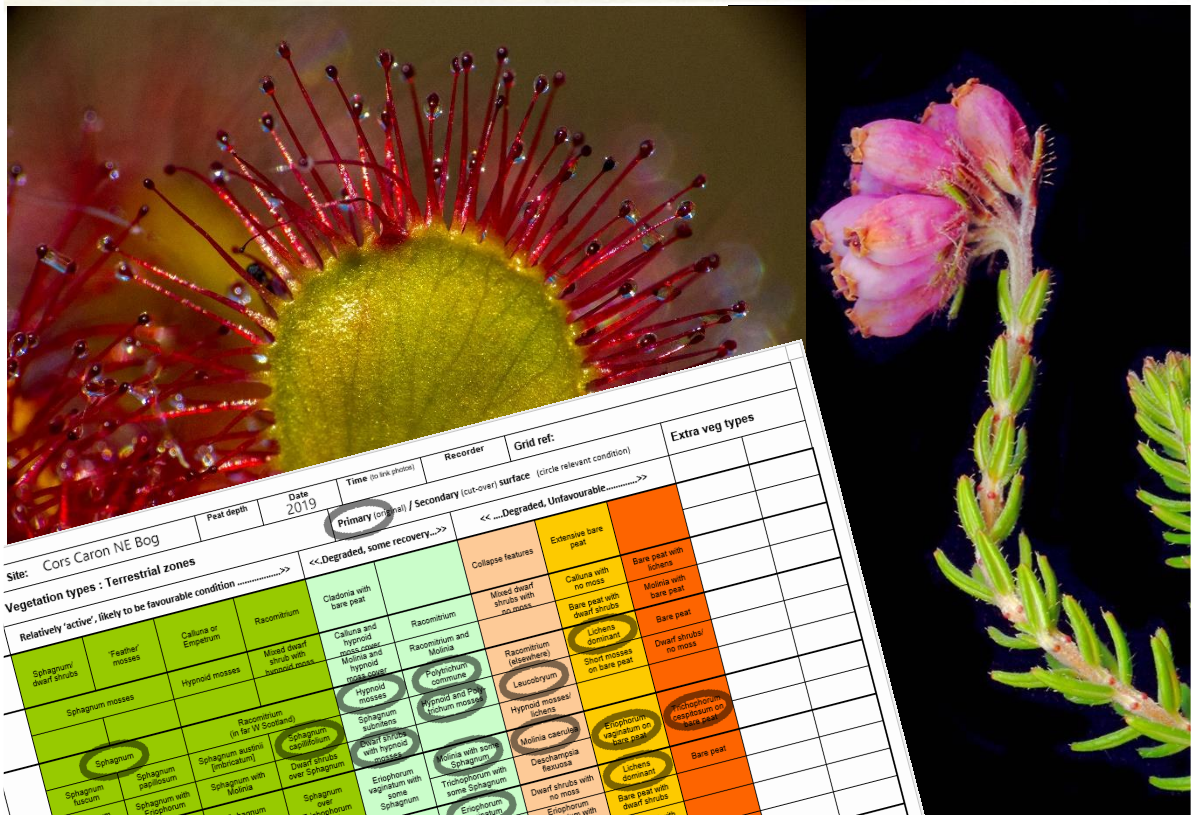
Manual for the Peat Bog Condition Matrix



Manual for the Peat Bog Condition Matrix

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Overview

The peat bog condition matrix has been designed to supplement the JNCC Common Standards Monitoring scheme for raised bog and blanket bog. It provides a simple 'traffic light' approach to indicating the condition of the various identifiable sectors of ground that collectively make up a raised bog or blanket bog. More particularly, while the traffic-light colours indicate a condition-state at a particular moment in time, the condition matrix is also designed to reveal, *on repeat survey*, changes (good or bad) to that condition-state in a readily understood way.

The fundamental basis of the condition matrix is the natural tendency of peat bog systems to generate a microtopography, which is central to the hydrological and ecological functioning of such systems. This microtopography may be modified by human or natural agents. Characteristic vegetation assemblages occupy, and in some cases create, differing parts of the various microtopographic structures. The *combination* of structure and vegetation is the key to condition assessment.

Furthermore, because the matrix is focused on condition-state rather than ecological character, and its purpose is to guide conservation intervention, the *number* of features highlighted in the green (good condition) sector of the matrix is not as important as the presence of *any* features highlighted in the poorer condition-sectors. It is thus features in the turquoise, yellow and orange sectors that should be the stimulus for, and focus of, conservation action.

Illustration of the traffic-light system underpinning the matrix and its use over time. (Left) A baseline survey from a portion of blanket bog , revealing that the majority of identified features lie in the poorer-condition sectors, thereby highlighting features which then should act as target indicators for conservation action. (Right) The same area following conservation action, with only two features now remaining in the poorer sectors.

Beyond this simple traffic-light use of the matrix, it is possible to convert matrix data into quadrat format in order to create mapping units or to investigate other aspects of the data using a range of conventional analytical methods.

1. Introduction

1.1 The peat bog condition matrix has been designed specifically for assessing **peat bog condition**, embracing both primary uncut surfaces as well as secondary surfaces resulting from actions such as peat cutting or regenerating erosion complexes. It is not designed for fen systems, although the approach might be applied to moss-rich nutrient-poor systems after suitable modification of the individual boxes within the matrix.

1.2 The design of the matrix is based on three underlying principles:

- that *all* peat bog surfaces possess a microtopography, even though some sites may display only a single element of that microtopography and thus appear to lack any form of microtopography or 'pattern';
- that the unusually effective water-retaining properties of peat result in a marked zone of *high moisture content* within the peat (rather than the more traditional measure of current water-table depth which can vary depending on immediately preceding weather conditions) and can thus be used to identify elements of the microtopography;
- that features indicative of damage tend to be structural features that may nevertheless still retain a moisture-zone characteristic of the pre-disturbance condition.

