WORKING PAPER 491

# ANALYSIS OF UPLAND VEGETATION USING CLASSIFIED LANDSAT TM DATA AND A PILOT GEOGRAPHIC INFORMATION SYSTEM.

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## ABSTRACT

Categories of upland vegetation were distinguished by maximum likelihood classification of Landsat TM data and read into a pilot geographical information system (GIS). Each category of vegetation was held in the GIS as a quadtree image. The facilities of the GIS were used to manipulate these images in various ways, such as editing, separating, combining or generalising the images. For each category of upland vegetation, homogeneous regions were identified as separate objects and stored by location in the relational database, Ingres. Image or spatial data from Landsat TM could thus be analysed by using the power of the relational database management system. Such data could be augmented by other spatial data from thematic maps and by aspatial data.

Results show that encoding classified Landsat TM data as linear quadtrees is an efficient technique for accessing categories of vegetative cover. They show also that once these categories are established discrete objects within each category can be identified and labelled as instances of a particular vegetative cover type. The relational database allows these instances to be stored with relevant data such as the area and perimeter of each object. By associating information from other sources, such as the soil type, topography, assemblages of species within each category, grazing regime and ownership of the land, the GIS can be used to provide an inventory of upland vegetation. The full potential of the relational database Ingres can then be used to explore both spatial and aspatial relationships within the given study area. Initial indications are that this approach provides a flexible and efficient tool for inventory, management and planning of upland vegetation.

## INTRODUCTION

Patterns of upland vegetation in Great Britain are generally complex and continually changing. To a large extent they reflect local environmental conditions, although human interference cannot be ignored. To account for such patterns, many workers have made detailed studies of the physical environment and human activities within relatively small areas. When attempts are made to account for such patterns over more extensive areas however a major difficulty concerns the need to combine and analyse large volumes of geographic data from different sources and often with complex inter-relationships. With digital geographic data increasing in availability, computerised data handling methods become a necessity. The concept of a geographic information system (GIS) has evolved to describe systems which handle the input, storage, analysis and output of various forms of geographic data. The potential of GIS for manipulating both spatial and aspatial data, for integrating geographic information from remote sensing, thematic maps and other sources, and for exploring different approaches to solving problems related to the interface between soil, plants and atmosphere, are all areas that we as yet know little about.

This paper illustrates the potential of a pilot geographic information system for regional analysis of upland vegetation in Great Britain using classified Landsat TM data. The GIS has been used to produce an inventory of the major vegetative cover types for an area of the northern Peak District, to the west of Sheffield. The example given here is for the grassland cover type, and shows how the combination of spatial and object processing in a pilot GIS gives users flexibility not only to analyse and further modify classified imagery, but also to perform powerful querying operations.

To emphasise the novel feature of combined spatial and object processing, the example relies exclusively on grassland categories identified from Landsat TM data. The full potential of the GIS for land management and planning would be realised by integrating diverse types of geographic data into a massive common database. Individual users could then form queries by selecting only the subset of data types relevant to their specific application.

## BACKGROUND

### Upland vegetation in the Peak District.

The pattern of different types of vegetation above 250 m in the northern Peak District is complex and dynamic. It reflects local environmental conditions, such as geology, topography, soils and climate but human interference continues to be a major influence. The coarse sandstones and shales of the Millstone Grit series produce outcrops that stand out in contrast with the dales and plateaux of Carboniferous Limestone. With rainfall over much of the uplands exceeding 140 mm per annum, heather moor and blanket bog predominate over extensive tracts on the Millstone Grit, with minor variations in vegetation mainly related to altitude and wetness. Heather (calluna vulgaris), bilberry (vaccinium myrtillus) and cotton grass (eriophorum vaginatum) communities are dominant, with the heather presenting a patchwork of closely grown stands resulting from the burning cycle. In many areas the sphagnum bog has become dissected and is undergoing rapid erosion, and redistributed material is being colonised by mat grass (nardus stricta). Most of these areas are given over to extensive uses such as sheep grazing and grouse moors.

### Requirements for an inventory of vegetation.

The compilation of inventories of upland vegetation is a challenging task for land resource managers. Upland vegetation presents a complex patchwork with transitional zones between communities and with seasonal variations in both the communities and their boundaries. There is a need to provide accurate information about the current extent and condition of each vegetative type. As a consequence, there has been growing interest in assessing the contribution of remote sensing as an aid to vegetation inventory. Curtis (1978) and Curran (1980) reviewed various aspects of multispectral remote sensing of vegetation, and examples using upland vegetation include recent work by Wardley (1987) and Weaver (1987). The multispectral image can show the current pattern of vegetation cover for extensive areas at the same time, which is particularly useful for inaccessible upland areas. A comprehensive inventory also needs to include knowledge about the vegetative distribution built up from various sources over many years. One means of combining a diversity of existing geographic data from maps, historical records and field surveys and relating this to a remotely sensed image is to make use of a GIS.

**GIS for analysis of upland vegetation.**

A GIS can be regarded as an integrated suite of computer programs for handling and analysing geographic data. It is designed to accept large volumes of geographic data derived from a variety of sources and to store, retrieve, manipulate and display these data according to specifications laid down by users. (Marble and Peuquet 1983). Recent developments in computing theory and technology, including the improvements in database systems, image processing, optical storage and digital mapping, are now making it feasible to combine the various types of digital data into one GIS, allowing a new approach to solving problems in land resource management with remote sensing. (Burrough 1986).

