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Remote Sensing of Bog Surfaces

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1. Summary of Main Findings

The aims of this contract were to:

- review the current approaches to raised lowland bog classification and to identify how remote sensing might provide an information source for such classifications;
- develop a cost-effective method of using the best currently available civilian satellite sensor data to produce habitat maps for raised bogs, to a level of accuracy appropriate for management;
- investigate the opportunities offered by advanced airborne sensors currently available for hire in the UK (e.g. ATM, lidar).

The project focused on three lowland raised bogs: Wedholme Flow in Cumbria, Cors Caron (Tregaron Bog) in mid-Wales and Ballynahone Bog in Northern Ireland.

Ikonos satellite sensor data were found to be highly suited to the task of lowland raised bog habitat classification. Although this sensor has only four relatively broad spectral bands, they are located in parts of the spectrum which were well able to identify the major raised bog land cover classes. Most of the spectral information required for the task was found to be contained within the three visible bands. The near infra-red band, which is often so useful in vegetation mapping and monitoring, was found be of little use, although data in this band could be used to identify the outer limits of a lowland raised bog. The most important attributes of Ikonos data for this task were found to be its high spatial resolution (4 metres in multispectral mode) and its excellent geometric properties. These properties made it possible to interpret the Ikonos image as one would a small scale colour aerial photograph. Indeed, one of the outcomes of this project has been a renewed sense of the importance of visual image interpretation, albeit based upon digital data which have been manipulated and enhanced to maximise their information content.

The project also investigated the potential of airborne lidar data for lowland bog habitat assessment, and we concluded that this data source has a great deal to offer. Unfortunately, the archived lidar data coverage of our sites was very limited, but we have no hesitation in stating that it has a major role to play in both the qualitative categorisation of lowland bog habitats and the quantification of surface microrelief. The combination of Ikonos satellite sensor data and airborne lidar data would be a very powerful tool to monitor and map lowland bog habitats.

We also investigated the potential of remote sensing in other spectral regions for lowland raised bog habitat mapping and monitoring, and concluded that the short-wave infra-red (SWIR) region (around 1.55 – 1.75 m) contained significant additional information not found in the visible wavelengths. However, an operational system reliant upon data collected in the SWIR band would be problematic as there are very few such systems in operation and data from them tend to be expensive. In essence, we felt that the SWIR band was a useful and interesting addition to the visible wavelengths, but its additional utility would not justify the additional cost if the aim was purely to meet the EU Habitats Directive.

Our aim has been to recommend an approach which is reliable, cost-effective, and achievable with minimal additional staff training in remote sensing and Geographical Information System (GIS). Furthermore, we have explicitly considered the need to base any operational method on remote sensing systems which have a reasonable expectation of long-term availability and have alternative sources of data supply. For example, the Ikonos data could be replaced with data from many different visible and near infra-red sensors, including the CASI airborne imaging spectrometer or digital aerial photography. In the same way, the lidar data could be replaced with data from an interferometric synthetic aperture radar (e.g. NEXTMap).

In conclusion, there are two areas which warrant further investigation. The first concerns the use of airborne imaging spectrometry to estimate directly the proportion of an area dominated by 'colourful *Sphagnum* species'. Our research indicates that this should be possible using the CASI instrument, which is operated by the Environment Agency on the same aircraft as the lidar system provided the data we used for this project. The second area of further research concerns the use of an expert system to codify the various approaches to lowland bog habitat classification and to provide a robust means of resolving conflicts when they occur. Remotely sensed data could provide a rich source of information for such an expert system, with the added advantage inherent in this approach that it would be just one of many data streams informing the decision making process.

2. Introduction

Lowland raised bogs are an important and declining habitat throughout Western Europe. The majority of lowland raised bogs in the UK have been damaged to varying degrees and by various human activities over a very long period. The classification and categorisation of the extent of this damage, the extent of natural or near natural active peat growth and the ability to restore active peat formation is central to the management of remaining sites and the application of appropriate restoration measures on degraded sites.

Existing categorisations are varied and based largely on field inventories and surveys. The adoption of remote sensed techniques allows the potential for consistent assessment of the condition of sites over a wider area. However, such approaches will only be effective if the level of discrimination and classification is appropriate to the determination of the impacts and the indicators of the land cover classes (in terms of degree of degradation). This project seeks to assess the capability of remote sensing to discriminate these classes or to generate classes that approximate closely to those of the Lowland Bog Resource Inventory (LRBI) and EU Habitat Directive classes.

