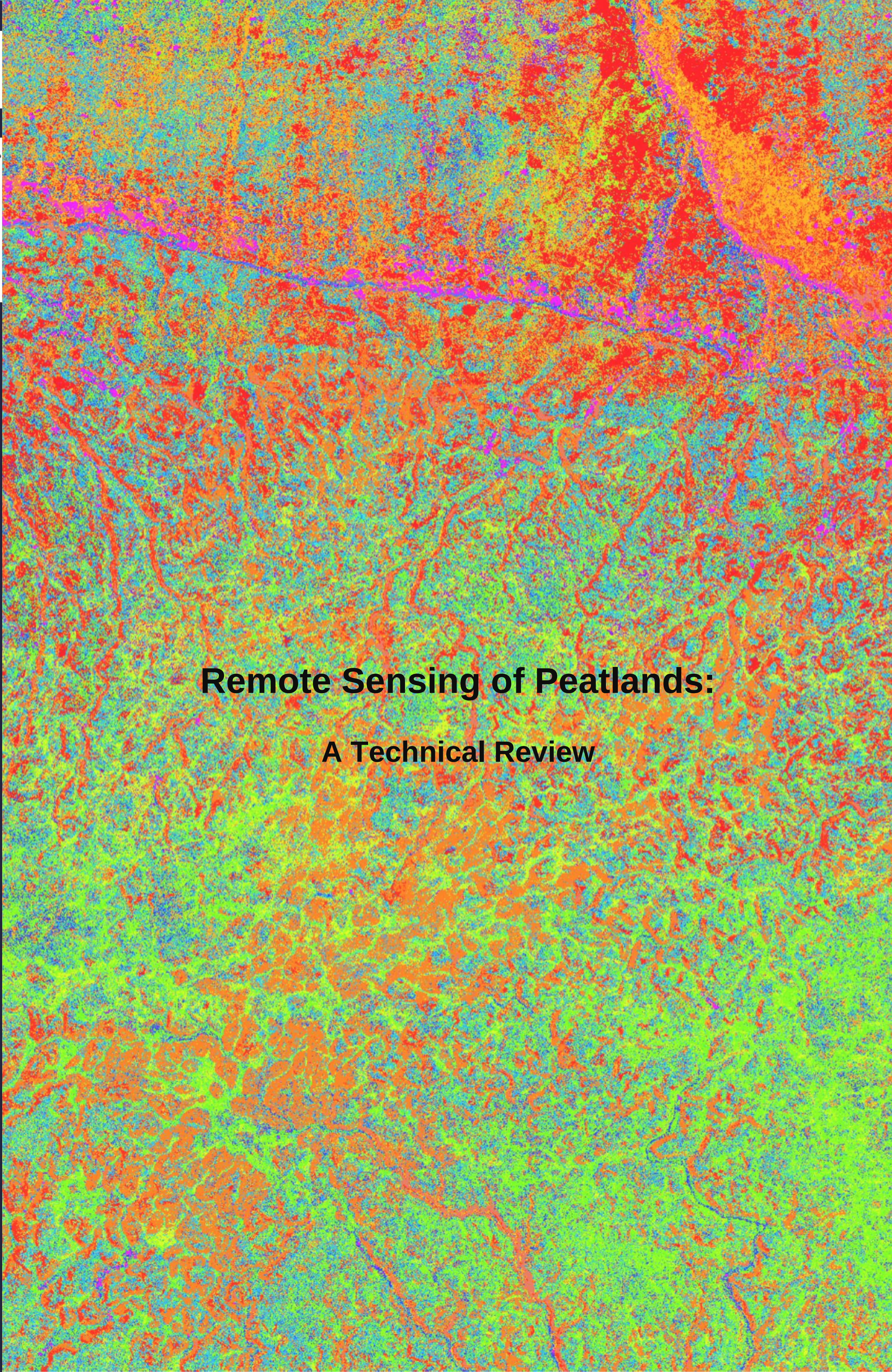

Remote Sensing of Peatlands:

A Technical Review

TECHNICAL REPORT

CS Conservation Survey

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Foreword

This technical briefing was produced by Drs Adrian R Yallop and Ben Clutterbuck, commissioned by the IUCN UK Peatland Programme (IUCN UK PP) to provide an overview of the potential and applicability of remote sensing technologies for ecological monitoring of UK peatlands. IUCN UK PP provided a list of suggested metrics and minimal resolutions to the authors to guide the content of the briefing, based on feedback from those involved in the restoration and monitoring of UK peatlands.

Authors note and caveats

It is not within the scope of this document to provide a grounding in remote sensing techniques. However, for those with limited experience in the field, a glossary of key terms is provided, together with brief contextual notes in most sections.

Contents

1. Introduction

1.1. Why Remote Sensing?

There is growing interest in the role of remotely sensed data, including optical, radar, and LiDAR, to detect changes in peatland condition and extent. The use of remotely sensed data may:

- Enable mapping at scale (e.g., national inventories of peatland);
- Increase (or maintain) accuracy and reduce costs in detecting changes in peatland condition (relevant to the Peatland Code and greenhouse gas (GHG) accounting for peatlands in the UK's GHG Inventory) through direct measurement or the measurement of proxies;
- Have other policy applications, for example in targeting sites for restoration with public funds and identifying impacts of activities such as drainage or burning and monitoring the outcomes of publicly funded restoration schemes.

There is a great deal of innovation in the field of remote sensing and its application to habitat assessment. This, coupled with limited understanding of the current capabilities and limitations of remote sensing by the wider peatland community, can make it challenging to utilise these technologies in peatland policy and practice. In addition, there are companies willing to provide remote sensing data, but these require coordinated effort to help ground truth the data sets. This briefing presents several key metrics required for ecological assessment of peatlands, suggesting desired spatial and/or taxonomic resolutions against which existing remote sensing technologies are then assessed. These metrics are by no means exhaustive but provide a framework against which to explain important considerations when employing a remote sensing approach, and the applicability of remote sensing in supporting peatland monitoring.

1.2. Precepts, aims and purpose of this review

This briefing aims to act as a summary and reference document for peatland restoration practitioners, which outlines a range of specific metrics required for peatland assessment and assesses whether existing remote sensing technologies are applicable. It is also intended to provide background information for: landowners prior to judging capabilities and specifying services to be contracted; those undertaking their own 'in-house' survey work; and contractors offering services.

This document covers the application of remote sensing techniques for the initial quantitative evaluation of site potential for improvement, monitoring of restoration progress, and the final metrics of success. It deals solely with physical phenomena directly measurable using absolute, not relative, units and does not address the interpretation of this quantitative data.

These guidelines aim to be as agnostic as possible regarding data types and classification protocols: *providing all final derived data meet requirements and are statistically bounded, verified and those results reported in academically standard ways*. This process must extend into all inferred statements of meanings of those data. By otherwise not defining how surveys are to be executed, it is intended to provide the freedom to innovate and develop new suitable methodologies, whilst still ensuring that the reported data and interpretations made for each project are fully justified by reference to statistical evidence.

2: Optical mapping of land cover

2.1. Introduction

Remote sensing of land cover or vegetation should never be considered an *alternative* to fieldwork. Rather it provides the opportunity to map more extensive areas, in more detail, and more cost-effectively, than would be possible using manual survey techniques alone.

