

ASSESSING THE EXTENT AND SEVERITY OF EROSION ON THE UPLAND ORGANIC SOILS OF SCOTLAND USING EARTH OBSERVATION AND OBJECT ORIENTATED CLASSIFICATION METHODS

Medcalf K.A¹, Jarman M W¹ and Keyworth S J¹

¹Environment Systems Ltd, Cefn Llan Science Park, Aberystwyth, Wales – Katie.medcalf@envsys.co.uk

WG IV/4

KEY WORDS: Peat Erosion, Earth Observation data, Aerial Photography, Rule-based classification, Image Segmentation, Object Orientated Classification.

ABSTRACT:

Much of Scotland's uplands are covered by organic peat soils, these form a significant proportion of the global peat resource. Peat ecosystems play a key role in the global carbon cycle through sequestration of atmospheric carbon during peat accumulation, and release of carbon gases in the form of CO₂ and methane when they erode. This project set out to find a cost-effective means of identifying peat erosion features within a study area of 320 sq km on the Monadhliath Mountains in Northern Scotland.

An innovative, object-orientated classification system method was used. Within Definiens eCognition software, SPOT5, IRS P6 and ASTER satellite imagery were prepared, including full geometric and atmospheric correction. In order to obtain the spatial detail required, digital aerial photography was integrated into the automated processing chain. This image data was complemented by GIS datasets that provided a set of core thematic information. Using image segmentation and a rule-base the spatial details from the air photos were integrated with the spectral detail from the satellite imagery and the thematic attributes from the GIS layers.

Two levels of classification were produced: 'core level' data and 'application level' data. The application level data was produced from the core level data in the form of peat erosion maps. Erosion features were successfully identified that ranged from small gullies only a metre across, to larger exposed bare peat areas. Overall map accuracy was calculated at over 84%, with clear visual coincidence between the classified map and both the in-situ field data and aerial imagery.

1. INTRODUCTION

1.1 The Importance of Peat Soils

Estimates of the global extent of peat-forming systems vary significantly, and there is a real need to better quantify their extent and subsequent role within the global carbon (C) cycle (Anderson 2002). Peatlands are one of the most important ecosystems in terms of carbon retention. In order to understand the carbon budgets within peatland complexes, it is essential to understand the spatial extent of exposed peat, vegetated bog surfaces and bog pools (Bridgman *et al.*, 2008).

Blanket peat covers almost 9% of the land surface of the United Kingdom and 10.45% of Scotland's (Taylor 1983). The UK deep peats (over 45 cm deep) contain around 5000 Mt C which represents about half of the C in all soils and which is almost 40 times the C content found in UK vegetation (Cannell and Milne 1995). Most of these peatlands are bogs, and the majority of these (over 70%) are found in Scotland (Lindsey and Immirzi 1996).

Scotland's peatlands are a highly important ecosystem not just with the UK, but also in Europe. They are located on the Atlantic extremity of the continent's climatic gradient and are generally less degraded when compared to the peatlands of countries in mainland Europe (Bragg 2001).

Mapping of peatlands as a distinct land cover type has evoked many challenges and has often led to their omission or inconsistent representation within many global vegetation maps (Frey and Smith 2007). Landcover maps on continental or

global scales at a 1 km resolution are likely to omit peatlands due to their small size within the matrix of other land cover types (Krankina *et al.*, 2008). Improving the representation of these areas within land cover maps is therefore an important objective for future global mapping and will subsequently increase the understanding of their effects on global climate change (Herold *et al.*, 2008).

Previous attempts to map the distribution of upland peatlands have been reliant on aerial photography and broad EO sensors such as Landsat (McMorrow *et al.*, 2004). This project focused not only on mapping the peatlands but also the erosion features within the peat.

1.2 Peat Erosion Features

Peat erosion features vary in scale from local events to the extensive degradation of plant cover and associated exposure of bare peat. This exposure of bare peat leads to the surface layers within the peat mass becoming less structurally cohesive through the actions of frost and desiccation. Rain may then penetrate down these desiccation cracks, leading to the development of gully systems (Figure 1).

Other erosion features prevalent in peatland environments include rills and sheet features induced by low magnitude, high frequency events, and high magnitude low frequency events such as peat slips and peat bursts. These high magnitude events give larger areas of bare peat but happen much less frequently than those causing rill and gully formation.



Figure 1: Peat erosion gully.