In general, there has been little attempt made to investigate the full range and sequence of operations that can be carried out in a GIS to perform inventories and assessment of upland vegetation resources. (Young 1987). A preliminary assessment can be made using relatively static environmental variables, such as geology, soils and topography. (van Keulen et al. 1986, Hogg et al 1986,1987). The inclusion of remotely sensed data in the spatial database of the GIS provides more frequent and extensive information on ground cover than can be gained from map or field survey data. In addition, a thorough assessment should consider attributes of the terrain such as cultivation practice, fertilizer treatment or grazing regime. These attributes, which are often of the human environment, are not usually found from map or remotely sensed data, but from field observation or statistical records. These can be included in the GIS as aspatial information in the relational database.

There is the difficulty of how to manage and manipulate complex and often large volumes of spatial and aspatial data involved in performing a land assessment. At a more sophisticated level, there is the problem of how to include the new information derived from remote sensing and ancillary sources into the decision-making processes of land management. In essence, these problems are what a fully integrated GIS is designed to overcome. (Crain and Macdonald 1985).

The key question is whether such a combination of GIS and remote sensing will yield insights not otherwise available or results of sufficient theoretical or practical importance to justify the large computational effort involved. As part of a project to evaluate the potential of geographic information systems (GIS) for regional analysis of land resources, a pilot GIS based on linear quadtrees and a relational database has been developed (Gahegen and Hogg, 1986). (Fig. 1) It consists of two parts: a spatial database of binary images represented as linear quadtrees; and a relational database of objects abstracted from the quadtrees and augmented by aspatial data provided by users. The two parts are integrally linked within the GIS to allow users quick access to explore spatial objects and relationships. Descriptions of the pilot GIS are given by Hogg, Gahegen and Stuart (1986,1987), Hogg and Gahegen (1986) and Gahegen and Hogg (1986).

**Storing regions as linear quadtrees**

The raster image of a region, as shown in Fig. 2, can be encoded using the linear quadtree data structure. The quadtree is suitable because it supports efficient and flexible manipulation of locational data for regions. (Peuquet 1984). The location of any quadtree block can be calculated, because the quadtree is a regular tesselation of space. Since the structure exploits the spatial coherence commonly found in geographical scenes, regions can often be represented in a relatively small number of maximal blocks. The theory behind the linear quadtree and its use in GIS is described by Samet et al. (1984, 1986).

**Relational Databases**

An object, such as a particular plant community, reservoir or wood, can be related to its location in an image by its unique position in the linear quadtree. It may have spatial attributes which are specific to it alone, such as size or shape. In addition however objects may have aspatial attributes such as ownership of a region of land, population of a census district or fertilizer treatments on a particular field of crops. Quadtrees are generally unsuitable for storing this type of data, so an alternative must be found.

By forming a data base of objects in the relational data base, it becomes possible to store aspatial data, related to individual objects (or regions), which can be supplied from various sources. The relational database can also be used to store various definitions of objects which can then become part of the query language. For example, the definition of 'improved_pasture' might be quantified. And, though we are only just beginning to use this facility, the relational database offers a convenient and excepionally powerful tool for modelling the relations and attributes that are held in the GIS. This gives a flexible and powerful GIS. For more details of relational databases and object management the reader is referred to (Date 1984, Oxborrow 1984)

## METHODS

### Data source: Landsat TM data.

A GEMS image processing system at the National Remote Sensing Centre (NRSC) was used to perform a maximum likelihood classification of part of a Landsat TM scene of the Peak District, Derbyshire, acquired on 26th April 1984.( KIFU L5 TM 203/23 ) Spectral bands 3,4,5,7 and 4/3 ratio were used to produce ten land cover classes at 25m ground resolution. A square window was abstracted as a raster image of side 512 pixels. April imagery was selected as it was felt that at this time of year there would be less confusion between grassland and other crops in the scene.

### Quadtree encoding

The classified Landsat TM scene was read from computer tape to produce an array of 512 by 512 characters in a disk file. This was used as input to a quadtree encoding program which builds a set of linear quadtrees to represent the distribution of pixels by their classes. For the Peak District scene, ten quadtree files were produced. Four of these were used to plot the maps shown in Figs. 3 to 6. The GIS is presently mounted on multi-user VAX 11/780 computer. Consequently the time taken to perform operations varies considerably, depending on the number of concurrent users. Bearing this in mind, the encoding program can take about 5 minutes to encode the most complex images shown. Once encoded however the speed at which these images can be processed is relatively fast, (e.g. 3 - 4 mins for the union of the quadtree images of Figs. 3 and 4). Further advantages of the quadtree encoding are its suitability for generalisation of images, border tracing, nearest neighbour determination and component labelling.

**Spatial processing - set operations and image generalisation.**

Once the Landsat TM data is in the spatial database of the GIS, it can be processed in exactly the same way as any other thematic image. To identify the maximum area of grassland for instance, the four quadtrees shown in Figs. 3 to 6 are combined. This operation was performed because the individual classes of the maximum likelihood classification were highly fragmented. For interpretation, one may wish to identify areas in the image of similar brightness, and attempt to relate these to a vegetative cover type. The combined image shown in Fig. 7 allows separate objects to be distinguished, and compared to ground data on the location of grassland areas.
This image was produced by the GIS query:

grassland = class3 U class4 U class5 U class6

The new image resulting from the three union (U) operations is stored in a linear quadtree file 'grassland'. (Fig. 7.) Note that although this is a simplification to allow similar areas to be identified, there is no loss of data, since the base files are still retained. It is merely one view which can be generated by a user. The system permits an experimental approach to find the most suitable combination for a particular application.

**Border tracing and object labelling.**

The border tracing program of the GIS was used to process the 'grassland' quadtree and report the perimeter length. Separate components of the image were then identified and automatically labelled using the connected component analysis function which operates on the quadtree file. Because the quadtree carries implicit locational information, it is possible to tabulate occurrences of separate components or regions by their location in the scene. The area of each separate region is also calculated from the quadtree nodes that form it.