The acquisition of appropriate ground data for both 'training' of classifier algorithms and verification of outputs is a core component of remote land cover survey methods. Indeed, it is likely to be one of the most time-demanding aspects of any such project. The need to collect ground data should therefore form an integral part of the initial planning of a project.

This section covers the mapping of vegetation, exposed unvegetated surfaces, and standing water by use of optical wavelength remote sensing: typically defined as visible light up to thermal IR (0.4-15 μm). It deals with the five main aspects of a remote sensing project: typology; potential data sources; field data collection; image processing; and error assessment.

It should be noted that the proposed imagery capture and field-data acquisition approaches rely on adoption of working methods yielding exact geolocational data (i.e. use of post-processed DGNSS and/or RTK positioning) to deliver highly detailed survey supported by statistical evidence.

MAV and UAV sensors together with GNSS geolocation technologies have improved markedly over the past decade. Image pixels can resolve a few centimetres on the ground and these, together with matching field sample data, can be geolocated with the same precision. These new tools, if correctly exploited, open up completely new opportunities for detailed quantitative vegetation/land cover mapping for baseline survey, monitoring and restoration appraisal. They do however require adoption of more precise working practices using currently available equipment. It is acknowledged that these guidelines are for now and the future, paying little regard to past practices.

2.2. Components of remote sensing

Remote sensing mapping projects can be considered as comprising five discrete, but linked, components: typology; potential data sources; field data collection; image processing; and error assessment. Monitoring, or change detection, adds a sixth. The IUCN UK Peatland Programme suggests metrics that are useful for peatland assessment using remote sensing (see **Table 2.1**) and these can be used to help guide options for each component during project planning.

Table 2.1. Summary of desired objectives for mapping peatland using remote sensing

Objective	**Key variables**	**Comments**	**Explicit minimal resolution**	
			Spatial	*Taxonomic*
Cover	*Sphagnum* cover (m^2) species *if possible*	Peat mire Peatland: peat soil > 30cm	cm^2- m^2	Genus-sp.
	Eriophorum cover (m^2) species		cm^2- m^2	Genus-sp.
	Other key indicators *Trichophorum cespitosum,* *Drosera* spp. *Narthecium ossifragum*	See guidance in JNCC (2009) for other pertinent indicator species of condition	cm^2- m^2	Sp. Genus-sp. Sp.
Indicators of degradation	Presence, abundance, and structure of *Calluna* (m^2/cm)	See also **Section 3**	cm^2- m^2 cm in z	Sp.
	Presence and cover of trees/scrub tree height (m)	See also **Section 3**	cm in z	Genus-sp.
Structure	Bare peat		m^2	
	Height of canopy including *Sphagnum* hummocks and hollows		cm in z	
Hydrology	Microtope pattern change	See also: Lindsay (2010)	cm in z	
	Standing water		m^2	

Typology

The core of any quantitative survey or monitoring programme, whether field-based or remotely sensed, is to define what exactly is to be measured. In the case of vegetation mapping, this starts with deciding how land cover types are to be divided up and classified i.e., the units or classes to be mapped: usually referred to as a typology (see **Box 2a**).

The spatial aspects of the suggested objectives require a typology that is:

i: differentiable at centimetric spatial scales (this in turn helps determine optimal imagery sources (see below);

ii: able to map the extent and change of numerous plant *species* as essential indicators of condition assessment.

These both preclude the use of many 'traditional' conservation survey approaches (see **Box 2b** for a brief discussion).

BOX 2a

Typology

All survey and monitoring approaches require suitable units of evaluation. This is usually referred to as a typology and comprises a series of units or classes. Remote sensing is no different.

To be of any practical use for quantitative ecological survey, and especially monitoring, it is a fundamental prerequisite that the typology used is totally unambiguous, i.e., all field surveyors are enabled to:

assign the same class - at the same sample locus - at the same time.

The typology used must therefore be independent of any *subjective* judgements or need for estimation. This 'repeatability' of a field survey protocol: i.e. its ability to record the same value through time where no change has occurred is a fundamental necessity of quantitative survey.

If the typology does not meet this requirement, it is impossible to differentiate actual changes observed from those arising solely because of differing judgements between observers. The adoption of an unambiguous typology is therefore suggested as the key criterion of any protocol used for peatland condition monitoring.

Suggested typology

Given the desired spatial and taxonomic objectives, it is suggested that the typology used for peatland site survey simply becomes plant species for vegetated areas, with the addition of unvegetated classes such as bare peat, rock and mineral soil. This will provide unambiguously identifiable sample data for field survey, image training and classification, mapping and error appraisal.

If required for later visualisations etc., individual species distributions can be readily merged, *post hoc*, into larger taxonomic groupings, communities or habitat types. Such an approach eliminates all potential issues of surveyor ambiguity and offers the ability to produce simplified outputs for visual clarity whilst providing for full statistical appraisal of accuracy based on field observation. Such a workflow has been successfully demonstrated over several years in conjunction with Moors for the Future Partnership (Yallop et al., 2021).

BOX 2b

Repeatability and traditional conservation monitoring

Historically, vegetation field survey methods for conservation in the UK have been invariably based on the identification of habitat types or phytosociological associations, e.g., Phase 1 and NVC, BAP, etc. Alternatively, less defined 'ad hoc' classes such as *'dense heather'*; *'moderate heather';* '*mixed heather/monocot sward*' or 'woodland' are also often used. Simply put, none of these approaches are fit for the purposes of mapping and monitoring, whether by field survey alone or by using remote sensing. They simply fail the unambiguity criteria.

It is therefore strongly recommended for all parties wishing to plan field survey and monitoring programmes, for direct reporting or remote sensing use, to become conversant with the full implications of the findings of Cherrill & McClean (1995; 1999) and Hearn et al. (2011)**.** The use of such classes would still be unsuitable for monitoring, even if ambiguity was not present, because they are aggregates of species, i.e., no single species defines a single NVC community, and no community defines an absolute suite of species. Many species can come and go 'invisibly' to a monitoring programme based on such a typology. Many of these might be good indicator species of change or be of conservation interest.

Attempting to use habitat, plant associations/communities at VHR/XHR resolutions faces another obstacle. These typologies are no more than conceptual constructs that only become apparent at larger spatial scales: this is explicit within NVC suggested mapping scales and Phase 1 approaches. At scales of a few cm, vascular vegetation will mostly exist 'on the ground' as single species and any community or habitat cannot be said to exist. Only by reference to surrounding areas can the concept be imagined. With few exceptions, field surveyors given a picture of a single plant could not identify a community. Likewise, pixels in an image exist in isolation, i.e., they do not contain any information about those around them. This is exactly analogous to identifying a specimen in, for example, an NVC survey. A single plant, at a single place, does not define a community, and neither can a single pixel. Hence it would be irrational to attempt to assign plant community membership to the species with solely the information in a pixel.

To circumvent all these issues, it is therefore recommended that the units used to survey vegetation simply become ***species***, with the addition of bare peat, standing water, rock and bare mineral soil to cover unvegetated areas. It is simple and all competent surveyors will be able to unambiguously assign such a typology.