1.3 Current methods of peat bog condition assessment within the UK rely either on the Mires and Heaths volume of the NVC (Rodwell, 1991) or the JNCC Common Standards Monitoring scheme (JNCC, 2004, 2009). In the former, the volume opens with the statement that the NVC categorisation is not based on *"gross morphology or fine-scale patterning"*. It is also widely accepted amongst conservation practitioners that the NVC is not an effective tool for describing mire condition.

1.4 The Common Standards Monitoring (CSM) scheme (JNCC, 2004, 2009) provides guidance for lowland raised bog and blanket bog and, separately, for upland blanket bog. For lowland bogs, the guidance simply states that there should be no change in character or extent of microtopographic features. For upland blanket bog the guidance simply states that there should be no signs of disturbance to 'sensitive areas', which include: *"Areas with noticeably uneven structure, at a spatial scale of around 1 m^2 or less. The unevenness should be the result of Sphagnum hummocks, lawns and hollows, or mixtures of well-developed cotton-grass tussocks and spreading bushes of dwarf shrubs."* As will become clear later, the latter part of this particular description may be somewhat misleading.

1.5 Recognition that small-scale surface patterning (microtopography) is a characteristic feature of peat bog systems can be found in some of the earliest scientific accounts of peat bog habitats (e.g. Weber, 1902; Pethybridge and Praeger, 1905; Osvald, 1923; Katz, 1926; Gams and Ruoff, 1929). These, and subsequent accounts, describe the way in which particular vegetation assemblages occupy distinct positions relative to the average water table within this small-scale microtopography.

1.6 Indeed Ivanov, in his seminal book *Water Movement in Mirelands* (Ivanov, 1981), continually highlights the fact that hydrological functioning of bogs and many fen systems is primarily determined by three factors - water, microtopography and vegetation, with the mapping of microtopography being fundamental to any understanding of both hydrology and ecosystem dynamics.

1.7 Microtopographic zonations have various names in differing languages, so Lindsay, Riggall and Burd (1985) and subsequently Lindsay (2010) proposed that simple codes be given to these zones. Differing vegetation assemblages may then be found to occur within any one of these structural zones depending on geography and/or condition of the bog habitat.

1.8 Gams (1918) had previously proposed that the smallest functional ecological element of an ecosystem should be termed a 'synusia' (although the term 'ecosystem' would not be coined until 1938 by Tansley). Thus within the microtopography of a peat bog surface, a synusia would consist of a spatial location within the microtopography together with a specified vegetation assemblage.

1.9 The peat bog condition matrix is thus a matrix of synusiae comprising particular species assemblages positioned within a particular microtopography zone relative to the water table. It is especially important to understand that any given vegetation assemblage may occur in more than one microtopography zone, and the two examples would then represent two distinct synusiae.

1.10 The matrix is designed to permit rapid assessment of peat bog **condition** and thus incorporates microtopographic features indicative of damage or degradation. Such features are often **structural elements** (*e.g.* erosion gullies, or tussocks) rather than being linked to specific locations of the high moisture-zone within the peat (**hydrological elements**) and are thus highlighted as such within the matrix. In the case of these structural elements it will often, however, still be possible to identify the location of a high-moisture zone, in which case the structural element should be recorded as well as the relevant hydrological element within the matrix. While this may seem like double-counting, such information provides a valuable indication of the potential for damaged areas to return to a better condition-state.

1.11 The matrix requires relatively limited botanical skills. At its simplest, the matrix provides an immediate visual picture of condition using a 'traffic light' system of colour codes, but the data contained within the matrix can also be analysed using quantitative techniques should more in-depth understanding of the data be required (see Figure 1). Click here to Download a colour version of the Condition Matrix.

1.12 Use of the matrix involves at least three stages but if more detailed analysis is also required then a fourth stage can be added. The matrix is also designed to enable change over time to be readily identified. An example showing the use of the matrix and all four stages is provided by Lindsay and Reed (2024) as part of the EU/NRW New LIFE for Welsh Raised Bogs Project.

1.13 The four potential stages are set out in the remainder of this handbook, and comprise:

- desk study;
- field survey;
- consolidation of matrix sheets;
- analysis of matrix data.

1.14 If, in addition, an assessment of the **ecological character** of the peatland is required, additional data can be gathered, again using the synusial approach.

