) and overlaid by a 1km grid.

1b. The rasterised polygons and their boundaries, transferred to exactly register with the satellite data (20.00m pixel).

Only three feature codes are represented, open water, arable land, and pasture land, in successively lighter shades of grey. The land parcel boundaries and grid are in white and all other feature codes and uncoded areas are in black. These five intensity levels are indicated by the superposed grey scale.

TABLE 2

THE SIX LANDSAT MSS SCENES OF BROADLAND

date	cloud cover	comments	no. of ground control pts.	RMSE (m)	max error (m)
31 Jan 1980	N partly obscured	low radiances	17	66	196
12 Apr 1980	clear	OK	25	56	137
18 May 1980	clear	OK	20	48	107
11 Jan 1982	clear	low radiances, snow in SW	19	63	106
20 Apr 1982	clear	N partly missing	22	65	141
26 May 1982	some small clouds in SW	OK	18	55	138

The OS 1:50 000 Sheet 134 includes the area of interest. Sheet 134 covers an area of 40x40 Km centred on 637000E and 310000N in the BNG coordinate system. For detailed intercomparison, all six MSS scenes were registered to the BNG. This involved several data processing steps (Sections 5.1 - 5.6).

5.1 DATA SELECTION

Each MSS scene covers an area of approximately 180x180 Km. Having read an entire scene from computer compatible tape into the I2S, the location in the scene of the point 637000E and 310000N was determined and a reduced area centred on this point but covering the region of interest extracted for further processing.

5.2 SYSTEMATIC RADIOMETRIC EFFECTS

The scene showed the six band striping inherent in the MSS scanning system. This was effectively removed by a locally variant analysis which minimised abrupt changes in mean and standard deviation over a relatively large window around each pixel.

5.3 SYSTEMATIC GEOMETRIC EFFECTS

Next the scene was corrected for non-linearities in the scanning mirror velocity, for the aspect ratio of the scanning system, for the effects of Earth rotation during scanning, and was rotated to a grid with north uppermost. A cubic spline interpolation of the 4x4 window about each pixel was used to retabulate the original scene onto this new grid.

5.4 FURTHER GEOMETRIC EFFECTS

The above corrections only include the most significant systematic effects. Not included are small effects due, for example, to variations in satellite altitude and attitude from their nominal values over the time of imaging. Thus a further geometric correction stage is needed to reduce systematic errors to the magnitude of random errors, i.e. less than 1 pixel.

After combining MSS bands 7, 5, and 4 into a false colour composite, a simple linear contrast stretch displaying the central 90% of each spectral channel was found to be the most effective for ground control pointing. For features easily recognised both on this stretched image and on the map, sample and line numbers were determined from the starting image, and BNG coordinates read off the map were converted to sample and line numbers in the target image. Accurate ground control pointing requires points with high contrast and reproducible positions. Road and runway intersections provide good ground control points, but care must be exercised with natural features. About 20 control points for each scene were used to determine the second order polynomial describing the transformation from the starting to target coordinates. RMSE of the fit was typically about 0.6 pixels. Details are given in TABLE 2.

5.5 GEOMETRIC CORRECTION

Each scene was then reduced to the target frame required, with an origin at the north-west of the image of 617000E and 330000N. A pixel size of 20.00m was selected to cover an area of 40.96x40.96 Km in an image of size 2048x2048. Although the MSS data is heavily oversampled with this pixel size, the results are more interpretable than those where pixel size and resolution are comparable. Also such data can be easily integrated with those from the higher resolution sensors which will also provide imagery of the area.

5.6 MULTISPECTRAL STATISTICAL ANALYSIS

At this point all six MSS scenes and the Broadland map sheet were on a common coordinate frame ready for comparison. Statistics determined for each scene included the covariance matrix, Eigenvalues, and Eigenvectors, and these were used for a Karhunen-Loeve transformation. The choice of wavelength bands for the

MSS sensors is such that usually bands 6 and 7 are highly correlated, and to a lesser degree bands 4 and 5. The Eigenvectors showed that the first principal component was almost entirely a combination of bands 6 and 7, while the second was almost entirely composed of bands 4 and 5. The Eigenvalues showed that these components accounted for 0.99 of the total scene variance, leaving little information to be shared between the third and fourth principal components.