Raised bog surfaces pose a significant challenge to current remote sensing techniques. The areas involved are relatively small, and the spectral differences between plant communities are very subtle and change seasonally. However, in the UK at least, the major part of the raised bog habitat is characterised by a short, open sward that lends itself to detailed analysis using remote-sensing techniques. The habitat is thus more intrinsically amenable to such investigation than more structurally complex habitats such as woodland, scrubland or even tall sedge-fen. Raised bog is also a habitat generally characterised by low surface gradients. Consequently the typical problems associated with remote sensing in upland areas, such as extreme slope angles, markedly differing aspects, and hill shadows, do not generally arise. Indeed there is every reason to believe that as remote sensing becomes more capable, so raised bog sites will yield to the unique advantages that it offers. In particular, remote sensing has the potential to determine the surface extent and configuration of bogs, their species composition, and physical variables such as surface moisture content and the degree of humification of exposed peat. This report describes the results from a contract which set out to achieve three things:

- to review the current approaches to raised lowland bog classification and to identify how remote sensing might provide an information source for such classifications;
- to develop a cost-effective method of using the best currently available civilian satellite sensor data to produce habitat maps for raised bogs, to a level of accuracy appropriate for management;
- to investigate the opportunities offered by advanced airborne sensors currently available for hire in the UK (e.g. ATM, lidar);

3. Raised Bog Habitat Condition Classifications and Remote Sensing

The aim of this section is to review the definitions relating to the Lowland Raised Bog Inventory (LRBI) and European Union Habitats Directive classification systems. The two systems will be evaluated in terms of their potential for discrimination by remotely sensed methods.

3.1 European Commission 'Habitats' Directive classification system

3.1.1 Introduction

The European Union 'Habitats' Directive (Council Directive, 1992) establishes a common framework for the conservation of wild plant and animal taxa and natural habitats of importance to the European Community. The directive provides for the establishment of special areas of conservation (Natura 2000). The aim of these conservation areas is to "*maintain and restore, at favourable conservation status, natural habitats and species of wild fauna and flora…*" (European Commission, 1996). Annex I of the 'Habitats' Directive lists 198 European natural habitat types, which includes 65 labelled as priority "*habitat types in danger of disappearance whose natural range falls mainly within European Union territory*", European Commission, 1996).

The CORINE Biotopes project, led by Professor Noirfalise, was used as the basis for the list of habitats in Annex 1 of the Habitats Directive published in May 1992 (EUR12). The CORINE hierarchical classification of European habitats was subsequently updated, whilst the original Habitats Directive was being adopted. The revision introduced various changes to codes and habitat types, such that Annex I of the 'Habitats' Directive (version EUR12) no longer matches the CORINE classification. The Task Force/European Environment Agency later produced a paper describing the differences between Annex I and the revised CORINE classification (Task Force Agency, 1992). EUR12 has since been updated to EUR15, which incorporates habitat types from Austria, Finland and Sweden.

3.1.2 Interpretation Manual of European Habitats

The interpretation manual that accompanies Annex I of the 'Habitats' Directive (Council Directive, 1992) is primarily focused on the 65 'priority habitats'. The manual includes full descriptive sheets for each of these habitats, which "*establish clear, operational scientific definitions of habitat types, using pragmatic descriptive elements (e.g. characteristic plants).*" (European Commission, 1999). Similar descriptive sheets are provided for a further 36 non priority habitat types, which commonly cause interpretation problems. The remaining habitat types are represented by the CORINE Biotopes definitions (1991 version), which are considered to be "*a minimal interpretation*" (European Commission, 1999). The simple biotope definitions omit subtypes and regional varieties.

3.1.3 The Classification of Ombrotrophic Bogs in Annex I of the 'Habitats' Directive

Lowland Raised Bogs appear under the '*Sphagnum* acid bogs' classification in Annex I. Two habitats are relevant to the present literature, namely 'Active Raised Bogs' (habitat code: 7110), which are priority habitats and 'Degraded raised bogs still capable of natural regeneration' (habitat code: 7120). Three further ombrotrophic bog types appear in Annex 1; Blanket Bogs (habitat code: code 7130), Transition Mires and Quaking Bogs (habitat code: 7140) and Depressions on peat substrates of the *Rhynchosporion* (habitat code: 7150). These latter three habitats fall outside of the scope of the present review.