Mire texture no:		**Site:**			**Peat depth**	**Date**	**Time** (to link photos)	**Recorder**	**Grid ref:**			
Zone (structural features, and/or zones in relation to w/t)	**DFR (321) Freq.**	**Vegetation types : Terrestrial zones**				**Primary** (original) **/ Secondary** (cut-over) **surface** (circle relevant condition)					**Extra veg types**	
		Relatively 'active', likely to be favourable condition ....>>				**<<.Degraded, some recovery...>>**		**<< ....Degraded, Unfavourable............>>**				
T5 (peat mound) **found only in far north & west of Scotland**		Sphagnum/ dwarf shrubs	'Feather' mosses	Calluna or Empetrum	Racomitrium	Cladonia with bare peat		Collapse features	Extensive bare peat			
T4 (erosion complex hagg top)		Sphagnum mosses		Hypnoid mosses	Dwarf shrub with hypnoid moss	Calluna and hypnoid moss	Racomitrium	Mixed dwarf shrub with no moss	Calluna with no moss	Bare peat with lichens		
						Molinia and hypnoid moss	Racomitrium and Molinia	Erica cinerea with no moss	Bare peat with dwarf shrubs	Molinia with bare peat		
Tk (tussock) (hard unyielding feature obvious underfoot		Schoenus nigricans **(only in far W of Scotland)**	Sphagnum over Eriophorum vaginatum tussock	Sphagnum over Molinia tussock	Sphagnum over Trichophorum tussock	Eriophorum vaginatum with some Sphagnum	Molinia with some Sphagnum	Molinia caerulea	Eriophorum vaginatum on bare peat	Trichophorum cespitosum on bare peat		
							Trichophorum with some Sphagnum	Deschampsia flexuosa				
T3 (hummock) (30 cm to 50 cm)		Sphagnum		Racomitrium (in far W Scotland)		Hypnoid mosses	Polytrichum commune	Racomitrium (elsewhere)	Lichens dominant	Bare peat		
		Sphagnum fuscum	Sphagnum papillosum	Sphagnum austinii [imbricatum]	Sphagnum capillifolium	Sphagnum subnitens	Hypnoid and Poly-trichum mosses	Leucobryum	Short mosses on bare peat	Dwarf shrubs with no moss		
		Sphagnum medium (magellanicum)	Sphagnum with Eriophorum	Sphagnum with Molinia	Dwarf shrubs over Sphagnum	Dwarf shrubs with hypnoid mosses		Hypnoid mosses with lichens				
T2 (high ridge) (15 cm to 30 cm)		Sphagnum				Hypnoid mosses	Eriophorum vaginatum	Dwarf shrubs with no moss	Lichens dominant	Bare peat		
		Sphagnum with Rubus chamaemorus	Sphagnum and Erica tetralix	Sphangum medium (magellanicum)	Sphagnum with Eriophorum	Calluna with some Sphagnum	Dwarf shrubs with hypnoid mosses	Eriophorum vaginatum with no moss	Bare peat with dwarf shrubs			
		Sphagnum papillosum	Sphagnum capillifolium	Sphagnum with Molinia	Sphagnum with dwarf shrubs	Sphagnum subnitens	Hypnoid and Poly-trichum mosses	Sphagnum compactum	Bare peat with Trichophorum			
		Sphagnum fuscum	Sphagnum austinii [imbricatum]									
T1 (low ridge) (1 cm to 15 cm) If S. capillifolium is dominant at this level it suggests drying		Sphagnum (not S. fallax)				Hypnoid mosses	Eriophorum vaginatum	Dwarf shrubs with no moss	Lichens dominant	Bare peat		
		Sphagnum papillosum	Sphagnum medium (magellanicum)	Sphagnum with dwarf shrubs	Campylopus atrovirens (in W Scotland)	Sphagnum capillifolium dominant	Sphagnum tenellum dominant	Dwarf shrubs with hypnoid mosses	Bare peat with dwarf shrubs			
		Sphagnum with Erica tetralix	Sphagnum with Eriophorum	Sphagnum with Drosera	Racomitrium and E. angustifolium sward (Shetland)	S. fallax	Sphagnum subnitens	Sphagnum compatum	Bare peat with Trichophorum			
T1/A1 (0 cm to 5 cm) edges of pools/ hollows, or 'runnels'		Sphagnum pulchrum	Sphagnum tenellum	Aulacomnium palustre	Narthecium ossifragum	Sphagnum fallax	Sphagnum compactum		Bare peat with Trichophorum	Bare peat		
		Drosera anglica	Rhynchospora	Sphagnum	Sphagnum cuspidatum	Non-Sphagnum moss						
Notes:												

Figure 1. One side of the two-sided condition matrix sheet, in this case the side for recording terrestrial-zone features, while the reverse side is for recording aquatic zones and zones characterised by erosion features. Note the distinction between **structural elements** and **hydrological** (moisture zone) **elements**, indicated by shading of the former.

2. Desk study

2.1 The Desk Study phase consists of several inter-related steps. In theory these steps are not essential because a random series of matrix sheets would still provide some indication site condition. However, the steps described below are designed to make field survey as informative, efficient and effective as possible:

- Use of remote sensing to identify areas of consistent texture as polygon boundaries;
- Create sampling points within each texture type;

- Prepare matrix sheet for each sampling point;
- Initial input to the condition matrix sheets based on remote sensing information;
- Devise an efficient sampling route;
- Create GPS waypoints on the sampling route to indicate polygon boundaries.

2.2 *Identification of texture using remote sensing*

2.2.1 The condition matrix is based on the fact that microtopographic elements combined with particular vegetation assemblages (i.e. synusiae) provide a repeatable and effective method of describing bog condition. The initial assumption, therefore, is that 'texture', as visible using remote sensing, represents particular combinations of such synusiae. However, it is generally the case that differing parts of a bog will display differing condition-states. In order to generate a spatial picture of condition across a site it is thus necessary to identify the location and extent of these various synusial textures.

2.2.2 A core concept of the condition matrix is that different parts of a peat bog will display different textures arising from the differing synusial combinations but these visual textures may in fact result from little more than differences in vegetation height rather than actual microtopographic elements. They may thus not represent different synusial textures but this will become clear during field survey.

2.2.3 **Remote-sensing images** can be obtained from a variety of sources though perhaps the most readily available is the 'satellite' view from Google Maps. It might be assumed that the most detailed imagery possible is desirable but this is not necessarily the case. The objective here is to identify broad areas of consistent texture within the site in order to identify sectors of a site that are meaningful in terms of, for example, site management. An image that is too detailed can make it difficult to 'see the wood for the trees', so for large blanket mire sites even the resolution provided by Sentinel satellite imagery may be suitable. Screen-grabbed images can be obtained on Windows machines using the SHIFT-WINDOWS-S combination of keystrokes, though appropriate image credits and copyright issues must be acknowledged.

