The potential of land cover classification techniques for conservation of Wedholme Flow, a lowland raised peat bog in Cumbria

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Abstract

Land cover classification of a lowland raised bog, (Wedholme Flow) Cumbria was undertaken using remotely sensed fine spatial-resolution Ikonos data coupled with airborne LiDAR data. The aim of this work was to provide spatial data which could be used to aid future conservation of the site. Conventional Maximum Likelihood classification was compared to fuzzy object-oriented classification techniques to assess which technique is most suited to spatial assessment of semi-natural peat environments. Object-orientated classification using eCognition software was used to aggregate spatial and contextual information into a hierarchical configuration for land cover class description. This enabled investigation of morphological, topological and spatial structure of the site. This paper demonstrates that the technique can be used to distinguish between areas of extracted peat and original remnant bog surface and identify various levels of disturbance. The fuzzy nature of this classification enables assignment of each object within the image to several classes that best represents the gradual boundaries in semi-natural environments. The classification is used to recommend suitable restoration techniques for Wedholme Flow in comparison to current management and emphasises the importance of remote sensing in future scientific modelling.

Keywords: *Lowland raised bog, object-orientated classification, Ikonos, LiDAR*

1. Introduction

Lowland raised peat bogs are an important and declining habitat in Britain, many of which have been damaged by human activities through disruption of nutrient balance, surface morphology and drainage. It is important to identify the extent of this damage so environmental managers can preserve or restore 'active' peat growth, "still supporting a significant area of vegetation that is normally peat forming" EUR 15/2 (European Commission, 1999), where colourful *Sphagnum* mosses predominate. Lowland peatlands have acidic soil conditions (pH 3.5-5) and low availability of nutrients that support highly specialised and restricted flora, controlled by local water table depth in a complex array of micro-topographical hummock and hollow features. Bog vegetation zonation is characterised by the distribution of species along a wetness gradient in *Sphagnum* lawn and pool edge, cotton grass (*Eriopherum*) intermediate hummock and *Calluna* hummock communities (Charman, 2002).

This project employed remotely sensed data to assess the condition and potential conservation opportunities for an internationally important lowland raised peat bog which had been subjected to extensive peat cutting and morphological alteration. Remote sensing is well-suited to monitoring ecologically sensitive habitats as limited or no site access is required, thus leaving fragile environmental conditions undisturbed.

1.1 Site description

Wedholme Flow, National Grid Reference NY220530 (Figure 1), is a designated Site of Special Scientific Interest (SSSI) in South Solway Mosses National Nature Reserve in Cumbria; the largest intact, primary lowland bog area in England. Although 125 ha of original bog surface remains, vast areas of the 780 ha site have been damaged through anthropogenic exploitation. English Nature purchased 186 ha of the site in 1990 to regenerate cut-over areas and preserve active peat formation. Commercial peat extraction was continued by Scott's company in a 160 ha eastern area of Wedholme Flow until withdrawal in 2002 under pressure from Government and environmental groups (English Nature, 2002). The cumulative impacts of

more diffuse factors such as agriculture, forestry, urban development and pollution may also have contributed to the deterioration of the bog's condition.

2. Data

This project employed two remotely sensed data types obtained for Wedholme Flow: an Ikonos multispectral image (Space Imaging) and a DEM derived from airborne LiDAR acquired by the Environment Agency. The Ikonos image was acquired in autumn when bog species were spectrally distinct. It was atmospherically corrected using ATCOR2 software (Richter, 1996) and registered to the British National Grid using ground control points. The LiDAR data were corrected for aircraft motion by the supplier and interpolated to a 4m grid cell size so as to match the Ikonos data.

Figure 1: *Location of Wedholme Flow (source: www.jncc.gov.uk).*

3. Methodology

Two principal methodologies were compared, to assess their relevance to land cover classification of a semi-natural peat bog environment.

Supervised maximum likelihood classification (MLC) in ENVI utilized modified Lowland Raised Bog Inventory (LRBI) land cover categories following the methodology and initial unsupervised classification of Milton et al. (2004). Training areas were selected based on ecological knowledge and previous fieldwork. A 3 x 3 pixel centre-weighted majority filter was applied to all 8 classes to reduce class mixing and better define borders of potential management areas through smoothing of input signals via averaging of local mean spectral values.