Imagery

The minimum spatial resolutions desired for most criteria shown in **Table 2.1** (i.e., ≤1.0 m), together with the requirements imposed by the suggested typology, would seem currently to restrict suitable image sources to those captured by airborne sensors, either MAVs or UAVs. These are readily able to deliver GSD of <<1.0 m, up to ≈5 cm (or more typically ≈12 cm for the former and ≈5 cm for the latter), depending on flight altitude and sensor specifications. Both remote sensing platforms therefore are in principle able to meet the indicative protocols suggested in this review.

Although Orbital EO imagery can be obtained with sub-metre GSD, the current expense of such data is likely to limit their application. Data enhancement such as pan-sharpening (see **glossary**) also needs to be considered, as only three satellites currently achieve <1 m native resolution imagery, and most other satellite data are pan-sharpened to achieve this (see **Table 2.2**).

The use of higher and higher resolutions for image processing does however bring a requirement: a matched increase in the precision of all aspects of the remote sensing project and field data collection. The required accuracy of image/field data co-registration will require DGNSS usage during field survey and image capture. This is discussed further under the pertinent sections below.

There are inevitably advantages/trade-offs associated with the use of either data source. The choice will probably mainly be determined by project specifics, but the primary consideration is likely to be the areal extent of the site. The convenience and lower costs of UAVs (see **Box 2c**) will be best realised on small to moderately sized sites of up to 1-2 km^2 (100-200 ha). This is not to say they should not be considered for larger areas, but the increased number of flightlines and associated capture time required can become problematic. As sun-angle issues limit daily activity, this can interact with daily meteorological changes. Larger areas are the domain of MAVs, all else being equal, as these will deliver consistent imagery over large areas in short periods (see **Box 2d**). An additional advantage of MAV capture is the ability to fly over moorland during periods when access is restricted because of ground-nesting birds.

Hyperspectral sensors

There is no presumption against the use of hyperspectral sensors, and, in principle, these might provide improved class differentiation during image classification. However, it should be noted that current technologies produce far larger GSDs (i.e., lower image resolution) for a given flight altitude than MS sensors. In addition, most are 'push-broom' in operation and may readily suffer issues arising from roll instability with small platforms like UAVs. Currently, few studies have examined how well post-processing for mosaic and DSM creation controls these potential issues. There are also few data on how hyperspectral imagery increases class differentiation in the realms of XHR analyses, especially using the suggested typology.

Until these topics are more fully researched, we feel it advisable to not suggest investments in UAV HS sensors except for research.

Image ortho-correction and mosaic creation

It is expected that all contractors, or in-house operators, of UAV image capture can undertake full ortho-correction of imagery with RMSE targets of around one pixel. Even with RTK, this process might benefit from use of ground-targets used as GCPs.

BOX 2c

Imagery from unmanned aerial vehicles: UAVs

UAVs undoubtedly offer unrivalled flexibility in image acquisition over small to modest areas. They give great control in terms of timing allowing, in principle, matching with specific phenological phases of target vegetation or adjusting to meteorological conditions. They are cheap enough per flight (if operated in-house) to allow the potential of multiple flights per year. This can improve differentiation of species during image classification by incorporating temporal stacking approaches. If services are contracted, costs may still preclude this option.

UAVs can be fitted with numerous sensor options: the main options for image classification are presented in the Table below. For image classification it is recommended that a minimum of RGB, NIR bands are captured. Red-Edge, as an addition, may slightly improve class separability, but there are too few data to allow judgements to be made. It is probably best to advise that if operating a sensor that incorporates red-edge band/s, then incorporate the outputs.

The use of RG, NIR imagery has likewise not been directly assessed relative to RGB, NIR so, as with Red-Edge, no recommendations can be made.

Platforms:

UAVs generally come in rotary and fixed-wing forms. Although either would suffice for the tasks defined here, rotary types do generally have higher energy requirement. This can result in a frequent need to replace batteries during operations, thus increasing total time required. All UAV flights in the UK are restricted to a maximum height of 400 ft (*c*.120 m) unless specific operational permissions are obtained from the Civil Aviation Authority (CAA). This is one of the key factors limiting areal coverage achievable in a single flight.

Control software:

UAVs used for image collection for classification must be capable of GNSS guided autonomous flight over pre-programmed routes. Owing to the need to align imagery to field samples with a high degree of precision, RTK corrected location data are ideally to be collected during image capture. If RTK is not available, then post-correction DGNSS processes should be applied *post-hoc* to a series of ground control targets (GCPs).

Example UAV sensors commonly available for contract hire in the UK in 2024

Sensor	Bandwidth	GSD m	
		At 120 m	*At 60 m*
DJI MAVIC 3M	G R RE NIR	0.05	0.025
DJI P4	B G R RE NIR	0.06	0.03
Micaense Altum PT	B G R RE NIR TIR	MS 0.05 TIR 0.33	MS 0.025 TIR 0.16
Micasense RedEdge-P	B G R RE NIR	0.08	0.04
Micasense RedEdge-P Duo	CB, B, G1, G2, R1, R2, RE1, RE2, NIR1, NIR2	0.08	0.04

BOX 2d

Imagery sources: tasked capture or archive

'Bespoke' or 'tasked' capture

If you are contracting commercial suppliers to provide imagery from bespoke MAV flights, it is worth considering several factors. The usual activity of many commercial MAV operators is the provision of high-quality imagery for visual interpretation: not for computer image classification. This will probably be a relatively new field of application for their data, and this should be understood by them during contract negotiations. It would be highly beneficial to engage with technical staff, not sales, to negotiate what could be undertaken by them to, for example, increase ortho-correction precision, etc. This may entail additional ground-control points (GCPs) which may need to be identified, geo-located and supplied to the contractor.

Contractor workloads are also likely to be high and their planned schedules may be adversely impacted by periods of poor meteorological conditions. It is important therefore that limits for date/time are defined in contract based on your needs: shadow from topological features and vegetation can be highly problematic at XHR resolutions. A clear understanding of the possible consequences of changing target times will help in deciding how flexible you can be before cancelling the capture. Be particularly cautious of contractors working long hours to catch-up with workload: late afternoon shadow will generally reduce classification accuracies.

All imagery should be contracted for supply in uncompressed formats, usually geo-TIFF and, crucially, examined thoroughly for ortho-correction accuracies, illumination etc., before acceptance.

Archive

In addition to contracting or tasking 'bespoke' flights, extensive archives of 4-band digital imagery exist. Dating back to their first general use over the UK in around 2004, this can be a good source of data for image classification and/or analysis of site history. Note this refers solely to digitally captured RGB, NIR imagery captured from that date. Most earlier archive material was originally film-based and then digitally scanned for storage and retrieval. Imagery in this form will be unsuitable for image classification as it is only 3-band (RGB) and often contains significant lighting, colour-balance and mosaic issues. If attempting to classify imagery from archive, the only option is to use API for training and error assessment. This will restrict taxonomic resolution.

One critical thing to be aware of is that archive imagery is provided as a 'seamless' mosaic 'clipped' into 1 km OS tiles for download. From this it is easy to infer the capture date is the same across the image. This need not be so. Parts of the mosaic can have been flown on different dates of the year, e.g., spring/summer or summer/autumn. As a result, parts of an image may be showing vegetation in different phenological stages. In addition, differences in sun angle and colour balance can easily exist within single 1 km tiles. This makes classification extremely problematic as it widens spectral class signatures. Owing to the way images are colour and luminance balanced before being 'stitched together', it can sometimes be visually very difficult to identify if this has occurred or where joins lay. The best locations for identifying potential issues are areas of generally homogenous surface: blocks of water and roads are especially helpful in this regard.