**Object definition and abstraction.**

As a result of the above spatial processing, the combined image contained sufficient homogeneous regions for these to be abstracted as objects for further study. To do this, a formal definition of this type of object is required. In this case, the definition already exists; it is the sequence of operations needed to form the grassland image above. If the user types:

O grassland = class3 U class4 U class5 U class6

this declares an object of type 'grassland' to the relational database. If the command:

X grassland

is issued, the GIS consults the relational database for a definition of this type of object. If the resultant image does not exist, it is reformed from its definition. The image is then analysed, and all occurrences of this object are entered into a relation 'grassland'. The resulting relation is shown in Table 1. It contained a large number of objects - 3,023. Each has a unique label, the x,y co-ordinates of its surrounding rectangle and its size in pixels. Finally, a high level definition of grasslands is updated with the total number of these objects i.e. 3023, and their total size and perimeter.

**Object processing - image filtering.**

The relational database management system (RDBMS) was then used to filter out much of the unwanted information from this scene and produce results which would show the major features and thereby be of greater use to resource managers. An example of this is to filter out the majority of 'grasslands' objects which were too small to be significant for a specific application. By retrieving only those objects that had a size greater than say 100 pixels or 6.25 square km, only major areas of grassland were identified. In the scene of the Peak District, 41 major areas were detected as shown in the relation of Table 2. These areas only were then redisplayed to produce the filtered image of Fig 8.

### Output methods

At present output is produced on a Versatec electrostatic plotter driven by UNIX software for document production. As such, the method will not be able to produce high resolution output beyond 512x512 resolution. Work is underway to interface the GIS to a Versatec colour plotter recently installed at the university. A colour graphics display would greatly improve interactive processing operations, but currently one is not available.

## RESULTS

### Analysis of classified Landsat TM image.

The Landsat TM cover classes in Figs. 3-6 are relatively fragmented. A large number of small pixel clusters are present and the spatial coherence in the scene is relatively low. This suggests that the maximum likelihood classification produced classes that may be statistically significant, but do not form objects of any size which could be related to ground vegetation types. In the combined scene (Fig. 7), the total number of separate objects has increased but there has been some amalgamation to produce larger homogeneous areas. This scene conveys information on the possible location of grassland more clearly than either the individual scenes or the original classification.

### Grassland relation and filtering

The relation for grasslands, shown partly in Table 1, provides statistical analysis of the quadtree scene showing the locations and sizes of its 3,023 components. Most of the entries (tuples) have a small value of area in pixels, indicating that a large proportion of grassland occurs in small parcels. From the filtered relation of Table 2 it is apparent that only 41 out of 3023 objects were areas of grassland greater than 6.25 square kilometers. There is flexibility in choosing the size of filter to use; 6.25 square km. was selected to produce a manageable number of areas for display.

### Result of filtering

The resulting filtered image (Fig. 8) shows the probable shape and location of extensive grasslands. This example shows that large connected regions of grassland occur in several parts of the study area. Recognition of these regions is far easier than from the unfiltered image yet little useful information has been removed. This is partly because all regions shown in the filtered image are displayed in their entirity. This is in contrast to image generalisation, where pixels of less than a specified size are removed from all parts of the image, and small pixels forming the boundary of objects are lost. Further, since the original files are retained, other combinations of cover categories and filter sizes can be used and the results compared.

## DISCUSSION

There are several advantages in using a GIS based on linear quadtrees to analyse and manage geographic data. The format of Landsat and other raster data are compatible with that of the linear quadtree. Landsat data can be read directly into the GIS and classifications modified in response to information from ground surveys. Quadtrees are especially suitable for representing extensive homogeneous regions such as large areas of grasslands, and they support powerful set logic operations such as intersections between cartographic and thematic maps and remotely sensed images of a given area. Many shape analysis procedures can be implemented on quadtrees, allowing inventories to be produced which are referenced by location within an image. By linking regions in the spatial database of linear quadtrees to objects in the relational data base, each separate region or object within a scene can have attribute information associated with it. For example, a particular plant community identified on thematic mapper data can have attributes such as its floristic composition, management practice, grazing regime, ownership of land, or burning history. This greatly enhances the scope for using Landsat TM data in upland management.

The relational database has several advantages for geographic analysis. It can be used to provide statistics and reports which can be used during the preparation of inventories of vegetative resources. It can also be used for object processing functions such as filtering, fast retrieval and search by object type. By being able to define relationships between various objects within the relational data base, it is possible to use it for the construction of models such as those for biological productivity of a crop (Berkhout, 1986). Users from different fields of study may have different views of the same database and share a common core of information about a given geographical area. Thus each user may have his own definition of what constitutes 'poor upland pasture.' The discipline of having to define formally a particular type of object forces users to decide on the relevant parameters for their object of interest. This can be regarded as an advantage, as many users begin with somewhat vague ideas. This does not prohibit an empirical approach, where broad definitions are used initially but are progressively refined by experimentation.

The use of an integrated GIS allows upland resource managers to include remote sensing data into decision making. Remote sensing can provide up to date imagery for relatively extensive areas, and with reasonable regularity of update, making it particularly useful for analysing and monitoring upland vegetative patterns on a regional scale. In addition to improving terrain assessments using a GIS, there are reciprocal benefits for remote sensing. The information content of TM imagery can be improved by correction of classification errors; aspatial attribute information such as grazing practice, or ecological species data can be added to help explain disparity in classification; inter related terrain factors affecting spectral response can be taken into account, and definitions of relationships and modelling can be attempted.

Despite these theoretical advantages, there are several practical constraints on the current GIS. It is installed on a multi-user computing system which limits its performance in terms of available memory and interactive response. This restricts the size of image that can be processed at present. Finally, to make the most effective use of the GIS, an interactive graphics display is necessary for users to see the results of their queries in interactive time. Such a display is not available, but a colour Versatec plotter is currently being installed.