Definiens eCognition Professional 4.0 software was used to classify the combined Ikonos/LiDAR data using an object-oriented approach which involved multi-resolution segmentation followed by fuzzy classification of the resulting objects. eCognititon uses a patented segmentation procedure that enables creation of a network of objects at different scales and determines object size based on natural scales of interest, especially suited to textured data such as the Ikonos and LiDAR data available (Definiens, 2004). The hierarchical class structure allows child classes to inherit class descriptions from their parent classes which helps capture meaningful management information about the area in a way which mirrors human image interpretation. The most appropriate method of classification within eCognition was identified as user-defined class membership functions; descriptions that provide a fuzzy knowledge-based conceptual system. The advantages of fuzzy rules include more purposeful classifications, adaptable class descriptions and independence from sample object selection, meaning that results are better capable of being generalised across a wider area. Class membership functions were created via specific parameter values of various object features including spectral and LiDAR data values, contextual information about shape, orientation and size of objects plus textural or topological relationships dependent on sub-objects. Sod-cut peat was targetted as a potential area where management strategies could improve peat conditions and investigated further through extension and subsetting of LRBI categories derived from spectral properites of selected objects.

4. Results

4.1 Classification output

Figure 2 shows the final result of maximum likelihood classification applied to all four Ikonos bands with eight classes derived from modified LRBI classes. This classification demonstrates potential separation of bog surface into areas of disturbed and natural peat, but highlights the difficulty in separating sod-cut from degraded peat. Potentially, the bog surface may consist of both conditions but lack of spatial or contextual information restricts identification of indicative landform metrics using this classifier. High frequency mixing occurs around the core 'actively regenerating sod-cut peat' area and in boundary carr woodland that may be related to noise or provide meaningful information about areas which are recovering. This 'salt and pepper' effect can arise from heterogeneity within a land cover class, high similarity between classes, sample specification or incompatibility of the spectral per-pixel classifier to the bog habitat. The smoothed majority filter moderates spatial detail within the classification, resulting in more homogenous areas with improved boundary distinction, at the expense of less detailed representation of bog structure.

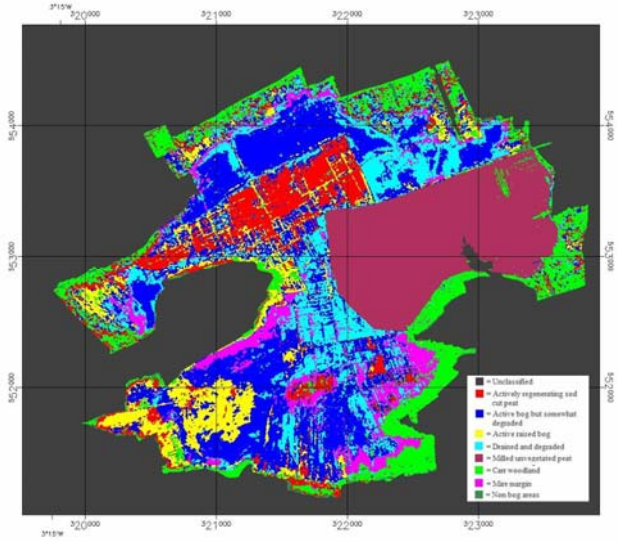

Figure 2: *Aggregated Maximum likelihood classification using a 3x3 centre weighted majority filter and LRBI classes***.**

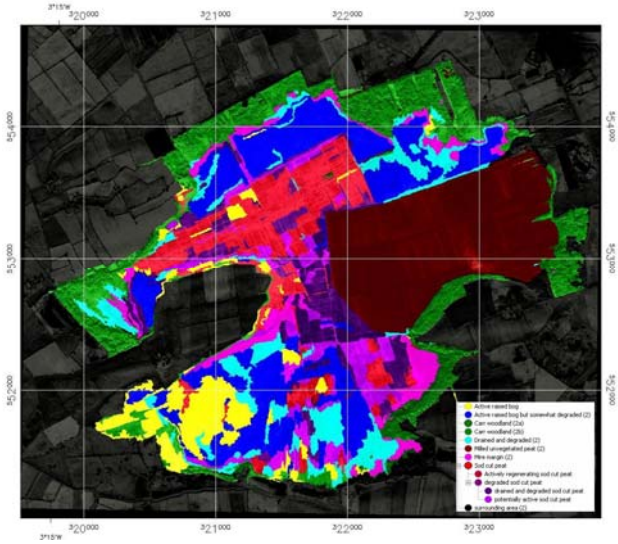

Figure 3: *Object-based fuzzy classification using modified LRBI classes and separation of sod cut peat into active, potentially active and drained and degraded subclasses.*