2.2.4 Having obtained a suitable image or set of images it is often helpful to **enhance** the image by increasing contrast and vibrance. However, before using such routines it is helpful to select out just the area of interest so that the enhancement routine uses the maximum range of tones within the area of interest rather than attempting to enhance the image for everything that may be in the image (e.g. areas of the sea, large lochs, conifer plantations). This selection process is usually quite straightforward within most image processing software systems. Figure 2 shows the selection of an area using the 'Selection Brush Tool' tool in Adobe Photoshop. Affinity Photo is a much cheaper alternative to Photoshop and offers the same type of selection process, but most other image-processing software will offer something similar.

2.2.5 The selected area can then be cut out from the larger image and either pasted into a new image layer or used to create a new image file before it is then subject to image enhancement. In Photoshop, for example, the 'Filter/Camera Raw Filter' offers various adjustments. Using the various sliders in Light, Color and Effects (particularly Dehaze) can significantly accentuate differences between the various areas of texture.

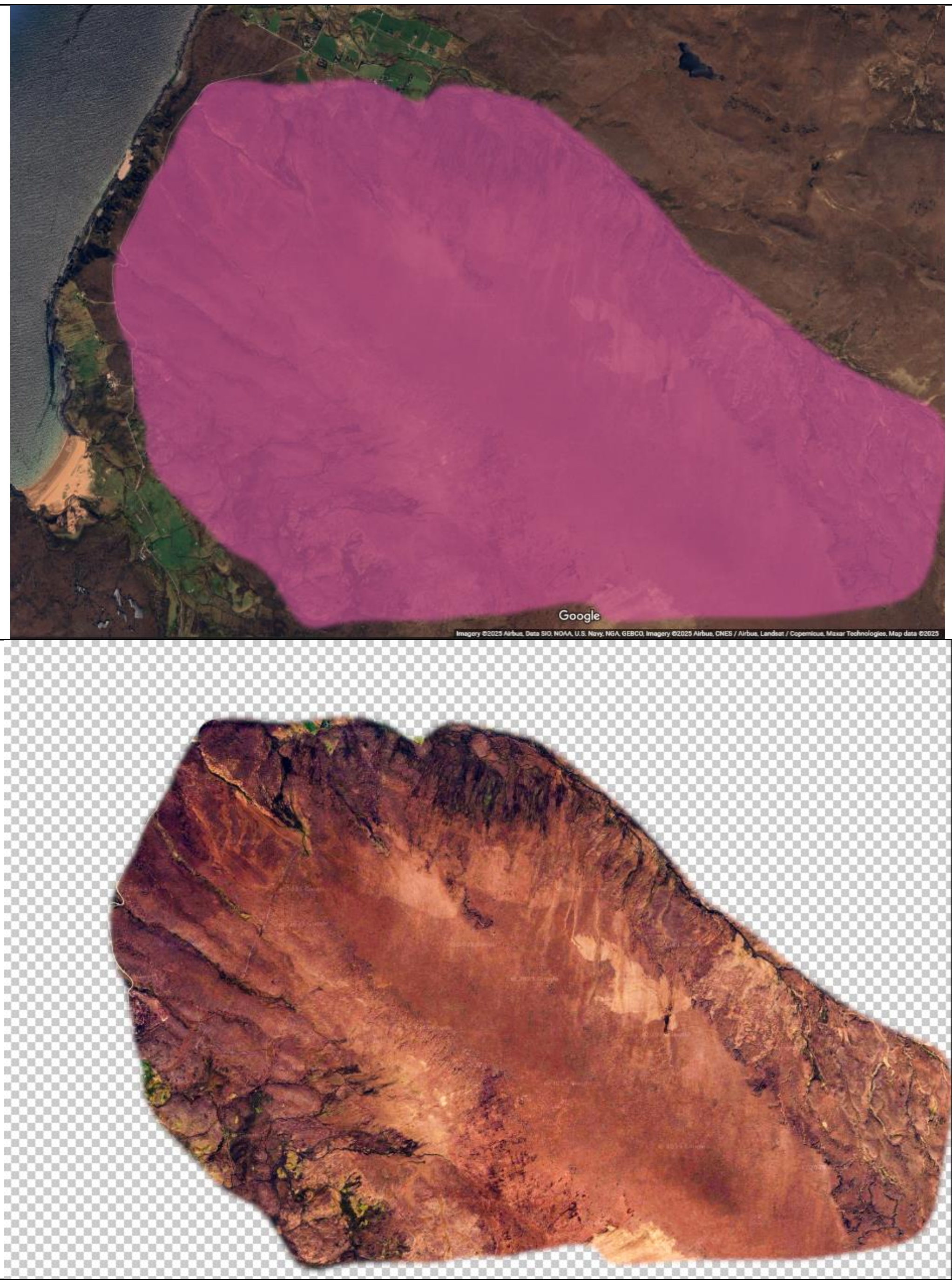


Figure 2. (Top) Area of interest selected using the 'Selection Brush Tool' in Adobe Photoshop. (Bottom) Area of interest after colour and contrast enhancement using the Photoshop Raw filter only on the selected area. This enhanced view is then used to determine texture boundaries. Images from Google Maps.

2.2.6 It is also often helpful to obtain **black-and-white aerial photography** from the post-war RAF aerial photography collection because although the quality of this imagery can be variable, the monochrome nature of a good image can often, counter-intuitively, reveal differences in texture more starkly than can be seen using more recent colour imagery.

<u>2.3 Identification of polygon or texture boundaries</u>

2.3.1 Having created the best possible image, or image-set, of the various textures displayed within a site, this image (or set of images) should ideally then be georeferenced into a GIS. Within the GIS, **polygon boundaries** should then be drawn around every distinct patch of texture. If instead the imagery is only available as a hard copy print, boundaries should be drawn either onto the print or onto a clear acetate film fixed firmly over the print (in such cases, during the subsequent gathering of field data it is usually possible to navigate accurately to defined locations, with care and experience, simply using the features visible on the aerial photograph) – see Figure 3.