Existing ground measurements of contemporary erosion rates on bare peat surfaces suggest that changes are in the order of 1-5cm per annum. A conservative figure of 350,000 ha has been suggested as the total area of blanket peat in the British Isles currently suffering from peat erosion processes (Tallis 1998).

In order to try and identify the erosion features within peatland, traditional methods included field mapping and recording from stereo pairs of aerial photography (Grieves *et al.*, 1995). Both have been successful, but they are very labour intensive and are therefore only practical over small areas. This study aimed to find a way of identifying features from EO data, therefore allowing for wide areas to be examined and mapped at a time, with the possibility of remapping for monitoring on an ongoing cycle.

1.3 The Study Site

The study site was a large area of upland peatland in the Monadhliath Mountains in the Scottish Highlands (Figure 2). The area is known to contain large areas of blanket bog which are located within areas of gently sloping ground within the valley bottoms and upon the extensive upland plateaux. Smaller areas of blanket bog are found throughout the area, forming in depressions and in mosaics with areas of wet heath and acid grassland (Dayton 2006).

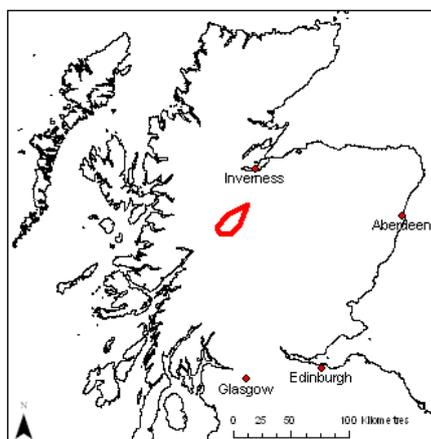


Figure 2: Monadhliath study area location within Scotland

1.3 Data

This project aimed to assess if peat erosion features ranging from less than a metre across to several metres wide could be routinely mapped by the use of EO data, and therefore whether such a method could become a practical way of monitoring erosion features within the extensive upland peat land areas of Scotland. This study was therefore a practical study of what was achievable and as such a broad range of data sources were examined and incorporated into the rule set.

The EO data investigated during this study was captured over the period 2006–2007, when off-the-shelf imagery was available (without any tasking of satellites required). Cloud-free or relatively cloud-free images were acquired by the French Système Pour l'Observation de la Terre (SPOT-5), the US Terra-1 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and the Indian Remote Sensing Satellite (IRS) Linear Imaging Self-Scanning (LISS) sensor. Imagery covered both spring and summer so a time series was available for analysis.

In addition to the spaceborne images, very high resolution 2006 aerial photography (red, green, blue) was also obtained from GetMapping UK.

Ancillary GIS data layers were also incorporated into the classification process alongside the NEXTMap Digital Terrain Model (DTM) data which provided information on landscape position, see Table 3 below.

<i>Dataset</i>	<i>Application</i>
OS MasterMap	Topographic structure for urban and water areas
SIACS	Topographic structure for agricultural areas
NEXTMap Britain	Elevation, slope, aspect and orthorectified radar image data
National Inventory of Woodland and Trees (NIWT)	Topographic structure for woodland areas

Table 3: Other data sets used in rule base.

2. METHODOLOGY

2.1 Imagery Setup

All imagery supplied was calibrated to radiance ($\text{W m}^{-2} \text{sr}^{-1} \mu^{-1}$) and subsequently to surface reflectance (%). Experience on work in Wales (Lucas *et al.*, 2006) has demonstrated that atmospheric correction of optical (e.g., SPOT and IRS sensor) data to surface reflectance is a critical stage in developing consistent decision rules and classifications.

In order to produce a classification of peat erosion it was necessary to split the vegetation up into classes which were of relevance to peat stability and the surrounding area. Several vegetation classification systems exist that could be relevant to

identifying vegetation types likely to contain peat erosion features. These include the Phase 1 habitat classification (Nature Conservancy Council, 1990) and the National Vegetation classification system (NVC) (Rodwell (1991, 1992, 1995 and 2000). Work by Lucas *et al* (2007) showed that the Phase 1 classes are too broad to be mapped as they are by EO methods, and classes need to be established that can be broken down into areas of similar species coverages, or similar mixes of species that are identifiable spectrally from the satellite data. The NVC classifications, on the other hand, are in many cases too detailed as the difference between one class and another depends on small plants with infrequent occurrence throughout the sward, and again these cannot be identified from space. As neither of the existing classifications provided what was needed for this project, a pragmatic approach was taken to dealing with the vegetation classes. The vegetation classes found could be placed within the Phase 1 classification system, but they did not follow it specifically. Instead, the vegetation classes chosen were based on land cover types that contained different upland vegetation types split into the fewest groups by the spectral data from the remote sensing imagery and the air photography, whilst retaining enough ecological information to enable them to be assigned to an 'erosion risk' class. The broad habitats that resulted from this were named with descriptive titles which outline the sort of plant communities that could be expected to fall within these areas.