5.7 MULTITEMPORAL STATISTICAL ANALYSIS

A more detailed statistical analysis was performed on a 512x512 section of the 20m pixel image. The region of particular interest was a 10.24x10.24 Km area with a north-west corner at 641000E and 311000N, and included the area for which digital ground truth data was transferred to the I2S. This area was cloud free on all six acquisition dates.

Firstly a principal components analysis was performed on the four band scenes from each date separately. Because this area covered a much more restricted range of habitats than the 40x40 Km area analysed earlier (Section 5.6), the feature space rotation to yield the principal components was more scene specific. In Fig.2 the first principal components derived for each of the six separate dates are displayed. Secondly the analysis was performed on eight band scenes, combining in pairs the three dates from one year. Thirdly the analysis was performed on a twelve band scene combining all dates from one year together. The results are summarised in Table 3. The contribution of the second principal component remains approximately the same for 4, 8, and 12 band analyses. However as the number of observed bands increases, the third principal component increases in importance. Thus for the twelve band analyses the first principal component does not overshadow the higher order components to the extent it did for the four band analyses.

TABLE 3

SPECTRAL CORRELATION FOR THE SIX MSS SCENES OF BROADLAND.

Proportion of total scene variance in the first four principal components.

	1980					1982				
	PC1	PC2	PC3	PC4	Total	PC1	PC2	PC3	PC4	Total
Jan	0.906	0.060	0.018	0.015	1.000	0.838	0.138	0.012	0.010	1.000
Apr	0.878	0.113	0.004	0.003	1.000	0.836	0.155	0.005	0.003	1.000
May	0.903	0.089	0.004	0.002	1.000	0.864	0.127	0.005	0.002	1.000
Jan+Apr	0.858	0.102	0.023	0.005	0.988	0.779	0.133	0.058	0.017	0.987
Apr+May	0.834	0.082	0.060	0.015	0.991	0.754	0.120	0.093	0.024	0.991
Jan+May	0.871	0.082	0.032	0.004	0.989	0.806	0.115	0.054	0.015	0.990
Jan+Apr+May	0.823	0.079	0.062	0.016	0.980	0.731	0.112	0.090	0.029	0.962

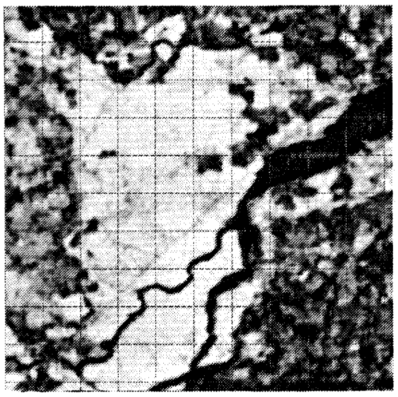
6.0 THE INTERPRETATION OF CARTOGRAPHIC AND SATELLITE DATA

In 1982 Imhoff et al.(5) stated that "boundary information on processed satellite data can provide an image product ideal for assessing the ability of a particular data processing technique to delineate such boundaries", and described a method for achieving this. As long as this integration is achieved, it should be possible to go one step further than Imhoff et al. and actually use the map derived boundary information in analysis of the satellite data. Integrating data sets from these two very different sources (i.e. vector digital cartographic and raster satellite data) requires that the sets be:

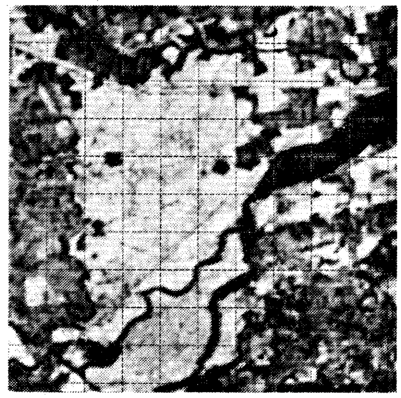
1) in the same format;
2) transformed to a common coordinate system;

FIGURE 2

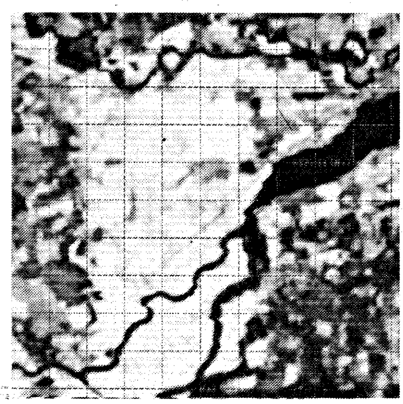
The First Principal Component of the MSS data for a 10x10 Km area of Broadland