2.3.2 **The process of defining textures is critical** because it is easy to become drawn too far into detail. The matrix provides the capability to describe many synusial elements *within a single matrix sheet or pair of sheets* representing a single texture. Thus, for example, a blanket mire hill-slope may be riven with erosion gullies while non-eroded slabs lie between these gullies. If taking a sufficiently broad view of texture, this hill-slope represents a texture consisting of **both** the gullies **and** the slabs between, and can thus be described using a single matrix sheet where the gullies and slabs are both recorded as 'Frequent', whereas a too-detailed view might attempt to separate the gullies from slabs as two different textures. If the gullies are widely-spaced, the matrix sheet still provides the ability to indicate their presence by noting that they are 'Rare' in frequency. It is often helpful to half-close one's eyes to identify such broad areas of texture, or simply to zoom out until textures become distinct blocks of tone.

2.3.3 An alternative to, or supplement to, the Mk.1 half-closed eyeball or screen zoom is the use of **segmentation routines** provided within image processing packages.

2.3.4 Having isolated the area of interest, segmentation can then be performed on the image. Photoshop, for example, has the 'Filter/Filter Gallery/Artistic/Cutout' option, where sliders can generate coarser of finer versions of the textures seen by Photoshop. Affinity Photo offers the same kind of tool, but there are many segmentation routines available on the internet and these can help in the decision-making process. An alternative, or supplement, to segmentation routines is the 'posterization' routine also available in many image-processing packages. Comparing posterized versions with the colour-enhanced and the segmented versions can assist in defining texture-polygon boundaries.

2.3.5 It is helpful to use a combination of the approaches described above because this can highlight those texture types that appear consistently when using any or all of these techniques and thus provide a degree of confidence in selecting such textures.

2.3.6 A further consideration, given that the Condition Matrix is only designed to work with bog systems, concerns the presence of fen systems within the blanket mire landscape. These will generally show up as the palest patches within an aerial image. While it is fine to include such features within a polygon identified on the basis of its bog texture, field sampling locations ('viewpoints' – see 2.4 below) should not be located within such fen areas.

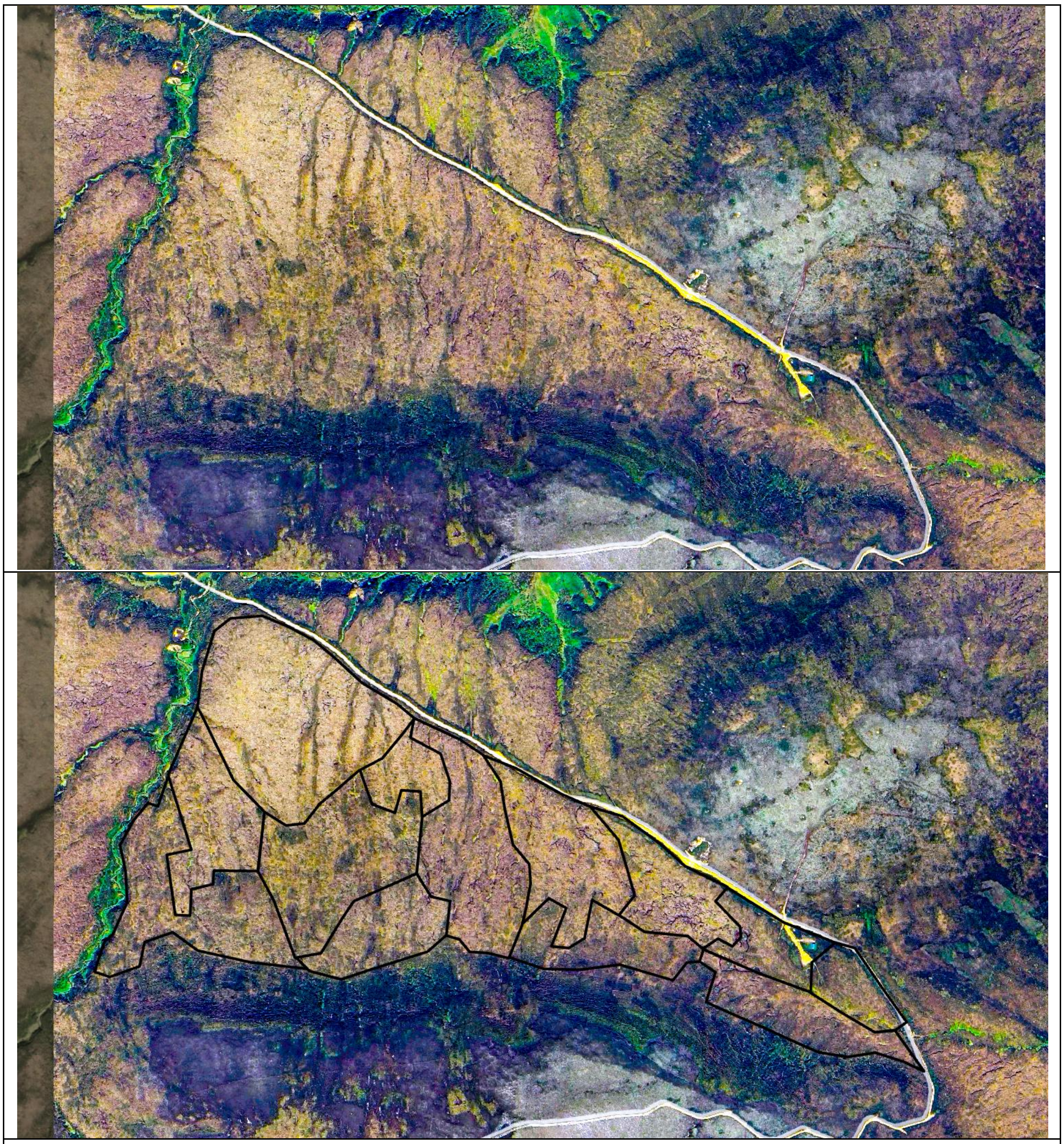


Figure 3. (Top) Area of blanket mire after colour and contrast enhancement using the Photoshop Raw filter. (Bottom) Polygon boundaries drawn around areas of distinct texture and colour. Images from Google Maps.