2.2 Classification

Definiens eCognition object-orientated rule-based classification software was used to classify the imagery into a set of 'core level' data, which comprised the main vegetation types. These core layers were then used to produce 'application level' data, in this case peat erosion maps. eCognition was chosen due to its ability to take into account both the spatial and spectral information in high-resolution remote sensing imagery. It is also able to process large remote sensing datasets, and has the ability to include ancillary information in the segmentation process. Outputs include standard vector and raster formats which can be easily used as inputs within future analyses.

To aid in the classification of the landscape within the Monadhliath, over 30 EO-derived features were generated for use in the form of either a derived layer, or as a 'customised feature' created within Definiens eCognition software.

A rule-base was devised and implemented using a three tiered hierarchical approach. The first level (Integration Level) was used to remove any unwanted features such as the forestry and urban areas and to distinguish areas where peat erosion features will most likely be present (Blanket Bog) through the incorporation of EO and aerial photography within the segmentation processes.

The purpose of the second level (EO Level) was to establish the level of detail with which peat erosion features could be established from the EO data. This was achieved by bringing the classification down from 'Integration Level' and re-segmenting within classes that potentially may have peat erosion features present. Through analysis of the EO data, thresholds were then developed for the peat erosion classes developed for this level. The SWIR bands within the SPOT and ASTER were of great importance here.

A third level was then introduced to enable the classification of peat features from the high spatial resolution aerial

photography. This process again involved the classification from the level above (EO Level) being brought down and a much finer segmentation utilising the aerial photography applied. Peat gullies and areas of bare peat could then be distinguished by generating thresholds using indices and bands taken from the aerial photography. Specialist shape features within Definiens were used for the delineation of gullies as these features were noted to be long and thin within the segmentation produced.

3. RESULTS

Example maps produced from the 'core level' (Air Photo level classification) and from the 'application level' (Erosion risk classification) are shown in Figure 4. This map demonstrates that it was very possible using this method to obtain a clear picture of peat erosion features often under a metre in width.

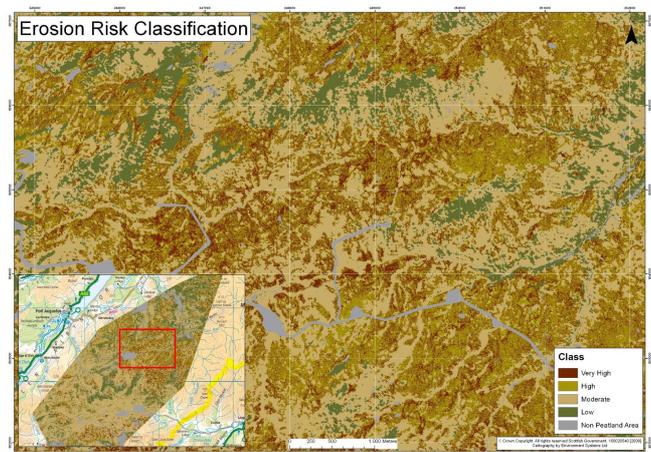


Figure 4: Peat erosion risk map

Several levels of accuracy assessment were carried out, as peat erosion features are not 'hard' features with definite boundaries and a number of uncertainties exist in the data. For example, where a degraded bog becomes a peat erosion feature is not necessarily a 'hard' line on the ground. In many cases the slump at the end of a peat hag has resulted in clumps of bog vegetation within the bare peat area. Where these are frequent the area is eroding bog, where they are infrequent the area would be considered 'bare peat', but the land in-between has a degree of uncertainty (See Figure 5 below).



Figure 5: Example of fuzzy boundary between degraded and bare peat.

Both qualitative (visual) and quantitative (statistical) accuracy assessments were carried out. Field data were collected using GPS devices and this was compared to the maps. However the precision of the field GPS device was also found to be a source of uncertainty. In order to overcome these issues, we moved from the use of Boolean classes to the concept of plausible classes. In the example given in Figure 5 above it would be allowable for the area of vegetation in the centre of this photo to be mapped as eroding bog or bare peat as both are plausible descriptions of it. User producer tables were calculated and overall map accuracy was over 84% with the classified map and both the in-situ field data and aerial imagery clearly coinciding with one another.