***Active Raised Bogs (priority habitat)**
The EU interpretation manual defines 'Active Raised Bogs' as acid bogs, which are poor in mineral nutrients and mainly sustained by rainwater (ombrotrophic), with a water table level generally higher than the surrounding water table. "*The bogs are characterised by colourful Sphagna hummocks allowing for the growth of the bog*" (EUR15 /2, 1999). The interpretation manual is specific in defining the term 'active'.

> "*The term 'active' must be taken to mean still supporting a significant area of vegetation that is normally peat forming, but bogs where active peat formation is temporarily at a standstill, such as after a fire or during a natural climatic cycle e.g., a period of drought, are also included*". (European Commission, 1999).

The main plant species considered to be characteristic of oceanic 'active' raised bogs listed in Annex I include the following indicator species: *Andromeda polyfolia*, *Carex pauciflora*, *Cladonia* spp., *Drosera rotundifolia*, *Eriophorum vaginatum*, *Odontoschisma sphagni*, *Sphagnum magellanicum*, *S. imbricatum*, *S. fuscum*, and *Vaccinium oxycoccos*.

'Active' raised bog may be further defined using the Nation Vegetation Classification system (NVC) (Rodwell, 1991). Annex 1 of the habitats directive identifies four NVC communities as corresponding to 'active' raised bog (M1, M3, M18 and M20a). However, classification schemes used in the guidelines produced by the British conservation agencies differ to varying degrees with respect to the NVC communities recorded as 'active raised bog'.

Table 1 provides a comparison of the classifications used by the different organisations and the Habitats Action Plan (HAP).

Table 1. Comparison of NVC categories included in 'active raised bog' by different authors

Phase 1	NVC communities	EU habitat	Comments
E1.6.2 raised bog	EU HD M1, 3, 18, 20a JNCC (1994) M1-4, 15, 16, 18, 20, 21 HAP (1999) M1-3, 15, 18, 19, 25 CCW (1999) M1-3, 18, 20, 25	'active raised bog'	Colourful *Sphagnum* Peat forming Acid Mineral nutrient poor Include M15, 16 only if peat >0.5m deep
E1.7 wet modified bog (derived from raised bog with *Sphagnum* spp. present at surface)	Dargie and Maier (2001) M15, M19, M20	'active raised bog'	Colouful *Sphagnum* Peat forming Degraded raised bog Include M15, only if peat >0.5m deep

Modified from Dargie and Maier (2001)

The EU 'Habitats' Directive recognises that some marginal areas of lowland raised bogs of relatively low quality will need to be identified and included in special areas of conservation to ensure that the active portions of the raised peatland systems can be secured. This may also require the regeneration of degraded areas.

3.1.4 Remote sensing of 'active raised bog'

The distinctive features of 'active raised bogs' identified by the 'Habitats Directive' are that they are peat forming, they maintain a raised water table and contain colourful Sphagna. The field guidance notes produced by Countryside Council for Wales (CCW) adds another important feature, namely that active raised bog has a characteristic hummock / hollow topography (CCW, 1999). Remote sensing techniques such as lidar may be able to characterise the topography of the mire surface, whilst CASI data could be used to explore the proportion of colourful Sphagna present.

3.1.5 Degraded raised bogs still capable of natural regeneration

This habitat type (habitat code 7120) includes raised peat bogs that have suffered damage to the natural hydrology of the peat body, usually as a consequence of anthropogenic disturbance such as hand and machine turf cutting, ditching and peripheral extraction. The plant communities of sites in this category usually contain species typical of the drier parts of raised bogs as there main constituent. But the cover of individual species may differ from the natural state. (European Commission, 1999).

The degraded category is considered to include sites where the damage to the hydrology can be repaired to the extent that peat forming communities re-establish within a timeframe of 30 years.

Management strategies might include ditch blocking and the installation of bunds or staggered sets of pools around the periphery of the intact raised peat dome.

3.1.6 Remote sensing of Degraded raised bogs still capable of natural regeneration

Degraded raised bogs are usually but not always a result of major anthropogenic disturbance to the bog hydrology. Old damage from hand peat cutting is usually restricted to the periphery of sites but this may still have a major impact on the raised water mound across the whole site. By contrast industrial scale modern exploitation may involve ditch cutting right across a site or stripping of vegetation from large sections of a raised mire. Bog bursts, such as the one that occurred at Solway Moss in the late nineteenth century are an example of a natural disturbance to a raised bog system that could disrupt the surface hydrology to the extent that long term changes occur to the vegetation communities. In all cases the damage leaves very distinctive traces long after peat surfaces have begun to re-vegetate. These signs of disturbance are readily detected from the air by simple manual interpretation techniques using either air photographs or Ikonos imagery. Lidar may also prove to be a highly affective method of surveying the surface topography of degraded bogs, since this technique has sufficient resolution to detect even subtle changes in relief. More complicated automatic techniques are probably not necessary for detecting damage that is sufficient to disrupt the overall site hydrology of raised bogs.