## CONCLUSIONS

We have shown that it is possible to produce an inventory of upland grassland vegetation using a pilot GIS and a classified Landsat TM scene. We have also shown that the quadtree encoding of spatial data from remote sensing and, by implication from raster scanning of thematic maps, provides an efficient means of accessing and processing spatial information. Quadtrees suit spatial analysis by supporting border tracing, set logic and area operations on locationally referenced images. Although quadtree building is a relatively slow process, particularly as the size of binary arrays increases, the operations on quadtrees can be carried out interactively, allowing alternative strategies to be explored.

The concept of identifying regions in a scene, which may then be labelled and held as objects in the relational database, allows the attachment of attribute data supplied from diverse sources. The full potential of the relational database can then be used to explore both spatial and aspatial relationships within a given study area. The combination of spatial and object processing provides a relatively fast and flexible system for analysing large amounts of diverse geographic data, allowing decision makers to define relationships, model alternatives and investigate sensitivity between related parameters of the terrain.

Whether a combination of GIS and remote sensing will yield insights not otherwise available, or results of sufficient theoretical or practical importance to justify the large computational effort involved, remains a matter of conjecture. We believe however that the use of a GIS will improve predictions and classification, probably reduce the amount of field observation required, and produce major benefits for resource managers such as land resource inventories. By including remote sensing within a GIS, it is hoped that the advantages of both approaches can be combined, for mutual benefit. One particular area where this may apply is the field of management and monitoring of regional land resources.


## ACKNOWLEGDEMENTS

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# REFERENCES

Burrough, P.A. 1986. **Principles of Geographic Information Systems for Land Resources Assessment.** Clarendon Press, Oxford.

Crain I.K. & Macdonald C.L. 1985. From land inventory to land management- the evolution of a GIS. **Cartographica** 21 no 2:40-46.

Curran, P.J. 1980. Multispectral remote sensing of vegetation amount. **Progress in Physical Geography,** No 4: 315-341.

Curtis, L.F. 1978. Remote sensing systems for monitoring crops and vegetation. **Progress in Physical Geography** No2 part1: 55-79.

Date, C.J. 1986. **Database Systems.** Addison-Wesley, pp 209-228.

Gahegan, M. & Hogg, J. 1986. A pilot GIS based on linear quadtrees and a relational database for regional analysis. in: **Spatial Data Processing Using Tesseral Methods.** (eds Diaz B.M. & Bell S.B.M). NERC, Reading, September 1986.

Hogg, J. Gahegan, M. & Stuart, N. 1987. Regional land evaluation using a pilot geographical information system based on linear quadtrees and a relational database. **Working Paper 487,** School of Geography, University of Leeds, April 1987.

Hogg, J. Gahegan, M. & Stuart,N. 1986. Evaluation of regional land resources using geographic information systems based on linear quadtrees. **International Archives of Photogrammetry and Remote Sensing,** vol. 26, part 7/2 : 917-925.

Hogg, J. & Gahegan, M. 1986. Regional analysis using geographic information systems based on linear quadtrees. **International Archives of Photogrammetry and Remote Sensing,** vol. 26 (4): 113-124.

Keulen H. van & Berkhout, J.A.A. 1986. Quantitative land evaluation for agro-ecological characterisation. **Inter Centre Workshop on Agro-economic Characterisation, Classification and Mapping.** Rome, 14-18 April 1986.

Marble, D.F. & Peuquet, D.J. 1983. Geographic Information Systems and Remote Sensing. in **Manual of Remote Sensing**, ch. 22: 923-958.

Oxborrow, E. 1986. **Databases and Database Systems.** Chartwell-Bratt, pp. 254.

Peuquet, D.J. 1984. A conceptual framework and comparison of spatial data models. **Cartographica** 21, no. 4.

Samet, H. 1984. The quadtree and related hierarchical data structures. **A.C.M. Computing Surveys** 16, no 2: 187-260.

Samet, H. 1986. Recent developments in a quadtree - based GIS. **2nd Int. Symposium on Spatial Data Handling.** Seattle, USA. 1986.

Wardley, N.W. Milton, E.J. & Hill, C.T. 1987. Remote sensing of structurally complex semi-natural vegetation. An example from heathland. **International Journal of Remote Sensing**, vol 8 no 1:31-42.

Weaver, R.E. 1987. Spectral separation of moorland vegetation in airborne TM data. **International Journal of Remote Sensing**, vol 8 no1:43-55

Young, J.A.T. 1986. Remote sensing and an experimental G.I.S for environmental monitoring, resource planning and management. **International Journal of Remote Sensing**, vol.7, no 6:741-744.