2.3.7 Indeed where such fen features are widespread and extensive, it is helpful to cut these out from the image before starting to decide on possible polygon boundaries. This can generally be achieved using tools such as the 'Magic Wand' selection tool in Photoshop, or the 'Flood Select Tool' in Affinity, in order to identify and then cut out these areas from the image. Such tools generally require two important parameters to be defined: 'Tolerance' – which determines the tonal range over which any given selection will take place (usually between 5-10% on an enhanced image will suffice but sometimes as much as 45% can be helpful), and 'Contiguous' – which, provided it is unchecked, will find all examples falling within the defined tolerance.

2.3.8 Furthermore, where the ground is particularly complex and boundary definition is especially challenging, the 'Magic Wand/Flood Select Tool' approach can help to create an alternative approach to the manual process of polygon identification. Having created a set of textures using image enhancement followed by either posterization or segmentation, it is possible then to employ the 'Magic Wand' approach to select and cut out each of the various texture tones and create separate image layers or files for each tone. Instead of manually-defined polygons, the image layer for each tone can be used as the basis for field survey. Thus Figure 4 illustrates the selection of two layers based on tone. Each layer displays a scatter of a single tone created using the cut-out filter from which field sampling can subsequently be undertaken, and when all layers together combine to fill (largely) the area of interest this is a sign that sufficient layers have been identified.

2.3.9 Having made decisions about polygon boundaries or texture layers it is important that the polygons (or texture layers) are **archived safely** so that surveys of the same area in subsequent years can refer back to the image used to define the initial boundaries.

2.3.10 Each polygon or texture layer should be given a **unique code/number**. Even if two polygons are thought to display the same texture they should be given unique different numbers because in the field it may be found that the two areas differ in important respects. If they should prove to be the same, the data can be combined later.

2.4 Field sampling strategy

2.4.1 **A minimum of five 'viewpoints'**, suitably distributed, should ideally then be placed within each texture polygon, or within each texture layer, and the National Grid Reference of each point catalogued. This is why creating a great many small polygons is not helpful – they lead to enormous numbers of viewpoints. Logically, the points should be coded with the polygon code, then a subsidiary number is given from 1 to 5 (e.g. Point 6.3 indicates the third sample point in Polygon 6). If the texture layer method is used, viewpoints can be just distributed across main blocks rather than attempting to pick up small fragments and slivers.

Figure 4. (Top) Single tone extracted from 'cut-out' image using the 'Magic Wand' selection tool and pasted into its own layer, in the correct location, using Photoshop 'Paste Special/Paste in Place'. (Bottom) A second tone, also pasted its own layer in the correct location.

2.4.2 The points are termed 'viewpoints' because they represent the centre of an **area** over which the texture should be assessed. Thus the viewpoint position is not the sampling point but rather the location at which you can be confident you are standing well within the area to be assessed. The purpose of recommending five viewpoints is to encourage the surveyor to examine conditions throughout the whole polygon. A common tendency is for surveyors to focus on just a small area around a defined point, but if five such points are examined there is a good chance that the full range of conditions present within that polygon or texture will have been noted. It is possible to use fewer viewpoints, or even just a single viewpoint, if resources are constrained and provided that surveyors ensure that they adequately cover the ground of the polygon and note all features encountered.

2.4.3 At this stage the question of **available resources** becomes relevant. If resources for field survey are seriously constrained and it looks likely that some polygons contain the same texture, it is worth considering whether to distribute the five sample points across polygons of the same apparent texture rather than have five points in each of the similar polygons. There is always a danger that important information about difference will be missed, but the condition matrix is sufficiently robust that any unexpected differences can probably still be identified – and it is always possible to add further matrix sheets while in the field. Equally, limited resources may mean that only a single viewpoint is feasible for each texture type, but then conscious effort should be made to cover as much ground within that texture as is possible within the time and resources available.

2.5 Preparing the condition matrix sheets

2.5.1 Having settled on a survey strategy (given available resources) and thus determined the number of points to survey, a **condition matrix sheet should then be prepared for each viewpoint**. It is not necessary for the field sheets to use the 'traffic light' colour shading. Indeed for recording purposes it is better that colour printing is not used. Sheets can be printed as simple black-and-white text on a grid, which then makes printing, and subsequent writing on them in the field, easier than is the case for sheets displaying the traffic-light colour shading (because coloured inks tend to resist pencil and pen). Click here to Download a black & white version of the matrix.

2.5.2 Data which can be completed at this stage depend to some extent on the nature of the texture:

- Site name;
- Mire pattern number (Polygon code plus sample site number);
- If possible to determine, whether a primary or secondary surface;
- If hollows, pools or erosion gullies are present, indicate provisionally in pencil how frequent they are within the polygon – record this in the DFR column using whatever frequency score is desired (e.g. Domin, % cover, DAFOR), but the **minimum** should be **D**ominant, **F**requent, **R**are, though combinations can be used (e.g. **D/F** if desired);
- The DFR estimate is only provisional and in pencil because field survey may, for example, reveal a pool to be A2 (mud-bottom hollow) rather than a provisionally assumed A4 (permanent pool;
- It is **essential** that the Ordnance Survey grid reference is provided for the viewpoint.

2.5.3 If a particular texture appears to comprise an intimate mixture of primary and secondary surfaces, **two matrix forms** can be prepared, one for the primary surfaces and one for the secondary surfaces.