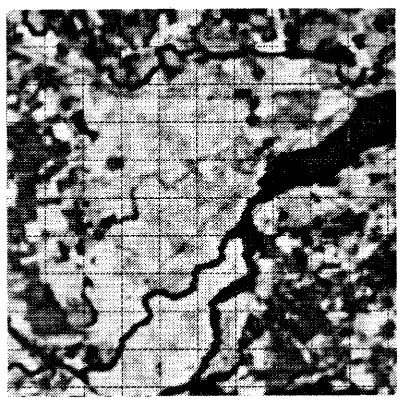
2a. 31 Jan 1980
(+0.037,-0.006,+0.638,+0.768)0.906



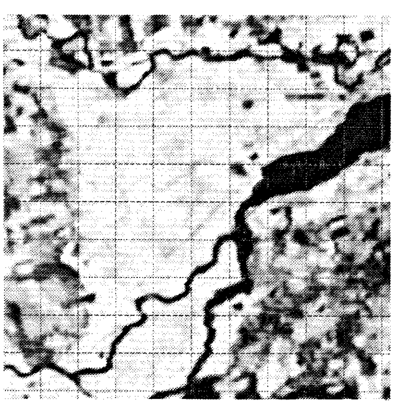
2b. 11 Jan 1982
(+0.098,+0.136,+0.607,+0.776)0.838



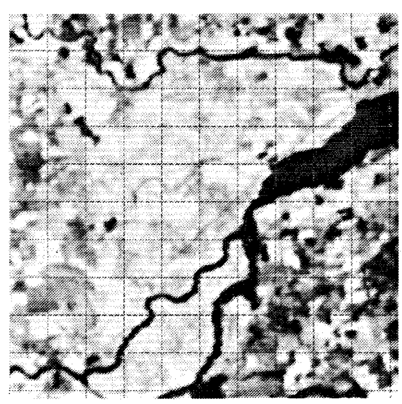
2c. 12 Apr 1980
(-0.077,-0.166,+0.556,+0.810)0.878



2d. 20 Apr 1982
(-0.050,-0.123,+0.577,+0.805)0.836



2e. 18 May 1980
(-0.064,-0.144,+0.564,+0.810)0.903



2f. 26 May 1982
(-0.032,-0.107,+0.576,+0.809)0.864

The four numbers in brackets refer to the weights with which MSS channels 4,5,6,and 7 combine to give the first principal component. The final number represents the fraction of total scene variance contributed by that component. A 1Km grid is overlaid on each scene.

3) of compatible resolution; and,
4) some of the cartographic and satellite data sets be contemporaneous.

The first condition has been satisfied by rasterising the cartographic polygons. The cartographic data is already in the BNG coordinate system (Section 3.), and the satellite data can be transformed to this system (Section 5.) so the second is also satisfied. Considering the third, the precision associated with polygon boundaries in the cartographic data is more than the precision with which these boundaries can be detected on the satellite data. However changing boundaries are not being monitored in this project, but changing vegetation within those boundaries. As polygon dimensions are all in excess of 10 Ha the required resolution of the cartographic data set is, for this part of the exercise, considerably coarser than its actual resolution. The satellite data resolution is 0.6 Ha and is compatible with the nature of the problem to be solved. The fourth condition is also satisfied here (Section 5.0). Therefore, the cartographic data set for the 5x5 Km area of Sheet 23 could be integrated with and subsequently used to supervise the classification of the coregistered multitemporal 1980 MSS imagery of the 10.24x10.24 Km surrounding area.

6.1 SPECTRAL SIGNATURES

Image analysis on the I2S can be performed on an entire image or limited to a user defined region-of-interest (roi) polygon, to several such roi's, or indeed to Boolean combinations of them. Different analyses can be performed inside and outside the roi's. These regions are usually cursor inserted, have a very simple geometry, and are known by the user to enclose a particular environment. It is equally possible to use complex roi's derived from external digital cartographic data sets as opposed to the simple data sets derived from cursor input. From the digital cartographic data set of 1980, roi masks were derived for the three surface types of interest, open water, arable land, and pasture land.