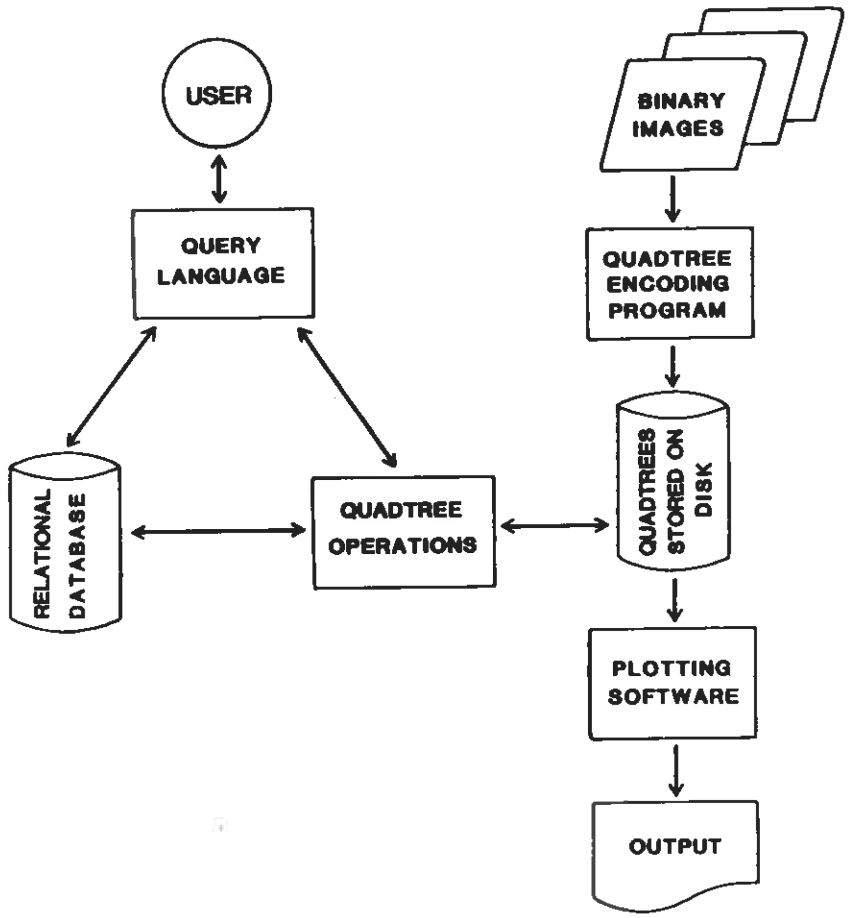
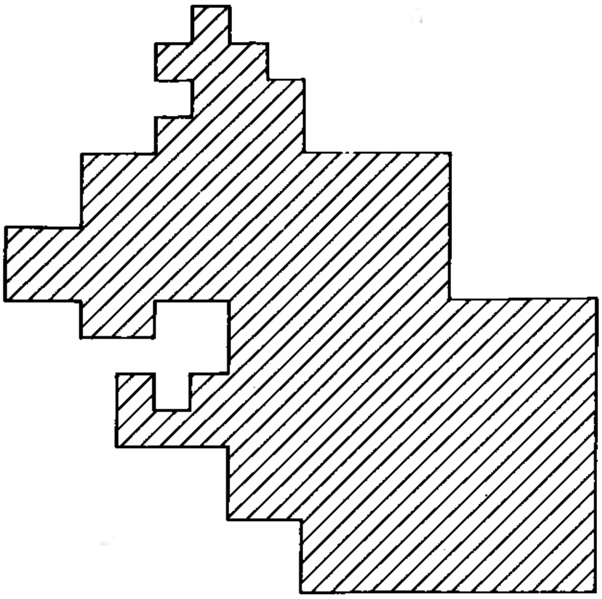


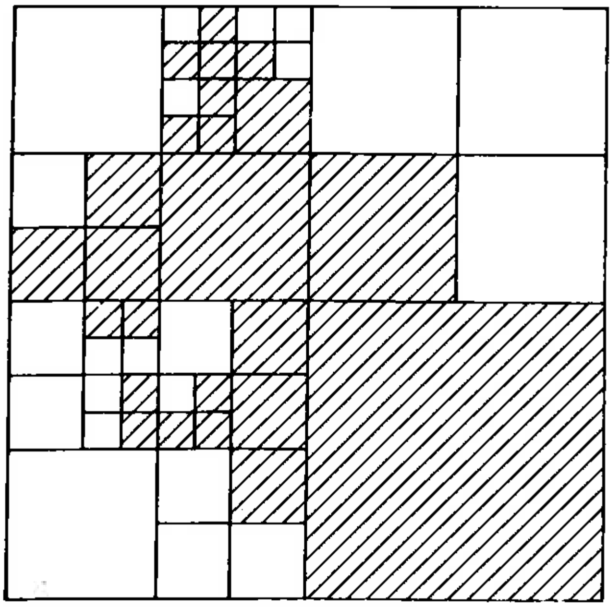

Fig. 1. The components of the Geographic Information System.



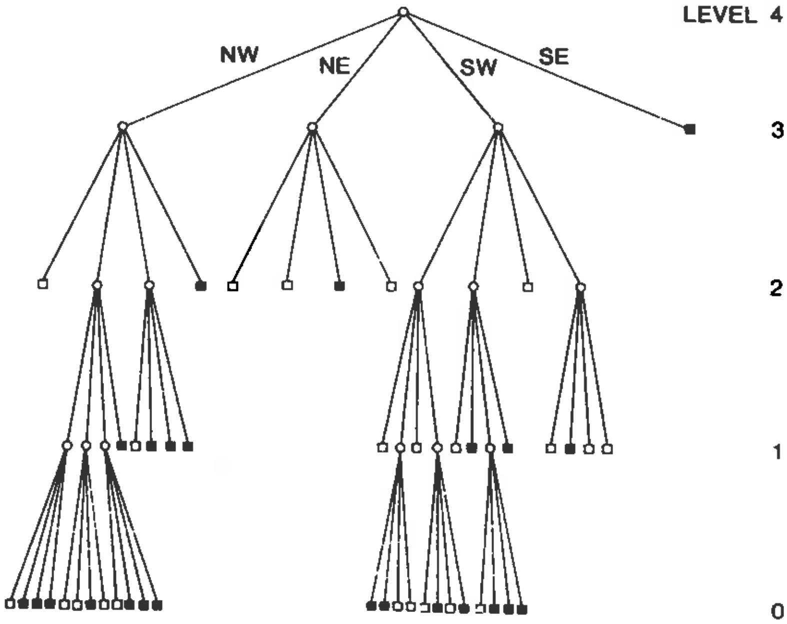
(a) A region, e.g. a forest area.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

(b) Region stored as a binary array.