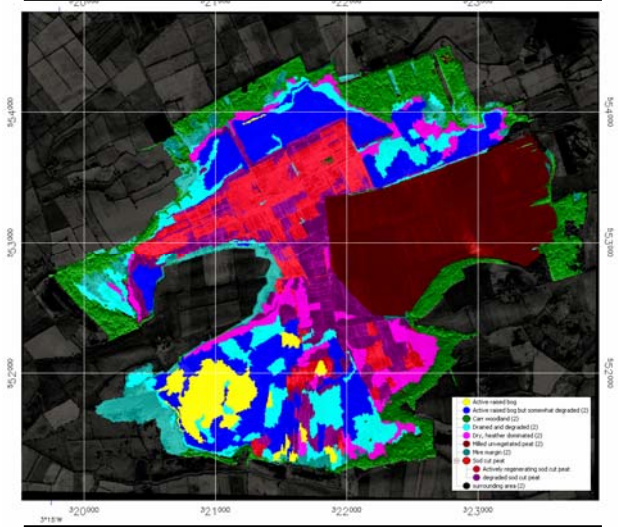

Figure 4: *Altered object-based classification based on field observations.*

Figure 3 shows the eCognition classification, with classes coded according to their highest membership class for each object, and identification of sod-cut peat based on spectral and spatial characteristics. This exhibits improved representation of class distribution over maximum likelihood when compared to existing maps, as discrete object segmentation permits better class definition and separation into sub-classes based on differences in elevation, spectral and spatial characteristics. Representation of sod-cut areas from cutting patterns has emphasized drainage ditches and possible disrupted areas in the southern bog that require further investigation. Two additional classes: potentially active sod-cut peat and damaged sod-cut peat denote the presence of peat-forming vegetation in regenerated areas. Areas of less damaged sod-cut peat, located proximate to original bog surface, could potentially be returned to an active state.

4.2 Validation and accuracy assessment

The accuracy of the classification was assessed by visual assessment of the rule images produced by the maximum likelihood classification, visual inspection of the eCognition results, including object class and stability for each hierarchical level, and field survey. A four-day visit to Wedholme Flow during July 2008 identified small inconsistencies between the derived object-oriented classification and current land cover. As a result, a final classification based on field observations of bog vegetation and morphology was produced. The extent of degraded remnant bog surface was enlarged, particularly in the north western area, whilst the southern intact bog consisting of areas with a complicated mix of classes was manually classified to represent vegetation present during survey. This resulted in alteration of the previous 'mire margin' class name to 'heather dominated' bog and introduction of a new mire margin by subsetting the previous 'carr woodland' class. It is not possible to determine the absolute accuracy of each classification as concurrent reference land cover data are not available, and the Ikonos data are now almost seven years old. However, qualititative assessment of Figure 4 by experts familiar with the site suggests that the final classification is credible.

5. Discussion / Analysis

5.1 Comparison of classification techniques

Conventional hard per-pixel classification techniques (including MLC) use procedures that are not sophisticated enough to handle the complexities of vegetation communities in transitional peatland environments. The parametric spectral data of

maximum likelihood was unable to seperate different surface reflectances such as water and shadow that were successfully separated using contextual information. Marceau et al. (1999) reasoned object-based classification could provide a solution to the Modifiable Areal Unit Problem (MAUP) as the hierarchical nature provides more realistic interpretation of geographical phenomenon including information on location, non-normal distributed data and irregular, discontinuous spatial patterns. Hence, eCognition's segmentation procedure is important for scene representation in object-based classification whilst fuzzy class rules allow portrayal of gradual boundaries that act to reduce the MAUP further. On the other hand, classification of high spatial resolution data increases spectral variance and class heterogeneity and provides access to more numerous features to describe class characteristics. Extending these complex, highly specific, possibly unstable class definition rules between locations or to images acquired at different times will be challenging, yet this will be necessary if the highly effective procedures used here are to be applied more widely. The results presented here show the benefit of combining remote sensing expertise with ecological knowledge of the specific site.

5.2 Recommendations for Bog Management

3D visualisation of Wedholme Flow indicates peat milling has formed a sloped low-elevation concave depression where water may accumulate to cause nutrient or base enrichment and invasion by birch and *Molina*. Scrub removal and re-vegetation techniques should be implemented to adjust vegetation communities towards typical bog species. Wheeler et al. (1995) argued that separation of synergistic effects of peat extraction and other damage factors including direct drainage and previous peat cutting was not possible and thus proposed three methods to re-wet milled areas: ditch blocking, impounding of water in lagoons, and sculpted hollows. Sod cutting produced parallel baulk and cut-out channel patterns within rectangular drained fields, evident in both the maximum likelihood classification and the object segmentation. As sod-cut areas of Wedholme Flow adjoin uncut raised bog, surface re-wetting should be applied to the main bog water table, although precisely how this is done will depend on local conditions.

6. Conclusions

Application of the established LRBI classification scheme to fine spatial resolution remotely sensed data enabled meaningful separation of land cover classes of Wedholme Flow. Further land cover classification using the object-oriented approach facilitated recognition of possible sub-classes within the LRBI, enabling specific management techniques to target damaged peat areas. This land cover classification provides comprehensive information about Wedholme Flow's morphology and spectral reflectance but is limited by the absence of data from short-wave infra-red bands and by the representation of the site at one instance in time. Hyperspectral survey would provide additional information on hydrological processes and individual vegetation species (Harris, 2006). Furthermore, repeated satellite coverage would provide contemporary imagery of the site and allow study of temporal change.

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