4. DISCUSSION

Specific small-scale peat erosion features could not be identified using only moderate spatial scale EO data such as SPOT and ASTER. It was, however, possible to establish the larger areas of bare peat which are present. The SWIR band with both sensors was of great use within the classification of peatland areas as also noted by BenDor *et al.*, (1997). This should be of use within future mapping of peatland areas due to the frequent update and revisit times of these sensors (McMorrow *et al.*, 2004). The EO data did however allow the establishment of different types of blanket bog vegetation to be made, some of which were prone to erosion and some (normally with a high percentage of bog mosses *Sphagnum spp*) which were not so prone to erosion. It was therefore possible to target these vegetation types to look for erosion features in more detail.

The use of aerial photography enabled the smaller scale peat erosion features to be delineated with features such as peat gullies classified to a high level of detail. The classification indicates an extensive presence of many gully systems within the study area. In order to look at the severity of erosion it will be necessary to assess whether monitoring can pick up the changes in the gully systems over time in sufficient detail to note peat loss. However areas with severe erosion features can be identified from this method. These areas could then be studied in a more active way in regards to peat loss. This method has the potential to be undertaken over much larger areas and could therefore give an accurate state of erosion on peatland in the whole of Scotland.

The use of aerial photography alone, however did not enable the discrimination between areas of bare peat and dark,

vegetated areas dominated by species such as *Calluna vulgaris*. It was, therefore, necessary to utilise the greater spectral information of satellite-based EO data to initially target areas, within which the finer resolution aerial imagery could be applied. This has also been noted by Geneletti and Gorte (2003) who found that high resolution images lack the spectral information required to perform a classification. To overcome this and in order to produce accurate classifications, segmentations should be applied differently to each image and the subsequent results combined.

5. CONCLUSIONS

Of the main types of peat erosion in the uplands, large single episodic events such as bog bursts and peat slides are the easiest to sense and trace remotely. However, these events are infrequent and although of great extent in themselves, have been shown to be less significant than continual local erosion through gullying and rill formation on blanket bogs at high altitude and on shallow slopes. The focus of this work has been on the identification of these gullies and rills through the application of EO.

The object-orientated rule-based classification produced using a combination of very high resolution aerial photography, and high and very high resolution multispectral satellite imagery shows that it is possible to integrate these EO data sources with knowledge of the landscape processes to extract erosion features at the appropriate fine scale.

The success of the project is based on not simply considering this as an ecological project, or as a remote sensing project. Rather, coupling ecological knowledge with remote sensing expertise and EO information content provided a solution to a complex mapping challenge. EO, and in particular the combination of airborne and spaceborne imagery, offers the opportunity for consistent, objective mapping over a range of mapping scales.

6. REFERENCES

- ANDERSON, D.E., 2002, Carbon accumulation and C/N ratios of peat bogs in North-West Scotland, *Scottish Geographical Journal*, **118**: 4, 323-341
- BATJES, N.H., 1996, Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, **47**, 151-163.
- BENDOR, E., INBAR, Y. and CHEN, Y., 1997, The reflectance spectra of organic matter in the visible near-infrared and short wave infrared region (40-2500 nm) during a controlled decomposition process, *Remote Sensing of the Environment*, **61**, 1-15
- BRAGG, O.M., 2002, Hydrology of peat-forming wetlands in Scotland, *The Science of the Total Environment*, **294**, 111-129
- BRIDGHAM, S.D. PASTOR, J. DEWEY, B. WELTZIN, J.F. and UPDEGRAFF, K., 2008, Rapid Carbon Response of Peatlands to Climate Change, *Ecology*, **89**, 3041-3048.
- CANNELL, M.G.R. and MILNE, R., 1995, Carbon pools and sequestration in forest ecosystems in Britain, *Forestry*, **68**, 361-379