3.2 The Lowland Raised Bog Inventory (LRBI) (Lindsay and Immirzi, 1996)

3.2.1 Background to the Inventory

The Inventory of Lowland Raised Bogs in Great Britain was compiled in 1996 to provide a synthesis of information on the condition and conservation status of identifiable lowland raised bogs (Lindsay and Immirzi, 1996). The Inventory provides a general assessment of land cover, and it reports the extent of peatland types in Britain as well as their conservation status (e.g. SSSI, NNR or SAC).

The Lowland Raised Bog Inventory is only concerned with ‘confined’ raised bogs, which are systems that have developed solely or largely through terrestrialisation. As the lowlands of Britain are now generally subject to various degrees of agricultural activity, the concept of ‘lowland raised bog’ in practice was applied to those areas that currently form discrete units of ombrotrophic peat within an otherwise non-peat (*i.e.* agricultural) landscape. The lists of bog sites and their descriptions published by Lindsay and Immirzi (1996) consequently focus on a relatively small proportion of the overall national peatland resource. ‘Semi-confined’ lowland bogs are also listed by the Inventory. This latter peatland type consists of raised bog systems that may have a main peat dome contained within a basin and fringing mires that have developed via paludification of mineral ground beyond the confines of the original basin. The semi-confined mire systems are termed ‘intermediate’.

Lindsay and Immirzi (1996) recognise three broad conditions of raised bog: primary, secondary, and archaic. ‘Primary’ raised bog represents those parts of a raised bog that have developed through natural growth. Fires and drier climate periods may have caused the surface to cease peat accumulation for a time, but the stratigraphic profile is otherwise intact. ‘Secondary’ raised bog represents those parts of a raised bog that have lost part of the stratigraphic profile through peat removal, generally as a result of peat cutting or agricultural land-claim. The habitat is clearly still ombrotrophic peat, but the surface morphology is determined largely by the activities of peat removal and surface lowering. ‘Archaic’ peat was defined as ombrotrophic peat deposits that are now so subject to human activity as to be unrecognisable as ombrotrophic peat. Leys of *Lolium perenne* sown onto peat soils, for example, or the extensive tracts of root-crops dominating the Lancashire coastal plain, both represent ‘archaic’ peat areas.

The Lowland Raised Bog Inventory assumes that cutover bogs originally derived from raised bogs unless there is specific evidence to suggest otherwise (Lindsay and Immirzi, 1996). Oligotrophic peat found on blanket bogs and raised bogs is readily distinguishable from eutrophic to mesotrophic fen and fen carr peat on the basis of macrofossil remains. The latter peat types normally contain obvious remains of reeds (*Phragmites australis*), sedges (e.g. *Carex* spp. and *Cladium mariscus*) and wood remains (carr peat) whereas the former two categories of acidic peat are often rich in Ericaceous remains and Sphagna, or they may be humified to the point where plant remains are not readily distinguishable.

The definitions of ‘lowland’ and ‘upland’ used by the Inventory are deliberately flexible and not based on altitude alone. Instead Lindsay and Immirzi (1996) have adopted the ‘traditional’ definition of ‘upland’ as being land that extends either above or beyond the enclosed land. Generally though, most raised bogs lie at low altitude and they are most often found below 200m elevation.

3.2.2 Classification used by the Lowland Raised Bog Inventory

Table 2 presents the condition class scheme devised by Lindsay and Immirzi (1996), while Table 3 sets out the vegetation modifiers subsequently used by the Scottish Wildlife Trust for the Scottish Raised Bog Land Cover Survey (Parkyn & Stoneman 1997).

Table 2 : The Lowland Raised Bog Inventory (LRBI) uses the following land cover classes.

Class	Name	Description
P1*	Primary natural / near-natural	A primary peat dome with an extensive cover of colourful Sphagna, with the ability to accumulate peat.
P2*	Primary degraded	Primary surface where the vegetation has been modified by factors other than drainage (e.g. grazing).
P3*	Primary drained	Primary drained bog in which a regular drainage pattern exists.
P4	Primary open canopy	Primary bog supporting open canopy woodland or scrub.
P5	Primary closed canopy	Bogs supporting closed canopy woodland. Trees may have ‘self-seeded’ but often they are present because of deliberate planting. Self-seeding is often a symptom of damage. Tree cover enhances oxidation and drying of the peat surface.
S1*	Secondary re-vegetating	Surface layers of peat have been removed. Following abandonment of the site vegetation has re-established mainly through natural regeneration.