The first four principal components of the 1980 12-band scene were loaded as a 4-band image to the refresh memory of the I2S display and the roi masks were loaded to the graphics memory. Each roi mask selected out from the image those pixels belonging to the training set for that class, c , and from a statistical analysis of these pixels the mean radiance and its standard deviation in each principal component band, b , or U(c,b) and V(c,b) were calculated. U and V thus determine the feature space location and spread of the cluster derived from the training set to model the class. These spectral signatures are listed in Table 4.

As long as any errors in the 1980 cartographic data set cover only a small area, they will not cause the spectral signatures derived from the 1980 satellite data for the training set to be significantly contaminated. Fig.2 shows that the pasture class and particularly the open water class have much less variability than the arable land class. The spectral signatures of the three classes shown in Table 4 confirm this. The pasture and water classes are quite tightly defined but the arable class is not.

The spectral signatures derived from individual dates of acquisition show that the signature for arable land varies very much more on a seasonal basis than the signatures for pasture land or open water.

A direct overlay of cartographic data on remotely sensed data will include boundary or mixed pixels (mixels) or, in the case of geometric misregistration, pixels in adjacent land parcels. Training areas selected interactively by a user will, however, tend to be smaller in extent, have less internal variability, and lie away from boundaries between different land-use types. To minimise this problem the roi masks used for extracting spectral signatures excluded all pixels on the boundaries between land parcels. And to minimise the problem of the training sets having rather too great a spread, V , a tighter threshold than normal was adopted in assigning pixels to a class, during the classification

TABLE 4

SPECTRAL SIGNATURES FOR THREE SURFACE CLASSES IN 1980.

YEAR		1980	
CLASS	1	2	3
PC1	232.7 (17.1)	94.0 (30.0)	61.3 (19.0)
PC2	69.1 (10.7)	123.4 (17.3)	110.9 (9.4)
PC3	119.6 (13.3)	138.7 (20.6)	110.8 (14.9)
PC4	122.5 (16.4)	112.2 (26.2)	124.4 (12.6)

Key: classes 1, 2, and 3 represent open water, arable and pasture. The parameters tabulated are the mean and (bracketed) standard deviation of each class for the first four principal components of the twelve band scene of 1980.

procedure. A threshold of 2V as apposed to 3V was adopted so that only 95% rather than 99% of all pixels belonging to the class could be expected to be found to lie within the cut off limit.

6.2 SUPERVISED CLASSIFICATION

The spectral statistics described above were employed, together with the image to be classified, as input to the minimum distance classification algorithm which runs on the I2S. System limitations meant that only the first four principal components could be used in the classification. But these four components do cover between them over 0.98 of the variance in a twelve band scene.

Using the spectral signatures from 1980 for the limited 5x5 Km area over which digital ground truth data had been rasterised enabled classification of the larger 10x10 Km area of the 1980 satellite scene (Fig.3a). These same 1980 spectral signatures were also used to classify the 1982 satellite scene (Fig.3b). Some classification inaccuracy resulted from this procedure as the spectral characteristics of the 1980 and 1982 scenes were not identical. Two classification images for 1980 (Fig.3a) and 1982 (Fig.3b) have also been compared to determine which pixels changed class between these two dates. This comparison is shown in Fig. 3c and summarised in Table 5a. As the arable land class was rather loosely defined it was merged with the reject class to provide a new class, then the entire scene reclassified. This comparison is summarised in Table 5b.

The percentages in Table 5 refer to the whole 10.24x10.24 Km area of Fig. 3 and thus to the intensively farmed area on the higher ground surrounding the floodplain as well as the lowland area within the jurisdiction of BA.

6.3 INTERPRETATION OF THE CLASSIFICATION RESULTS

In the areas which overlap, the internal consistency of cartographic and satellite data can be checked. Comparing Figs.1b and 3a shows that some areas interpreted as pasture from the 1980 photography are classified as arable from the 1980 satellite imagery. Reinspection of the aerial photography confirms that the satellite classification is correct, providing a basis for revising the digital cartographic data set.