(c) Maximal block representation of the binary array of (b).




(d) Quadtree representation of the blocks in (c).

Fig. 2. Quadtree encoding of a region held as a binary array.

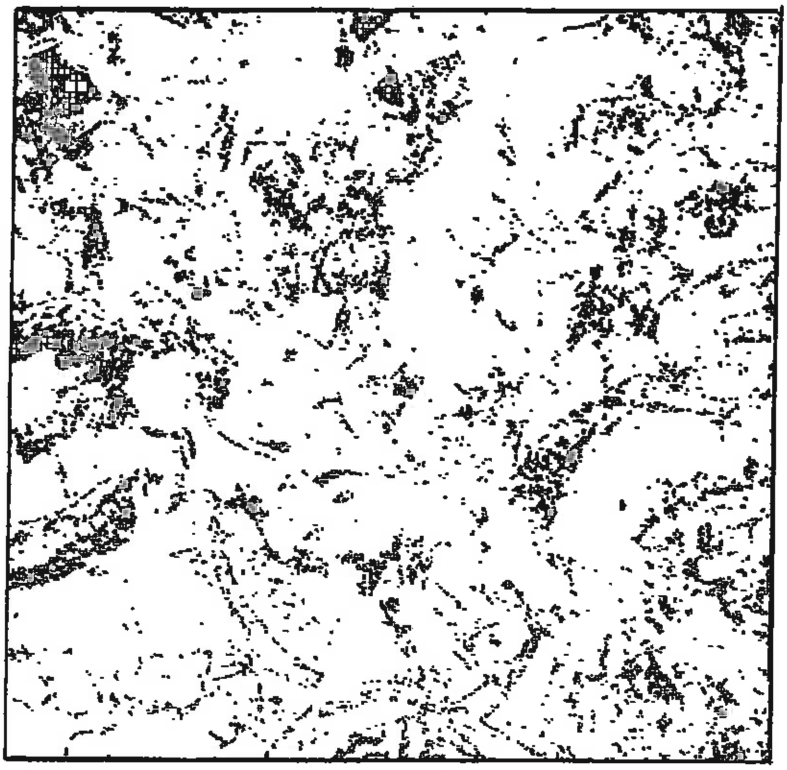


Fig. 3. TM class for Cotton grass with eroding peat.

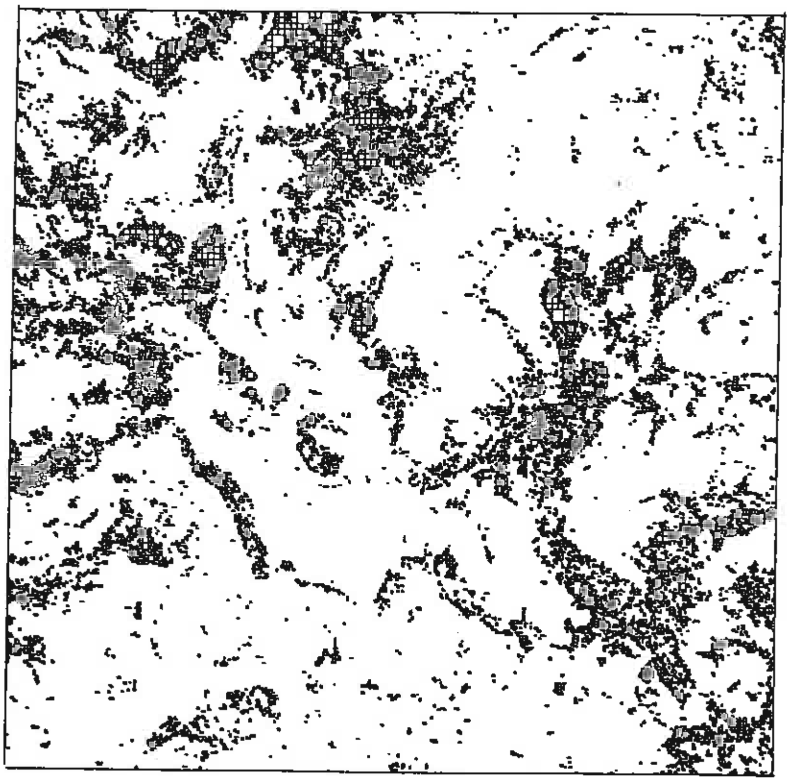


Fig. 4. TM class for Acid grassland with cotton grass.

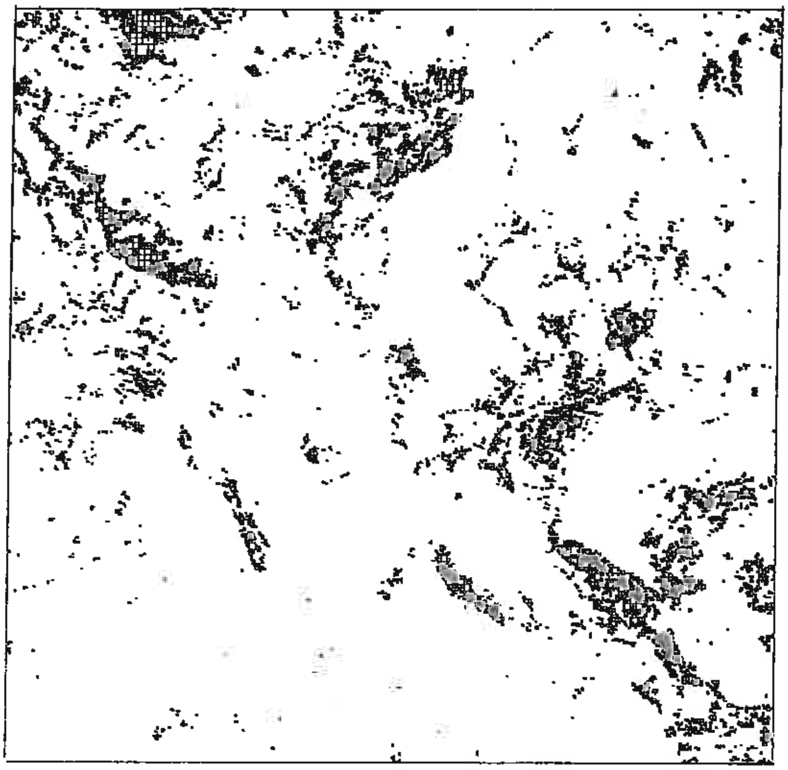


Fig. 5. TM class for Cotton grass with acid grassland.