2.6 Field survey route planning

2.6.1 Ideally, a **route can be planned** between viewpoints in order to ensure that the field survey is undertaken in as efficient manner as possible, thereby enabling the maximum possible area of the site to be assessed within the constraints of available resources.

2.7 Waypoints for field survey

2.7.1 Finally, in addition to the waypoints registered as the centres of each viewpoint, additional waypoints can be determined for the position at which the planned route **crosses polygon boundaries**. This is to alert the surveyor that they should be starting work on the next set of appropriate condition-matrix sheets.

3. Field survey

3.1 The Field Survey phase consists of several steps which are determined by the structure of the condition matrix sheet. It is important to understand this structure.

3.1.1 Column 1 identifies the structural and hydrological elements present and provides a description to aid recognition. They are also extensively described and illustrated in Appendix 1. **Hydrological** elements give the relative position of the high-moisture zone, while **structural** elements (linked to damage) are indicated by light shading in the 1st column of the matrix sheet.

3.1.2 Column 2 requires a simple estimate to be made of how frequent any zonal element is considered to be around the viewpoint – is it dominant, frequent or rare? You can be more precise/quantitative if you wish.

3.1.3 Columns 3-9 represent synusia defined by their zonal element and their species/species assemblage.

3.1.4 Columns 10 and 11 are blank to permit synusia considered important for **condition assessment** but missing from the matrix.

3.1.5 The matrix sheet is two-sided, with the front listing only terrestrial synusiae and the rear listing aquatic synusiae and eroding synusiae.

3.1.6 Date and time of day can both be recorded, in part as an aid to correlating any photos taken.

3.1.7 There is a 'Notes' section at the bottom of each side for relevant observations to be made about any aspect of the polygon or the nature of the data recorded.

3.2 *Identification of survey area*

3.2.1 Each matrix sheet is a record of the entire area of ground around the viewpoint rather than being constrained by a formal quadrat area. The area surveyed at each viewpoint should therefore be constrained only by proximity of either the next viewpoint or by the polygon boundary.

3.2.2 A spiral walk extending outwards from the viewpoint is thus a good approach. It can be useful to stand a tripod, walking pole, or similar, at the viewpoint in order to act as a reference point.

3.3 *Identification of zonal elements* (see also Annex 1)

3.3.1 One of the most challenging aspects of the condition matrix, at least for people new to the system, is the need to identify the zonal elements. Fortunately, simple technology is at hand. It is based on the principle that these zones are characterised by their relationship to the relatively stable zone of high moisture in the peat (as opposed to the actual water-table position at that moment).

3.3.2 A simple plant-pot moisture meter with a 30 cm probe (costing around £15 from Amazon) gives a remarkably good indication of the depth at which the high-moisture zone begins, and does so in all weathers (even in driving rain) – see Figure 5.

3.3.3 The probe is pushed into the moss layer or the bare peat *until the needle first flicks up to the start of the blue zone* on the scale. The depth of probe insertion can then be compared with the descriptions provided in Column 1 of the matrix sheet. These simple probes use a capacitance sensor that fades over time so it is important to note the *first flick* up to the blue zone because if held in the peat and repeatedly jiggled up and down, the sensor will tend to fade causing the needle to fall back into the green or red zone. If this happens, take the probe out, wipe it dry and try again.

3.3.4 While this approach assists with the identification of the four key terrestrial **hydrological** elements of the microtopography (*i.e.* T3 hummocks, T2 high ridge, T1 low ridge and T1/A1 transition), **structural** elements associated with damage or degradation are recognised visually by their physical form. Thus T4 erosion hagg-tops occur along the edges of erosion gullies or micro-erosion channels, E1 and E2 erosion gullies are evident physical structures, while Em micro-erosion channels typically form an interconnected network between tussocks. Tk tussocks are identified as dense clumps of *Eriophorum vaginatum*, *Trichophorum cespitosum*, *Deschampsia flexuosa* or *Molinia caerulea* (the four typical tussock formers in the UK) which can be felt underfoot or which make walking through areas dominated by larger examples extremely difficult and tiresome.

3.3.5 It should be noted that 'Tk tussocks' can also be identified by the fact that the probe is not able to penetrate a typical dense tussock. Do not try to force the probe into a tussock. The probe should slide fairly readily into most zonal elements but attempting to force it into a tussock will likely damage the probe. If the probe meets significant resistance, this is almost certainly a tussock.

3.3.6 Apart from Tk tussocks, it may also be possible to obtain a moisture-probe reading for the various **structural** elements. For T4 hagg-tops, this will generally indicate the degree to which the moisture zone has been retained from a more natural state despite damage, and should also therefore be recorded within the appropriate **hydrological** zone, with a comment made in the Notes section. For erosion gullies/channels, the moisture probe will give an indication either of the proximity to the peat surface of the high-moisture zone, which is an indication of the potential for such channels to regenerate, or, in the case of already regenerating gullies/channels, an indication of the status of this **secondary** assemblage, so should be recorded both as structural elements and appropriate hydrological elements but in this case the 'aquatic' side of the matrix sheet should be indicated as **secondary**.

Figure 5. Examples of simple 30 cm moisture probes indicating differing depths of the high-moisture zone and thus presence of differing nanotope zones.

3.3.7 If there are primary and secondary elements on adjacent ground within a single texture, then both **Primary** and **Secondary** can be ringed and a note made in the **Notes** section. Alternatively, if the secondary assemblage(s) are extensive enough, a separate **Secondary** sheet can be made for these features.

3.3.8 If a bog is recovering well from (for example) a fire in the past, tussocks will tend to become overgrown by either Hypnoid/feather mosses or, eventually, by *Sphagnum*. In such cases the tussock becomes progressively softer and easier to probe. In the matrix, look for synusiae such as ‘Tk - Sphagnum over Eriophorum’ and variations on this for such improving conditions.