As indicated in Table 5, most of the pixels are assigned to the same classes in 1982 and 1980, but some open water pixels are classified correctly in one year but unclassified in the other. Table 5 does make clear that, over the whole

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FIGURE 3

Classification of the 10x10 Km area of Broadland. Digital cartographic data over an area of 5x5 Km (Figure 2) was used to supervise the classification of the first four principal components of the twelve band scenes.

3a. Classification of the 1980 scene, using 1980 spectral signatures.

3b. Classification of the 1982 scene, using 1980 spectral signatures.

Areas classed as open water, arable land, and pasture land are represented in successively lighter shades of grey. The land parcel boundaries are in white and unclassified areas are in black. These five intensity levels are indicated by the superposed grey levels.

3c. Changes in classification from

1980(a) to 1982(b).

Areas classed as open water, new arable land in 1982 and new pasture land in 1982 are represented in successively lighter shades of grey.

scene of Fig.3, about 10% of the area studied has changed its land-use between 1980 and 1982. This trend is almost entirely in the direction from pasture to arable. The magnitude of the trend has been slightly overestimated as the classification of the 1982 scene is noisier than the 1980 scene, and some sections of river bank have been mis-classified as arable. Oblique colour photography flown in autumn 1982 and made available by the BA and partial ground resurvey in autumn 1983 performed by the authors, in conjunction with the Nature Conservancy Council, were used to spot check the classification results. Two areas of arable land in Halvergate and Acle marshes (near A on Fig.1a) increased and amalgamated between 1980 and 1982. The progression of arablisation can be followed from the data presented here on a field by field basis.

TABLE 5

PERCENTAGE COVER FOR THREE SURFACE CLASSES IN 1980 and 1982.

a)three classes plus reject class

CLASS		0	1	2	3
1980%		10.4	3.7	45.6	40.3
CLASS	1982%				
0	9.1	4.4	0.3	3.1	1.3
1	3.8	0.3	3.4	0.0	0.0
2	55.7	4.8	0.0	39.4	11.4
3	31.4	0.8	0.0	3.0	27.6

b)three classes,amalgamating the reject class with class 2,giving 2'

CLASS		1	2'	3
1980%		3.7	56.0	40.3
CLASS	1982%			
1	3.8	3.4	0.3	0.0
2'	64.8	0.3	51.7	12.7
3	31.4	0.0	3.8	27.6

Key: Classes 0,1,2,and 3 represent rejects, open water, arable and pasture. 100% cover corresponds to the 10485.8 Ha shown in Figure 5.

6.4 REVISION OF THE DIGITAL CARTOGRAPHIC DATA SET

Two forms of cartographic revision are required. First errors in the original 1980 data set, as shown by the satellite imagery, must be corrected. Second any changes between 1980 and another year detected by satellite imagery must be inserted if appropriate. Currently this is achieved by reference to the index maps (Section 3.0). The index numbers of the vegetation zones which have undergone change as indicated by the classification described in Section 5, are identified and the centroid codes held in the vector data set are accordingly edited.

7.0 IMPROVEMENTS TO THESE TECHNIQUES

7.1 MORE RELIABLE SPECTRAL SIGNATURES

Spectral signatures are usually derived from training areas which the user selects interactively. Automatic derivation of spectral signatures using externally defined training areas (Section 6.1) places a high requirement on the geometric precision of the two data sets, if contamination of the spectral signatures is to be avoided. All errors in the cartographic and remotely sensed data should be identified and their effects determined in terms of the standard deviation of border coordinates. The borders of areas of uniform land cover can then be shrunk by for example three standard deviations so the reduced area avoids borders with adjacent polygons. The shrunken inner polygons have a greater certainty of correct feature coding and can be used to derive spectral signatures of greater reliability for classification.

7.2 MORE RELIABLE CLASSIFICATION

The classification maps of section 6.2 were generated using a pixel by pixel classifier. In this particular study spectral variations within a land parcel (polygon) are not of interest. A more useful and less noisy classification could be achieved by employing a parcel by parcel classifier. This could be implemented by replacing all MSS values in a parcel by that parcel's mean, variance, and higher order moments of the parcel pixels' radiances, or, to avoid mixel effects, of the parcel pixels further from the boundary than a distance related to the data set's precision (section 7.1). Thus rather than classifying each pixel within it, the parcel would be classified as a whole. A further technique to reduce the noise evident in the classification maps of Fig.3 is post classification filtering. This could involve a Tukey median filter, or a mode filter in which a given point is replaced by the mode of those in a neighbourhood area, or by region shrinkage followed by region enlargement of the same amount. These filters tend to reduce the number of isolated unclassified or wrongly classified pixels in an otherwise uniform area.