Field data

This refers solely to field data gathered for the 'training' of image classifier software and assessing the mapping accuracy of outputs.

As elsewhere in this guidance, the following is not meant to be obligatory. The proposals made are based on many lessons learned during the development of methods for mapping peatlands using XHR imagery. With any method, it should be noted that image classification requires precise alignment of field observations to corresponding image pixels. This becomes more difficult as image resolution (pixel size) decreases.

To facilitate use of the suggested species typology, while allowing for some inevitable residual inaccuracies between image alignment and field data, is it suggested that field survey is undertaken by identifying small areas of essentially 'pure-stands' for each species present on the site. These should have minimum dimensions of approximately 0.5 m x 0.5 m, although this area could be relaxed slightly depending on image GSD (pixel size) and the RMSE achieved during ortho-correction.

Sample number

Despite considerable literature on ground sampling for remote sensing, there are no hard and ready rules for determining the number of field samples per class required. Our experience on upland moorland suggests that 100 samples *per species* provides a good initial target for areas of perhaps ≈10 km^2. Given the need to identify minimum stand sizes (see below), this figure may be difficult to meet for some rarer species. Operators need to be aware that reducing sample numbers will possibly impact all aspects of classification and error appraisal.

For initial baseline surveys the most pragmatic approach will likely be the progressive relaxation of the minimum-stand criteria until adequate samples can be collected of all species present. This will most likely entail considerable systematic field effort. Depending on the ground-resolution, ortho-rectification precision, and GNSS accuracies achieved, it may be possible to work down to 5x pixel linear dimensions. Each sample should be geolocated using a DGNSS-enabled data-logger, either by RTK or post-correction. Creating and using an efficient custom data entry template will facilitate this process significantly over device default data entry screens.

Coverage

Sampling across the entirety of the study area, as far as possible, is preferred. It should be noted that the need to identify continuous 'stands' of individual species effectively makes using random approaches to locate sampling areas impractical, and a form of 'active searching' will most likely be required. One possible solution is to combine such searching with a grid of search zones to ensure good site coverage. This was adopted by Moors for the Future staff in the Peak District to cover an 11 km^2 area and generally proved successful (see Yallop et al., 2021).

Additional field work considerations

The use of minimum sized areas for field sampling will negate, or at least minimise, the probability of problems from misregistration between imagery and field data. It does, however, create issues where adequate examples of rare species cannot be identified at the desired minimum extents. From the perspective of peatland assessment, the most important of these is likely to impact mapping of Sphagnales and other bryophytes. Issues of rarity detection in all sampling methods is a well-known phenomenon and the implications of this ought to be understood during project planning and, ultimately, reporting. It is suggested that in this case where such species are encountered, their position is recorded normally but they are not included during the image classification process. Their occurrence and distribution can then be reported alongside the rest of the project data.

Issues are also likely to arise during monitoring of restoration progress in, for example, areas of Sphagnales planting, whether by use of 'plugs' or the general 'broadcasting' of propagules. Areal growth of many patches/plugs is likely to be slow within the overall project timeframe and finding patches of sufficient size for sampling will therefore be problematic. To help mitigate this it might be sensible to include, and identify by DGNSS, planting of numerous 'patches' meeting the single stand criteria within the planting scheme.

Timing

Phenology is probably a more important consideration from the perspective of flight dates rather than fieldwork and, in principle, field survey can be timed freely providing each species being surveyed retains sufficient characteristics to permit identification.

Using the proposed typology means the only information being used while classifying is a species identifier. Providing no obvious changes in species distribution or areal extent have occurred, or may occur, there is no requirement to capture field data and imagery on the same date. Most upland moorland species are generally long-lived and slow growing, providing more freedom than in other environments.

If multiple flights per year are undertaken to allow temporal stacking it might be informative for future development work to append phenological state and/or growth characteristics to sample records.

Image Classification

There is often confusion surrounding different approaches to image classification, and a brief overview of the potential approaches is provided to help assess their suitability for individual projects.

Following algorithm 'training' (see **Box 2e** for general overview) there are innumerable potential techniques for classifying imagery. These are summarised in **Box 2f**.

For the identification and mapping of individual plant species, it is likely that supervised pixel classifier algorithms will be the most successful. Of these we have found the simply interpretable maximum likelihood (MaxLik) able to produce results that are not significantly different from those resulting from more complex processes like those based on machine-learning. It is also most likely to be the approach most familiar to those with GIS training. It is recommended to be amongst the first options considered.

Box 2e

Spectral signatures and classifier training

Spectral signatures

Essentially these can be thought of as the 'colour' of each pixel, albeit usually in more than the usual RGB colour space we are familiar with as it can incorporate other wavelengths or bands e.g., near-infrared, far-infrared etc. The colour is represented by a DN or digital number, usually 0-255 for each band for 8-bit colour-space. Note that many sensors capture in more than 8-bits but this is usually downscaled to 8-bits for display and use.

There are no 'ready-made' databases of spectral signatures for each plant species that can be used for mapping. These must be created each time to allow for variations in image processing, phenology, solar irradiance (angles and colour balance) and the suite of species present in the image. This is what occurs during training.

Derived indices

Spectral indices are simply the mathematical combination of two or more spectral bands. One of the earliest used has become known as the normalised difference vegetation index (NDVI = (NIR - R) / (NIR + R)). This can be considered a measure of the "greenness" of plants, or density of visible chlorophyl. NDVIs of zero, or very close to, can generally be considered as indicating an absence of living vegetation and therefore good for mapping bare surfaces (or dead vegetation). Although there are innumerable spectral indices, the limited number of spectral bands available from most MAV and UAV sensors will limit their application in this case.

Classifier training

Before any image classification can occur, several steps need to be undertaken. Initially the field data samples are divided into two subsets (usually of 50% each), one for image training and the rest being retained for error assessment. It is best to stratify the field data by class and then randomly allocate samples from each into the subsets. This ensures all species have equal numbers in each subset.

Once this is complete, the operator must identify the pixels in an image matching the field sample locations within the training set and assign the class they belong to, in this case species. Following this the algorithm has the range or distribution of the 'colour' for each class present to compare to the rest of the image.

BOX 2f

Image classifiers

Pixel classifiers

These assign a class to every pixel based on their spectral characteristics ('colour') without regard to adjacent pixels, i.e., every pixel is treated individually. The process used to assign pixels to classes can be divided into two main strategies.

Unsupervised

As the name suggests the process is left to get on with it by itself. The operator merely selects the number of classes required and the specific algorithm to be used. Pixels are then grouped automatically, and an image extracted. The key point here is that classes derived by this method have no meaning 'on the ground', they are merely aggregates of 'similar looking' pixels. Field survey data can be used *post hoc* to match surveyed vegetation types to the mapped classes. In most cases there will only be partial matches, i.e., most species will occur in multiple classes in varying proportions. The exceptions may be classes with very distinct spectra compared to the rest, e.g., bare rock or soil. It might be expected that unsupervised techniques will provide little meaningful data for site baselining of monitoring.