- DAYTON, N., 2006, An assessment and evaluation of herbivore impacts on blanket bog habitat in the Monadhliath Special Areas of Conservation. Scottish Natural Heritage Commissioned Report No.165.
- FREY, K. E. and SMITH, L. C., 2007, How well do we know northern land cover? Comparison of four global vegetation and wetland products with a new ground-truth database for West Siberia, *Global Biogeochemical Cycles*, **21**, doi:10.1029/2006GB002706
- GENELETTI, D. and GORTE, B.G.H., 2003, A method for object-orientated land cover classification combining Landsat TM data and aerial photographs, *International Journal of Remote Sensing*, **24**: 6, 1273-1286
- GRIEVE, I.C., DAVIDSON, D.A. and GORDON, J.E., 1995, Nature, extent and severity of soil erosion in upland Scotland. *Land Degradation and Rehabilitation*, **6**, 41-55.
- HEROLD, M., MAYAUX, P., WOODCOCK, C.E., BACCINI, A., and SCHMULLIUS, C., 2008, Some challenges in global land cover mapping: An assessment of agreement and accuracy in existing 1 km datasets, *Remote Sensing of the Environment*, **112**, 2538–2556
- KRANKINA, O.N., DFLUGMACHER, D., FRIEDL, M., COHEN, W.B., NELSON, P. and BACCINI, A., 2008, Meeting the challenge of mapping peatlands with remotely sensed data, *Biogeosciences Discussions*, **5**, 2075–2101
- LIMPENS, J., BERENDSE, F., CLODAU, C., CANADELL, J.G., FREEMAN, C., HOLDEN, J., ROULET, N., RYDIN, H. and SCHAEPMAN-STRUB, G., 2008, Peatlands and the carbon cycle: from local processes to global implications – a synthesis, *Biogeosciences*, **5**, 1475–1491
- LINDSAY, R. and IMMIRZI, P., 1996, An Inventory of Lowland Raised Bogs in Great Britain. [In] The sensitivity of peat-covered upland landscapes, *Catena*, **42**, 345–360.
- LUCAS, R.M., ROWLANDS, A., KEYWORTH, S., BROWN, A. and BUNTING, P., 2006. Mapping habitats and agricultural land covers in Wales using multi-temporal remote sensing data. *International Journal of Photogrammetry and Remote Sensing*, **62**:3, 165-185.
- LUCAS, R., ROWLANDS, A., BROWN A., KEYWORTH S. and BUNTING, P., 2007, A Rule-based classification of multi-temporal satellite imagery for habitat and agricultural land-cover mapping. *ISPRS Journal of Photogrammetry and Remote Sensing*, **62**, 165–185.
- Nature Conservancy Council (England Field Unit) (1990) Handbook for Phase 1 habitat survey: A technique for environmental audit. Field manual Dept PHS Nature Conservancy Council, Peterborough.
- MCMORROW, J.M., CUTLER, M.E., EVANS, M. and AL-ROICHDI, A., 2004, Hyperspectral indices for characterising upland peat composition. *International Journal of Remote Sensing*, **25**, 313-325.
- RODWELL, J.S., (ed.) 1991, British Plant Communities. Volume 1. Woodlands and scrub. Cambridge University Press.
- RODWELL, J.S., (ed.) 1991, British Plant Communities. Volume 2. Mires and heath. Cambridge University Press.
- RODWELL, J.S., (ed.) 1992, British Plant Communities. Volume 3. Grassland and montane communities. Cambridge University Press.
- RODWELL, J.S., (ed.) 1995, British Plant Communities. Volume 4. Aquatic communities, swamps and tall-herb fens. Cambridge University Press.
- RODWELL, J.S., (ed.) 2000, British plant communities. Volume 5. Maritime communities and vegetation of open habitats. Cambridge University Press.
- TALLIS, J.H., 1998, Growth and degradation of British and Irish blanket mires [In] The sensitivity of peat-covered upland landscapes, *Catena*, **42**, 345–360.
- TAYLOR, J.A., 1983, The peatlands of Great Britain and Ireland [In] The sensitivity of peat-covered upland landscapes, *Catena*, **42**, 345–360.

7. ACKNOWLEDGMENTS

This project was funded by The Scottish Government and the British National Space Centre (BNSC) under the GIFTSS programme (Government Information from the Space Sector).

We are grateful to expert advice and input from Johanna Breyer and Stephen Ray from Environment Systems and Dr. John Scullion, Dr. Pete Bunting, Professor Richard Lucas and Dan Clewley (Aberystwyth University) and Dr. Ian Grieve (Stirling University)

We also acknowledge with gratitude the help and advice of Andrew Coupar, Dave Horsfield, Jenny Bryce and Dr. John Gordon of Scottish Natural Heritage and Alan Brown (Countryside Council for Wales).

We are also extremely grateful for the knowledge, advice and support of the project steering group, including Geeta Puri (Scottish Government), Matt O'Donnell (BNSC) and Richard Turner (BNSC, GIFTSS).