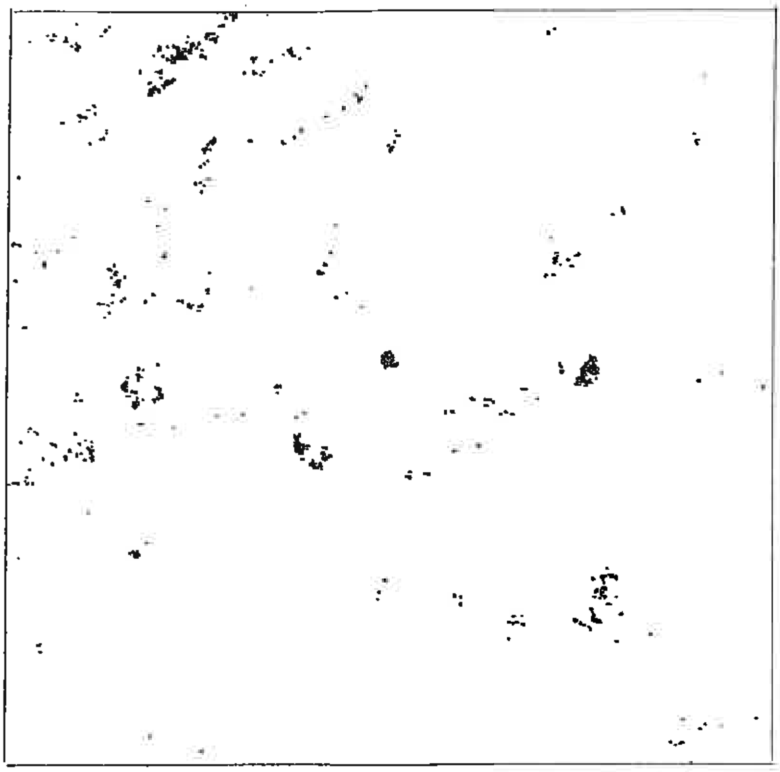


Fig. 6. TM class for Acid grassland.

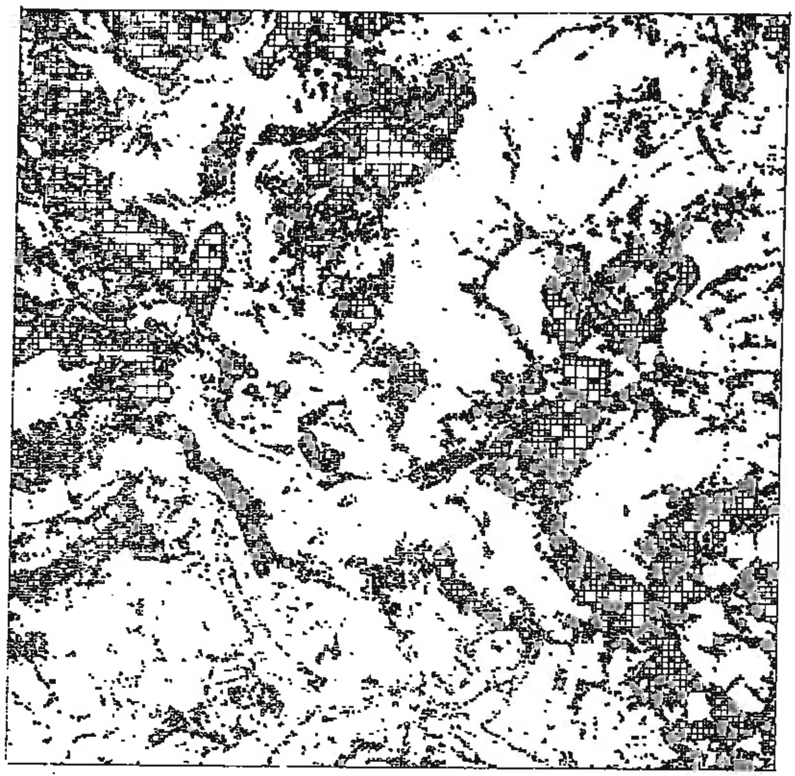


Fig. 7. Combined image of maximum area of grassland.