Supervised

To overcome the lack of real-world meaning in unsupervised maps, the supervised approach is to 'show' the algorithm what each surveyed class 'looks like' before the map is computed. This is known as 'training' (see **Box 2e**). There are numerous supervised algorithmic approaches for grouping unknown image pixels using training data, including those referred to as machine-learning or AI-based. While supervised maps are immediately interpretable in terms of meaning, very few classes (if any) will be accurate, and an unknown number of pixels will be misclassified. Unless estimates of the accuracy are presented alongside such a map there is no way to judge its veracity. Hence error/accuracy assessments are expected to be undertaken.

Vector classifiers

Unlike pixel classifiers, vector classifiers do 'consider' the characteristics of adjacent pixels. They can be considered as forming a two-stage process. Firstly, groups of *adjacent* pixels with similar spectral characteristics are grouped and a bounding polygon created. The operator has control over several aspects of the process, mainly shape characteristics and size. The polygons created are then treated as objects and assigned a class using the training data and then classification proceeds.

Vector maps look very different to pixel products. The former look 'blocky', like a jigsaw of solid colours, as class membership is applied to objects or groups formed of adjacent pixels. Pixel classifiers look 'speckly' as typological classes are assigned to each pixel. Such classifiers were conceived to identify 'objects' in the landscape that conveyed 'sense' from an image directly, in a way analogous to the manual identification of objects, e.g., blocks of cleared forestry, buildings, roads, lakes, etc., by shape. They can work very well in large-scale structured landscapes using generic classes.

However, their potential for vegetation mapping, especially at the detail proposed here, is far less obvious. If 'structures' do appear in upland vegetation, e.g., a patch of *Calluna*, they are not predictable in size or shape. Elsewhere, they cannot be said to exist as in reality most vegetation is an intergrading matrix of differing densities of many species. Such complexity can only be resolved by pixel classifiers.

Pretty pictures: *the overwhelming importance of accuracy assessment*

> *"Users will not and should not take a map at face value without some associated estimate of error."*
>
> Card (1982)

Since the early days of satellite remote sensing, it has been recognised that thematic land cover maps require accuracy (or error) assessments for them, or any data derived from them, to be meaningful. Maps without such uncertainty assessment put the user *"in a position similar to one who is given a point estimate without any notion of its standard error"* (Switzer, 1969). It has therefore become standard practice for academically based remote sensing thematic mapping projects to include accuracy determinations. As Cihlar (2000) puts it, '*No land cover classification project would be complete without an accuracy assessmen*t'.

However, since the advent of UAVs there has been a rapid increase in the practice of ignoring, or perhaps not understanding, such a fundamental requirement. Ownership of UAVs has become almost ubiquitous amongst conservation organisations, whether local authority, NGO, third sector or partnerships. Today, the making of bold statements of capability and success, amply decorated with 'pretty pictures', but lacking any accuracy statements, feature on the webpages of many organisations and their contractors. This is not to be confused with remote sensing, either mapping or data acquisition; it is simply the taking of aerial pictures.

There can be no justification in the 2020s for not undertaking this step for all remotely sensed projects purporting to report data. The execution and full presentation of the results for all land cover mapping is therefore one of the few parts of these guidelines that should be considered *mandatory*. Contractors, and in-house service providers, who do not undertake this operation where necessary, as part of standard operating procedures, should be considered as not providing a complete or appropriate service.

Methods

There has been ample debate on the best strategies for undertaking accuracy appraisal (see Congalton, 1991 and Foody, 2002 for good discussion and background). However, the commonest approach is the creation of error (or confusion) matrices. These are the simplest to perform, are taught most frequently in remote sensing courses and are the easiest to interpret. If any other process of determining and presenting accuracy data is adopted, then it must have an academic heritage and, crucially, be as informative, transparent and user accessible as an error matrix.

It is not acceptable to solely present overall average accuracies as these are invariably heavily influenced by 'abundant and easy', but possibly irrelevant, classes such as water, rock or bare peat*. Many species of conservation importance are usually rarer and classify less accurately. For example, an overall accuracy of 80-90% (fairly common) tells you little with regard to, for example, *Sphagnum* species that may be differentiating with <20% accuracy. Reporting should therefore always include full confusion matrices of species mapped showing both with user and producer accuracies alongside Kappa coefficients.

> * *Bare peat and standing water mapping accuracies are likely to be far higher than those of vegetated classes as they have relatively distinct spectral signatures. Classification can also be assisted by use of indices such as NDVI (see **BOX 2e**).*

Apparent accuracy

It is crucial to appreciate the meaning and application of the results of error statistics. They must be understood as being no more than a mathematical measure of the concordance between classified image pixels and field data. They report only on the data contributing to the process. Hence, they carry no information about the abundance of species not recorded in the field or not included in the classification because of their low frequency. This should be made clear in the reporting.

Change Detection

Fundamental to monitoring is the identification of changes within the data over time, whether numeric or within the imagery directly. It is the sixth main component of remote sensing monitoring.

Derived data

The simplest approach is obviously the enumeration of difference within the derived numeric data for each species/bare surface classes from each survey period. This requires consideration of the accuracy achieved for each period and reference to this should be explicit within project reporting. The most common approach for doing this, for the whole map, is the simple multiplication of accuracies of each period.

This only identifies changes in cover or frequency over the overall study area. While this might suffice for many applications it does not reveal where change has occurred within the area, something particularly useful in conservation and restoration monitoring.

Mapping change

The identification of the spatial location of change can most simply be accomplished by comparing each pixel in the thematic map at first survey with those from a second or subsequent surveys. This is usually accomplished by function calls or tools such as 'raster calculator' or 'spatial modeller', or their equivalents, in GIS/remote sensing software suites such as ArcGIS, QGIS, ERDAS Imagine, etc. These derived maps of differences in distribution between time periods are easy to understand and interpret.

The accuracy determination, or confidence interval, for species changes should also be explicit on all map products, i.e., forming part of the legend or insert to each figure, and not just within the main text of a report. Separation of these within a document readily leads to misinterpretation as usually only images are reproduced for oral presentations. The inclusion of accuracy details on the map sidesteps any possibility of misconception as all the key data are presented in one place.

Sometimes intensities or brightness of colours assigned to each class (species) can provide visualisation of the confidence of temporal change. However, this can be confusing unless correctly executed. It can also be both be time-consuming and dependent upon high quality colour printing, something that cannot be guaranteed 'down the line'.

Table 2.2. Summary of commonly available EO, MAV and UAV sensors in the UK appropriate to IUCN Peatland Programme survey and monitoring (only currently active EO sensors achieving <1 m GSD). Note: Band CB refers to coastal blue, DB refers to deep blue.