Class	Name	Description
S2	Secondary, commercial / domestic peat extraction	Large expanses of bare peat for modern industrial-scale peat extraction. Block getting and milling maintain a largely bare peat surface.
A1	Archaic (agriculture)	Bogs drained for agriculture. The peat is oxidised with a lowered surface. Eventually fen peats will be exposed.
A2	Built development	Peatland covered by structures such as buildings, roads or railway lines.
U	Not determined	Condition not yet classified.

Table 3. Vegetation modifiers used in land cover classification

Drainage Modifiers	Vegetation Modifiers	Erosion Modifiers
I irregular	BP broadleaf plantation	MIC micro-broken
N narrow	CP coniferous plantation	Y gully erosion
M moderate	MP mixed plantation	
W wide	PF plantation felled	
A absent	PFR plantation felled and replanted	
U unknown	BS broadleaf self-sown	
	CS coniferous self-sown	
	MS mixed self-sown	
	GS gorse, bramble etc	
	O or C open or closed canopy	
	L low shrub dominated	
	H herb dominated	
	SPH *Sphagnum* dominated	
	BRY bryophyte dominated	
	BAR bare peat dominated	
	BBA bryophyte / bare peat co-dominant	
	BS bryophyte / *Sphagnum* co-dominant	
	BAS bare peat / *Sphagnum* co-dominant	

* denotes condition classes that are considered to be ‘active’ under Annex I of the EC Habitats Directive.

3.3 A Remote Sensing Framework for Lowland Raised Bog Classification

Having established the current best practice in respect of bog habitat classification, the next step was to identify a set of procedures which would deliver these classes in an accurate, reliable and cost-effective manner, based as much as possible on remotely sensed data manipulated in a geographic information system (GIS). Additional requirements were that the overall processing chain be robust, so that alternative sources of data could be substituted if necessary, and so that high-level technical skills in remote sensing and GIS were not necessary to achieve a reliable and repeatable outcome.

3.3.1 Identification of lowland raised bogs on remotely sensed images

Although not strictly part of this project, it should be noted that remote sensing provides a simple means of identifying the extent of many lowland raised bogs, as the contrast between the area of bog and the surrounding agricultural land is often very high, especially in the near infra-red region. Many satellite sensors include a spectral band in the near infra-red, so, depending upon the spatial resolution required, it would be possible to map the extent of lowland peat bogs using data from Ikonos, SPOT HRV, Landsat ETM+ and many other systems.

3.3.2 Identification of physiographic units within lowland raised bogs

For the purpose of this project, the most important physiographic features were those related to past drainage of the bog and evidence of active or abandoned peat cutting. Ideally, mapping such features would be achieved using a sensor which responded to subtle variations in surface micro relief, such as radar, lidar or stereo air photo interpretation, but in the absence of data from these systems, it would be possible to use data from the visible, near infra-red and thermal infra-red wavelengths. The reason for this is that the spatial variation within land parcels, although primarily due to variation in topography, would also be expected to be mirrored in the land cover on a raised bog. Spatial patterns of healthy vegetation, saturated ground and standing water would be expected to have an expression in the spectral domain as well as the spatial domain.

3.3.3 Identification of plant communities on lowland raised bogs

Clearly, one of the most important indicators of active raised bog is the presence of ‘colourful *Sphagnum* species’ and it is very likely that these will have a characteristic spectral response within the visible and near infra-red wavelengths. There is also some evidence from the literature that reflectance in the short wave-infra-red, around the shoulders of the water absorption features at 1.4µm and 1.9µm, varies considerably for different plant species commonly found on raised bogs. Although very few remote sensing systems exist that could measure these spectral features in detail, most sensors have some spectral capability in the visible and near infra-red region.

3.3.4 Summary of remote sensing data requirements

The minimum requirement to achieve the task would appear to be data from a high spatial resolution sensor operating in visible and near infra-red wavelengths. Satellite sensor data are preferable to airborne data for the task as they have much better geometric properties and also cover larger areas of ground for lower cost. However, cloud cover is a major limitation on the operational use of satellite sensor data in the UK.