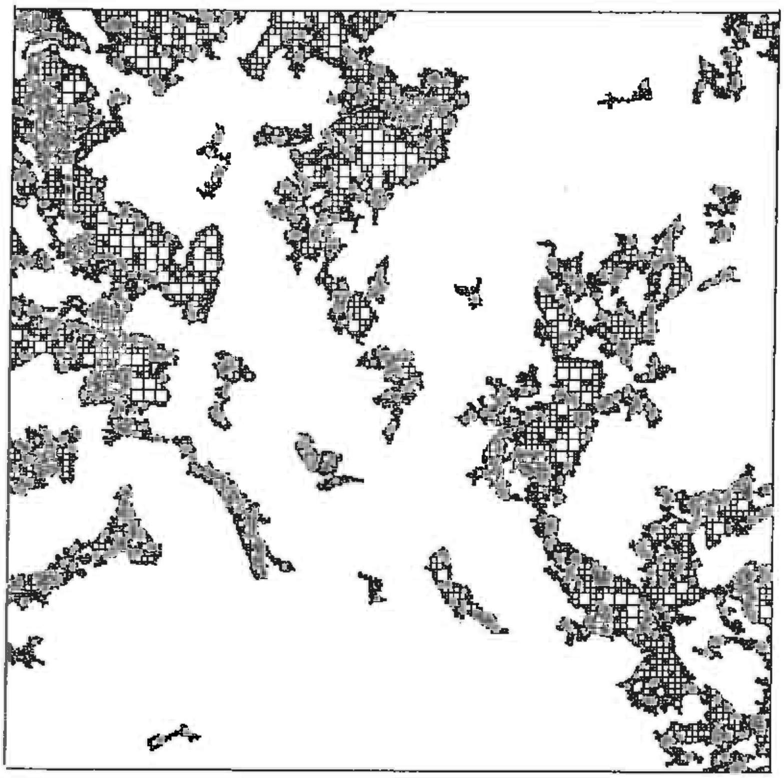


Fig. 8. Filtered image of grasslands > 6.25 sq. km.

grassland relation

| label | x1 | x2 | y1 | y2 | size |
|---|---|---|---|---|---|
| 1 | 0 | 50 | 0 | 34 | 683 |
| 2 | 0 | 2 | 21 | 22 | 2 |
| 3 | 2 | 7 | 20 | 22 | 6 |
| 4 | 7 | 8 | 20 | 21 | 1 |
| 5 | 8 | 11 | 17 | 20 | 6 |
| 6 | 0 | 1 | 31 | 32 | 1 |
| 7 | 0 | 140 | 23 | 294 | 13179 |
| 8 | 20 | 21 | 23 | 26 | 3 |
| 9 | 38 | 39 | 0 | 2 | 2 |
| 10 | 40 | 51 | 0 | 10 | 40 |
| 11 | 45 | 48 | 10 | 13 | 5 |
| 12 | 51 | 153 | 0 | 58 | 2943 |
| | | | | | |
| 3013 | 468 | 469 | 495 | 497 | 2 |
| 3014 | 475 | 477 | 495 | 496 | 2 |
| 3015 | 448 | 449 | 508 | 509 | 1 |
| 3016 | 451 | 453 | 508 | 509 | 2 |
| 3017 | 449 | 462 | 507 | 512 | 31 |
| 3018 | 467 | 471 | 498 | 500 | 5 |
| 3019 | 473 | 474 | 497 | 498 | 1 |
| 3020 | 464 | 465 | 507 | 509 | 2 |
| 3021 | 478 | 481 | 510 | 512 | 4 |
| 3022 | 510 | 511 | 488 | 490 | 2 |
| 3023 | 502 | 509 | 504 | 508 | 12 |

Table 1. Database relation for the combined grassland areas.

maingrass relation

| label | x1 | x2 | y1 | y2 | size |
|---|---|---|---|---|---|
| 1 | 0 | 50 | 0 | 34 | 683 |
| 2 | 0 | 140 | 23 | 294 | 13179 |
| 3 | 51 | 153 | 0 | 58 | 2943 |
| 4 | 62 | 77 | 53 | 74 | 137 |
| 5 | 122 | 144 | 76 | 101 | 155 |
| 6 | 122 | 144 | 101 | 127 | 153 |
| 7 | 148 | 306 | 0 | 178 | 10247 |
| 8 | 159 | 199 | 76 | 92 | 299 |
| 9 | 0 | 28 | 147 | 181 | 345 |
| 10 | 0 | 31 | 192 | 214 | 216 |
| 11 | 201 | 253 | 165 | 225 | 1069 |
| 12 | 132 | 162 | 229 | 283 | 506 |
| 13 | 230 | 278 | 225 | 292 | 922 |
| 14 | 393 | 428 | 44 | 65 | 155 |
| 15 | 474 | 494 | 0 | 25 | 207 |
| 16 | 455 | 480 | 29 | 62 | 255 |
| 17 | 473 | 490 | 23 | 60 | 215 |
| 18 | 495 | 512 | 1 | 33 | 255 |
| 19 | 464 | 488 | 116 | 137 | 214 |
| 20 | 298 | 317 | 179 | 201 | 119 |
| 21 | 300 | 512 | 154 | 512 | 15331 |
| 22 | 339 | 357 | 237 | 262 | 205 |
| 23 | 386 | 456 | 136 | 242 | 2331 |
| 24 | 386 | 397 | 176 | 199 | 104 |
| 25 | 465 | 484 | 140 | 155 | 134 |
| 26 | 460 | 488 | 171 | 188 | 131 |
| 27 | 419 | 446 | 229 | 250 | 189 |
| 28 | 0 | 48 | 281 | 328 | 1188 |
| 29 | 107 | 190 | 287 | 383 | 1166 |
| 30 | 0 | 101 | 320 | 405 | 1750 |
| 31 | 190 | 217 | 285 | 314 | 256 |
| 32 | 206 | 221 | 297 | 308 | 102 |
| 33 | 204 | 236 | 313 | 324 | 107 |
| 34 | 233 | 254 | 378 | 400 | 102 |
| 35 | 0 | 25 | 423 | 444 | 181 |
| 36 | 94 | 129 | 482 | 499 | 149 |
| 37 | 280 | 337 | 361 | 419 | 771 |
| 38 | 481 | 512 | 370 | 416 | 802 |
| 39 | 475 | 494 | 399 | 419 | 109 |
| 40 | 460 | 512 | 420 | 443 | 315 |
| 41 | 443 | 467 | 495 | 508 | 135 |

Table 2. Filtered relation showing grasslands > 6.25 sq. km.