Platform	Sensor	Bandwidth	GSD m	
			Native	*Pansharpened*
EO	Pelican (launching 2025)	R G B NIR	**0.3**	n/a
	Albedo (launching 2025)	R G B NIR	**0.4**	0.1
	WorldView-Legion	CB, B, G, Y, R, RE1, RE2, NIR1	**0.5**	0.3
	SkySat	R G B NIR	**0.5**	n/a
	Satellogic	R G B NIR	**0.7**	n/a
	WorldView-4	R G B NIR	1.2	0.3
	WorldView-3	CB, B, G, Y, R, RE, NIR1, NIR2	1.2	0.3
	Pleiades Neo	DB, B, G, R, RE, NIR	1.2	0.3
	SuperView-Neo	R G B NIR	1.2	0.3
	WorldView-2	CB, B, G, Y, R, RE, NIR1, NIR2	1.8	0.46
	GeoEye-1	R G B NIR	1.8	0.5
	Pleiades-1 & 2	R G B NIR	2	0.5
	SuperView-1	R G B NIR	2	0.5
	KOMPSAT-3A	R G B NIR	2.2	0.55
	KOMPSAT-3	R G B NIR	2.8	0.7
	Jilin-1	R G B NIR	2.9	0.7
	Gaofen-2	R G B NIR	3.2	0.8
	Triplesat	R G B NIR	3.2	0.8
Platform	**Sensor**	**Bandwidth**	**GSD m**	
			Tasked	*Archive (post 2011)*
MAV	Leica ADS100	R G B NIR	<0.05	0.125 RGB 0.5 NIR
	Vexcel UltraCam Eagle	R G B NIR	<0.05	0.125 RGB 0.5 NIR
Platform	**Sensor**	**Bandwidth**	**GSD m**	
			At 120 m	*At 60 m*
UAV	DJI MAVIC 3M	G R RE NIR	0.05	0.025
	DJI P4	B G R RE NIR	0.06	0.03
	MicaSense Altum PT	B G R RE NIR TIR	MS 0.05 TIR 0.33	MS 0.025 TIR 0.16
	MicaSense RedEdge-P	B G R RE NIR	0.08	0.04
	MicaSense RedEdge-P Duo	CB, B, G1, G2, R1, R2, RE1, RE2, NIR1, NIR2	0.08	0.04

3: Mapping peatland topography and physical features from elevation data

This section covers automated and semi-automated approaches to mapping topography and physical features from digital elevation data derived from remote sensing. It deals with four main aspects: potential data sources; data collection and processing; mapping approaches; and error assessment. Manual digitisation of physical features from aerial imagery is not covered here, but guidance for mapping some features is provided in the Peatland Code Field Protocol (IUCN UK Peatland Programme, 2023).

3.1. Data sources and types

The minimum spatial resolution desired for most criteria shown in **Table 3.1** (≤1.0 m), together with the required minimum vertical accuracy (typically cm level), would currently seem to restrict suitable elevation data to those derived by airborne sensors, either from MAV or UAV platforms. The required resolution and accuracy also currently restrict appropriate remote sensing technologies to LiDAR and digital photogrammetry (see **Box 3a**).

Table 3.1. Summary IUCN objectives for mapping physical features using remote sensing

Objective	Key variables	Comments	Explicit minimal resolution *Horizontal*
Soil erosion (areas of bare peat)	Rate of soil erosion – change in bare peat surface level (cm)		cm
	Depth of gullies, but also lateral extent of bare peat features (cm/m)		cm-m
Physical features of degradation	Extent of bare peat (m^2)	Covered in **Section 2**	m^2
	Presence of linear drainage features e.g., drains and tracks (length m)		cm-m
	Presence of haggs: hagg length (m) and depth (cm)		cm-m
	Built development e.g., wind turbine bases, housing		cm-m
Vegetation structure	Height of vegetation (cm) and scrub/tree height (m)		cm-m
Topography	Slope (degrees)		m

MAV

Very high-resolution (25 cm GSD) digital elevation data captured from MAVs cover the full extent of the UK. These data are derived from photogrammetry and are available in DSM format. The typical accuracy reported for these data are up to ±1 m in x and y, and up to ±1.5 m vertical. The values of accuracy report misalignment from absolute location and height, so these data may not be suitable for monitoring change. However, if bespoke surveys are chartered, it may be possible to improve the absolute accuracy of such products with the use of additional ground control (see **Box 3c**). The *relative* accuracy of archive data is likely higher, so these data are more suited to one-off assessments, such as determining the general slope of a peatland, measuring hagg height, or identifying the location of erosion gullies (see **Box 3b**). The data are less suited to estimation of vegetation/tree height where both DSM and DTM data are required.

Freely available LiDAR-derived DSM and DTM data at 1 m spatial resolution cover almost the full extent of England (https://www.data.gov.uk/) and Wales (https://datamap.gov.wales/). There is currently much lower coverage of Scotland (https://remotesensingdata.gov.scot/). The reported vertical accuracy of the data ranges from ±5-15 cm. Although the horizontal accuracy is not reported for these data, commercially available products at 1 m resolution report an accuracy in x and y of up to ±10 cm. The spatial resolution of freely available data at 1 m currently limits their application, but in some places 50 cm resolution data may be available, and bespoke surveys can be chartered, where a spatial resolution of 16 cm is now achievable (see for example Nottinghamshire County Council, 2024).

UAV

UAVs provide the opportunity to obtain far higher spatial resolution elevation data than MAVs with higher accuracy in all dimensions. Colour (RGB) photography are preferred over MS imagery for elevation model construction in photogrammetry, and the spatial resolution achievable with RGB sensors can be sub cm. The impact of changing sun-angle is less problematic for extracting height information than for image classification, although photogrammetric reconstruction will not produce reliable elevation values for any areas in shade (see **Box 3a**). It is therefore possible to cover larger areas, potentially comprising numerous flights over several days, and create a continuous elevation model for mapping and analysis.

It is expected that RTK or ground control would be used for any UAV image capture. If quantification of change is required (e.g., erosion of bare peat), the same, fixed ground control should be used in each survey, and this could be achieved by attaching targets to surface level markers (see IUCN UK Peatland Programme Eyes on the Bog Technical Manual Version 2, 2024).

LiDAR sensors are becoming increasingly available for UAV platforms, and owing to the nature of the sensor can only be operated with either PPK or RTK. This should enable the position of the sensor to be determined to within 1-2 cm in all dimensions during survey. However, ground control must still be used to assess the accuracy of height determined. The vertical accuracy of LiDAR sensors currently available for UAV deployment typically range from ±2-5 cm.

BOX 3a

Digital elevation data sources and types

Digital elevation data are commonly provided and analysed in two data formats: 3-dimensional point clouds and 2-dimensional raster files (gridded datasets comprised of pixels).

LiDAR (Light Detection and Ranging)

LiDAR operates by sending pulses of laser towards the ground and measuring the time taken for the pulse to return to the sensor (which determines the distance). As the laser exits the sensor, the beam diverges, and the footprint of the beam on the ground is approximately circular. From an aircraft at around 1000 m above ground level, the circle is around 1 m in diameter. The laser beam will be reflected by all objects within the footprint and the sensor can therefore receive multiple returns from a single pulse. If there are gaps in the canopy of vegetation present in the laser footprint, first returns will be received from the top of the canopy, and further returns will be received from lower parts of the canopy, followed eventually by returns from the ground surface.

Each return is recorded as a point in 3D space (with xyz coordinates), hence the term 3D point cloud.