7.3 ENLARGEMENT OF THE CLASSIFIED AREA

The techniques described in this paper for monitoring the conversion from pasture to arable over a limited area in Broadland, can now be used on the larger 40.96x40.96 Km area covering the whole of Broadland. By extracting the BA boundary from the cartographic data and transferring this large polygon to the I2S it can be used as a mask to extract the area of interest. The tables of change derived from the classification maps would then apply only to the area of BA jurisdiction, and the acreage table would sum to the total number of hectares in that area.

7.4 AUTOMATIC UPDATING OF THE DATA SET

At present this updating is performed interactively (secton 6.4). An alternative approach is to separate a polygon boundary from the feature code describing its contents. A separate land-use file could be set up, referring to each polygon by centroid or index number, and having several feature code positions for land use from the original survey and as derived from satellite classification in successive years. Based on a parcel by parcel classification of an MSS image, it is possible to check the internal consistency of the data sets and identify the polygon feature codes needing revision. The rasterised cartographic data set could be updated using the raster edit software described in section 3.0, or the land-use index file could be automatically updated. Such an updated data set could than be exported as a vector file to the PDP 11-45 vector processing system which supports most of NERC's cartographic software. It is from this system that either revised maps or historical maps could be produced.

8.0 CONCLUSIONS

Employing a digital cartographic data set to generate region of interest masks for the pertinent ground cover types, spectral signatures have been derived from registered multitemporal MSS data and used to supervise the classification of the contemporaneous scenes into classes of open water, arable land, and pasture land. These region of interest masks and spectral signatures have also been used to supervise the classification of a non-contemporaneous scene to study changes between the two years. Changes of land use on a field by field basis have been derived and used to update the 1980 digital cartographic data set to one having relevance for the year 1982. Thus this project represents a successful attempt to monitor a threatened area and revise the cartographic data as changes are detected. Much of the pressure for devising such a method came from a feeling that expensively acquired vector cartographic data should not be wasted. The remaining pressure to devise the method outlined was a conviction that LANDSAT 3 data was of sufficient resolution for the change monitoring needed in the project.

The three main bottlenecks in the project were at the digitising stage, at the polygon generation stage, and registering the satellite scenes to the British National Grid. The nature of the photointerpretation documents (hand drawn in multicoloured pencils on opaque draughting foil) and the very complex 'online-offline-left code-right code' coding which the project required precluded scan digitising. Polygon generation from line segments (as opposed to closed loops) requires geometrically excellent data. To achieve this an impractical number of interactive editing cycles had to be repeated. Software improvements at NERC have speeded up polygon generation, but the somewhat inelegant approach of digitising looped lines for all zones for which subsequent digital polygons will be needed is an extremely practical alternative.

9.0 ACKNOWLEDGEMENTS

Our paper deals with the cartographic and image analysis aspects of this project, but the contractual spadework for generating the 1:10 000 vegetation maps, and the photointerpretation were carried out by Robin Fuller of the NERC Institute of Terrestrial Ecology. He has authored other papers referring to this work, e.g. (4). David Brewster of the Broads Authority provided useful auxiliary data on land-use changes, and feedback on the accuracy of the classification achieved. Robert Driscoll of the Nature Conservancy Council was an invaluable source of information on every aspect of Broadland, and also supervised the ground truthing of the area. As those of you with any experience in production of map series using Computer Assisted Cartography will know, dedicated and concentrated effort has to be invested by those involved, so, although much of the practical, organisational, and theoretical work was carried out by the authors, they are greatly indebted to their colleagues (or former colleagues) in the NERC Thematic Information Service (now incorporating the Experimental Cartography Unit), in the NERC Computing Service, and at ITC for shouldering some of the burden of that over optimism which Computer Assisted Cartography and Satellite Remote Sensing often engender. Finally we are grateful to the Broads Authority for permission to employ their digital data set in this further work, and to the Natural Environment research Council for the support provided during this project.

The numerical analysis for the study was performed on the HP 3000-III/M70F12 image analysis system at TIS using algorithms within the S101 software applications package of International Imaging Systems.

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