Digital photogrammetry

Aerial photographs are 2D raster files where the pixel values represent the amount of electromagnetic energy reflected by object(s) on the ground within the pixel. Multiple overlapping images are collected during survey, and objects within the survey area are therefore viewed from multiple angles. The effect of parallax is used during image orthorectification to create a 3D model of the ground (as a point cloud) which is then used to correct the geometry of the images to be planimetrically accurate. The output is an accurately geolocated mosaic of imagery (orthophoto) that can be used for mapping vegetation (Section 2), but elevation data from the point cloud are a beneficial byproduct.

3D point clouds are converted to 2D raster files (referred to as digital elevation models (DEMs)) for use in a GIS.

Digital elevation models (DEMs)

The term DEM covers any form of 2D raster elevation data, but the term has two key sub-divisions: digital surface model (DSM) and digital terrain model (DTM).

When 3D point clouds are converted to 2D raster data, the pixel values are calculated from the value of a point that falls within the pixel or interpolated from the nearest points if none fall at that location. If all points are used, the elevation data contains points that represent open ground surface, plus any objects or features on the surface such as vegetation. This model is referred to as a digital surface model.

With LiDAR-derived point clouds, it is possible to identify only points that have hit the ground and exclude any points that represent surface features. The type of model derived from ground only points is referred to as a digital terrain model, or bare earth model. The same process can be performed on 3D point clouds derived from photogrammetry, but unless the ground in gaps in the vegetation canopy is illuminated, the photogrammetric model is unlikely to map the height of the ground.

BOX 3b

Hydrological modelling

Modelling surface water flow paths and delineating drainage basins (comprising watersheds and catchment areas) can be undertaken on 2D DEM data using hydrology tools available in most GIS packages.

A range of algorithms exist, but they all work at the pixel level and are based on the principle that water flows downhill. The direction of flow for any pixel within a DEM will be towards the adjacent pixel with the lowest elevation value. Summing the total number of pixels uphill that contribute flow to each individual pixel identifies where water will naturally accumulate and flow. This type of analysis is appropriate for mapping the location of natural erosion gullies, but it may not identify artificial drains (grips), particularly any drains that were dug across the slope of the terrain.

Hydrological modelling should be undertaken using DTM data rather than DSM data where possible, so that flow direction is modelled from the ground surface. Where DSM data are used, particularly at cm level resolution, water flow will be modelled around individual plants and false drainage routes may be identified as a result. This can be compensated for by resampling cm resolution DSM data to a larger pixel size.

3.2. Mapping approaches

Soil erosion

Mapping of bare peat is covered in **Section 2**, and this process should identify flat expanses of bare peat, hagged areas and non-vegetated erosion gullies. Such data can be used to identify areas where further information is required (e.g., gully depth or hagg height) or where monitoring change is proposed (e.g., erosion of bare peat). The location of erosion gullies can also be undertaken using hydrological modelling (see **Box 3b**).

Provided that the accuracy of the elevation data is reported, determining the rate of erosion on flat peat surfaces and exposed gully edges is relatively straightforward. Either 3D point clouds or 2D DEMs can be used, although the former data type may provide better representation of areas with complex morphology. By performing a cloud-to-cloud comparison of two survey datasets, the 3D distance between points provides the amount (and direction) of change. Where 2D DEMs are compared, the difference between pixel values can be determined to produce a DEM of difference.

For both approaches, all errors must be accounted for, and these are multiplicative (see **Section 2**). Direct ground measurements using erosion pins or surface level markers should be taken for a sample of areas being monitored for validation.

Physical features - height or depth

The height of a peat hagg and depth of an erosion gully can be determined from digital elevation data using tools in GIS. It is possible to create a series of points along a linear feature at a fixed interval (e.g., every 50 m along a gully) and subsequently create a fixed length transect perpendicular to the linear feature at each point (e.g., 5 m). Spatial analysis tools can report the minimum and maximum elevation values along a transect, and the difference is the height or depth of the feature being examined. The error of measurement will relate to the accuracy of the data used, but direct ground measurements should be taken for a sample of features assessed.

The difference in elevation values between DSM and DTM data provides information on vegetation height. LiDAR-derived data are the most appropriate, and whether they are captured by MAV or UAV data will be dictated by the scale of the vegetation being assessed (e.g., airborne LiDAR may be sufficient for mapping the height of trees on forested areas of bog).

Topography

One of the most common topographical metrics extracted from elevation data is slope. The type and resolution of data used will be dictated by the scale of the feature being examined. Where the general slope of a peatland is required, sub-metre resolution is not essential, and in fact coarser resolution data may be more appropriate as fine-scale variation is smoothed out. For example, if cm resolution data are used to report general slope, and steep-sided erosion features are present, the mean slope value determined will be influenced by unrepresentative high slope values. It is also advised that DTM format data are used so that the sides of large shrubs are not included.

Where the slope of gully sides and floors, or edges of haggs, are required, the highest resolution data possible should be used. A similar approach to determining height of features can be employed and the slope of transects across the feature of interest extracted using GIS. Determining the slope of areas of bare peat can help inform potential restoration approaches.

4: Burn mapping

Burn scars resulting from wildfire events or from fires that are conducted as controlled burns are detectable in remote sensing data. Visual assessment of optical imagery can identify burn features varying in shape, size and colour. However, several factors must be considered if these are to be mapped using automated approaches and reliable metrics derived. Firstly, automated mapping requires the definition of a typology (see **Section 2**), and it is not possible to simply use a class of ‘burn’. Prior to a burn occurring, the land surface, and thus the pixels in optical imagery, will contain vegetation. Depending on the severity and speed of a fire, the burn ‘scar’ may comprise a bare peat surface, or a combination of bare peat, partially burned vegetation and unburned vegetation. Thus, a burn scar is not a class or category, it is a number of pixels that either contain bare peat or vegetation, not ‘burn’. Whilst it may be possible to identify when burns occurred by mapping change in spectral response (i.e., from vegetation to bare peat), the impacts of burning last for several years. Ground survey has shown that areas of bare peat persist in burn scars for 7-8 years on average (Yallop et al., 2006), so mapping bare peat will provide the most reliable metric of impact from new and recent burns at any one time.

Further problems arise from the recent adoption of mowing or cutting of vegetation to facilitate, or replace, burning. In some instances, a strip of vegetation is first mown around the extent of a proposed burn area to reduce the likelihood of the fire spreading. In other cases, commonly now on areas of peat >40 cm deep, patches of typical burn sizes are mown completely instead of using fire. Mown areas will contain a mixture of bare peat and short vegetation with bare peat visible amongst the sward. There are currently no automated methods of distinguishing a peat surface revealed by cutting from a peat surface revealed from burning.

5: Near future

It is, of course, famously impossible to accurately predict the future, especially regarding technology. However, some developments in existing technologies are relatively predictable over the near future and these may be pertinent for monitoring the extent or condition of peatlands. They include:

GPR for measuring peat depth

GPR (ground penetrating radar) is currently the only remote sensing technology that can provide absolute measurements of peat depth. This technology is now being flown on UAVs, but due to the power of the radar, the sensor must be flown at a fixed height of *c*.1 m above the ground. The maximum survey area achievable in a single flight is therefore of the order of 100 m^2. If development of this technology allows operation from a flight height of that typical for optical or MS surveys (60 – 120 m), mapping areas of km^2 may become a reality.

Increasing optical resolution

Past trends of increasing sensor pixel density from optical sensors, both airborne and EO, will inevitably continue. How this will affect the trade-off between swath (area captured by a single image*) and smaller GSD is unclear as it will ultimately depend on user demands. We can currently capture MAV imagery of 5 cm ground resolution and given the applications to which most airborne imagery is put, it is hard to see much demand for routine capture using smaller GSDs. This may be evidenced by observation that although 5 cm is now practical, routine captures still take place at 12.5 cm for operational and user demand reasons. It is also important to consider the data storage and processing demands of increasing resolution. In terms of peatland monitoring, there is unlikely to be an adequate gain in classification accuracy from using imagery of much higher resolution, given concomitant increases in difficulty of image/field survey co-registration and data storage.

For UAVs, reducing GSD by flying lower has always been an option and increasing sensor resolution will continue to be part of that equation. Given that we may be approaching the practical limits of using higher resolution imagery for routine monitoring, future increases in sensor resolution might be more usefully traded for increased swath and reduced capture time for a given area.

* *For most remote sensing digital sensors, capture is quasi-continuous, and the older film-based concepts of 'image' or 'picture' are redundant. Swath width is the correct term although 'image area' can still be a convenient metaphor.*

Increasing spectral differentiation – from MS to HS

Hyper-spectral sensors have been around since the 1980s. While being able to identify reflectance at more wavelengths should, in principle, allow increased separability and higher accuracy in class differentiation, in practice this is not yet evidenced for vegetation, as most bands tend to be highly correlated.

Current hyperspectral sensors are of push-broom operation and correction to compensate for flight instability of smaller platforms may also be problematic. However, the main problem with hyperspectral sensors is that as reflected light is divided into more 'bands', the amount of light available for each is reduced. Therefore, to capture enough signal at acceptable signal/noise ratio, each sensor pixel needs to cover a larger area, reducing pixel density and ultimately resolution.

MAV hyper-spectral capture is available from a few operators, although it is used primarily for research purposes. Sensors suitable for UAV are available and this may increase if demonstrable benefits are shown.

Given the practical difficulties, e.g., much larger GSD that we feel would negate opportunities for species mapping, forcing the use of older unverifiable habitat classes, hyperspectral mapping is not recommended for routine peatland monitoring at this time. If future research shows repeated demonstrable improvements in accuracy in class differentiation, then this recommendation should be reconsidered.

InSAR

Interferometric Synthetic Aperture Radar is another technology that is a few decades old. However, the relatively recent establishment and continuing expansion of EO SAR satellite constellations and the availability of free to use data from the source, such as the ESA, have led to a rapid increase in interest in InSAR applications. This has resulted in a few commercial providers now offering services for peatland monitoring.

InSAR, very simply put, can assess extremely small* surface deformations occurring between two EO 'images'** of the same location, captured from almost the same point, but at different times, by comparing the phases of the two returned signals.

The robustness of InSAR measurements on natural vegetated surfaces is not for this document to determine. However, it needs to be recognised that InSAR, at best, determines no more than slight surface movements over time. The actual 'meaning' or interpretation of any slight changes in terms of peatland assessment is far less clear. They could be seen as evidence of the phenomenon of 'bog breathing'. Regrettably, the role that phenomenon has in understanding bog 'condition' is equally unclear.

Until both intensive and extensive long-term empirical studies are conducted, relating InSAR observed surface movements to rainfall, peat depth, detailed field ground moisture measurements, local topography and vegetation, can more of this phenomenon, and its possible role in monitoring, be understood.

* *a fraction of the wavelength of the signal, typically around a few mm to cms. The degree of averaging applied will modify this.*

** *the use of the term 'image' for continuously gathered data has been discussed above – it is convenient!*

Glossary of terms

Class differentiation		The success achievable in the separating units of a typology.
DEM/DSM/DTM	Digital Elevation/Surface/ Terrain Model	See Box 4a.
GCP/s	Ground Control Point/s	A series of features present across an aerial survey area that are recognisable in captured imagery. Their location, recorded in the field to within cm using DGNSS, can be used to improve geolocation accuracy and height reconstructions. In lieu of these, or in addition to them, artificial targets can be used.
GNSS/GPS/ DGNSS/DGPS	Global Navigation Satellite System/Global Positioning System (D – differential)	Note the use of GPS as an acronym has a longer currency than GNSS, thus it is more common in literature and more people are familiar with it. We tend to use the term GNSS for currency. It is of no consequence, they are synonymous. GPS technically refers to positional information determined solely using the original US NAVSTAR satellites. GNSS positional information is determined using multiple additional satellite constellations including BeiDou, Galileo, GLONASS and QZSS. Note that cm level accuracy can only be achieved using some form of differential correction (either post-processed, PPK, or RTK).
GSD	Ground Sample Distance	The smallest unit 'on the ground' resolvable by a sensor at the operating distance. In optical imagery this is equivalent to the pixel size.
HS	Hyper-Spectral	
LiDAR	Light Detecting and Ranging	See Box 4b.
MAV	Manned Aerial Vehicle (piloted aircraft)	
MS	Multi-Spectral	
NIR	Near Infra-Red	
NDVI	Normalised Difference Vegetation Index	See Box 3d.
Pan	Panchromatic	Panchromatic sensors are more 'sensitive' than RGB or MS sensors as they capture photons from the entire visible spectrum, not from just individual 'colours'. Hence pixels can be smaller and packed at higher density, i.e., more. They therefore have a smaller GSD (higher resolution) than 'colour' sensors.

Pan-sharpening		Pan-sharpening is the process of upscaling larger MS pixels by using the intensity or luminance data of the higher resolution panchromatic band. This is not 'magic', but does alter the spectral information within the adjusted MS pixels, potentially confounding classification accuracy.
Post-processed		GNSS positional data recorded in the field are raw and are corrected to cm level accuracy post-survey using information from a fixed base station with known location.
PPK	Post-Processed Kinematic	GNSS positional data are collected with reference to a temporary base station with unknown absolute position but have cm level relative accuracy. Post-survey the absolute location of the temporary base station is used to provide cm level absolute accuracy.
Push-broom		A sensor consisting of a linear array of photodetector cells orientated perpendicular to line of travel. The image is thus built-up row by row, or usually multiple rows at a time.
RGB	Red, Green and Blue	3 band image comprising Red, Green and Blue reflectance.
RE	Red-Edge	
RTK	Real Time Kinematic	GNSS positional data are corrected to cm level absolute accuracy in real-time using information from a fixed base station with known location.
Swath (width)		As some sensors (e.g. push-broom) do not capture an 'image' at an instant in time, the ground coverage a sensor can capture at one time is most correctly expressed as swath width.
Taxonomic resolution		The extent to which taxa can be differentiated successfully using remotely sensed imagery.
TIR	Thermal Infra-Red	
Typology		The 'units' used to divide and categorise ground cover, vegetation, etc.
UAV	Unmanned Aerial vehicle	UAS (unmanned aerial system) and RPS (remotely piloted system) are often used interchangeably.
VHR	Very High Resolution	EO sensor with GSD of a few metres, usually considered <4m native.
XHR	Extremely High Resolution	Used here to describe GSD of a few cms such as modern MAV and most UAV sensors can capture at practical altitudes.

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