3.3.9 The probe also does not work in free water so cannot be used to judge the depth of water in pools; for this a ruler or similar should be used.

3.3.10 If the probe refuses to register and the needle just wanders around somewhat, check with your finger that you are not attempting to sample water beneath a litter layer.

3.3.11 Test a number of structural elements around the viewpoint until you begin to gain a feel for what these elements represent within this texture, then circle those elements present in Column 1 and make an estimate in Column 2 of how frequent each of these elements is within the area of survey.

3.3.12 This is also the opportunity to correct any incorrect assumptions made during the desk work about the elements present. However, bear in mind that estimates of frequency for evident features such as gullies, or ridges between pools, are likely to be more accurate when made from imagery than when on the ground.

3.4 *Recording the synusiae*

3.4.1 The first core principle of the matrix sheet is that, apart from an estimate of structural zone frequency, **all other recording is simple presence-absence**, indicated by circling the relevant synusial boxes. There is, however, nothing to stop those who wish from writing estimates of cover for each synusia noted, though experience suggests that such estimates do not substantially alter either the visual message of the sheet nor any subsequent quantitative analysis.

3.4.2 The second core principle of the matrix sheet is that **every synusia present on the matrix sheet should be recorded if seen**, even if it occurs only as relatively small amounts.

3.4.3 This is also true even if it seems that data are being duplicated. This is because the matrix sheet is designed to cater for differing levels of expertise. Thus ‘Sphagnum’ is provided as one synusial box specifically for those only confident of recognising presence of *Sphagnum*. However, within the same structural zone there may also be boxes for individual named *Sphagnum* species. For those confident in identifying these species, they should circle **both** the ‘Sphagnum’ box **and** the boxes for individual species and any other relevant boxes referring to *Sphagnum*.

3.4.4 As mentioned above, the main purpose of the matrix sheet is to provide a ‘traffic light’ picture of condition, highlighting particularly those features indicative of harm. Having multiple circles within the columns of ‘good condition’ does not compensate for also having several circles in the columns indicative of poor condition which, from a conservation perspective, is the more important aspect of condition.

3.4.5 It helps to become familiar with the matrix sheet and the species used within the matrix prior to undertaking survey. Knowing the various synusial boxes contained within the matrix sheet saves a considerable amount of time in the field compared with constantly having to search through the sheet to check the sheet-contents against what can be seen on the ground – see Annex 2.

3.4.6 The purpose of the condition matrix is not to record every type of vegetation assemblage present but rather to record those of relevance to condition assessment. Concentrate, therefore, on the synusiae listed on the matrix sheet. They are sufficiently broad to cover most circumstances within UK peatlands. If, however, certain synusial types not given on the sheet feature as significant components of the bog system and are important in describing condition, the two blank columns to the right of the matrix sheet can be used to note further limited synusiae, but within the UK this should normally be the exception rather than the rule.

3.4.7 Micro-erosion and tussocks are the most widespread yet least recognised synusial features of UK peatlands. They are so common as to be almost the default condition for peat bogs in the UK. 'Em micro-erosion' is most commonly associated with 'Tk tussock' because it forms the interconnected anastomosing drainage network between tussocks. Tussocks are associated with loss of *Sphagnum* (see the explanation for this in the very last part of the final Appendix in Lindsay, 2010), and the vast majority of peat bogs in the UK have lost their vigorous *Sphagnum* swards. Damaging factors such as burning, drainage and aerial pollution thus encourage tussock formation. On a bog in good condition there should be no hard lumps underfoot and no parts that the moisture probe has difficulty penetrating.

4. Synusial *quadrats*

4.1 As mentioned earlier, the condition matrix is designed only to assess the **ecological condition** of a peatland. If, in addition, an assessment of the **ecological character** is required, each sample point, or each polygon type, can also be assessed by taking one or more **synusial *quadrats***. For those surveys seeking to characterise the ecological character of the bog in addition to assessing its current condition, it is possible to record synusial 'quadrats' in which the full species complement is recorded from each structural zone.

4.2 The synusial structures (*e.g.* T3 hummock, T1 low ridge) present within a polygon will already have been assessed as part of the condition matrix process. To take a synusial quadrat it is simply necessary to create a complete species list, with cover-abundance values if so desired, for each species within each synusial structure.

4.3 This can be done using simple presence-absence recording, DAFOR or DOMIN recording, or % cover, for each species within each structural zone. Thus *Sphagnum capillifolium* within a T3 hummock is recorded separately from *Sphagnum capillifolium* in a T2 high ridge because they are two distinct synusiae: T3-Sphagnum capillifolium and T2-Sphagnum capillifolium. These two records thus represent distinct *pseudospecies* of *Sphagnum capillifolium* and can be treated as distinct entities in subsequent analysis, particularly as it will likely be found that T3-Sphagnum capillifolium occurs regularly with a different set of companion species from those that accompany T2-Sphagnum capillifolium. Ecological conditions in T3 hummocks also, for example, differ from those associated with T2 high ridge.

4.4 For synusial quadrats employing presence-absence data or DAFOR, the same spiral walk from the sample point can be employed because the aim is to capture as many synusial pseudospecies present in that sample area as possible. For more quantitative values such as DOMIN or % cover, a quadrat of around 10 m x 10 m (paced out and then walked over) can be employed.

4.5 An example of a completed synusial quadrat sheet is provided as Figure 6. A blank form can be downloaded from here: Synusial quadrat sheet

4.6 It may be surprising to learn that adding abundance values to these pseudospecies may not have a material effect on the outcome of any subsequent analysis of ecological character. Simple presence-absence of the individual pseudospecies is often sufficient to achieve meaningful ecological characterisation. The main benefit of abundance values is that they help to describe the visual *__appearance__* of an ecological unit.

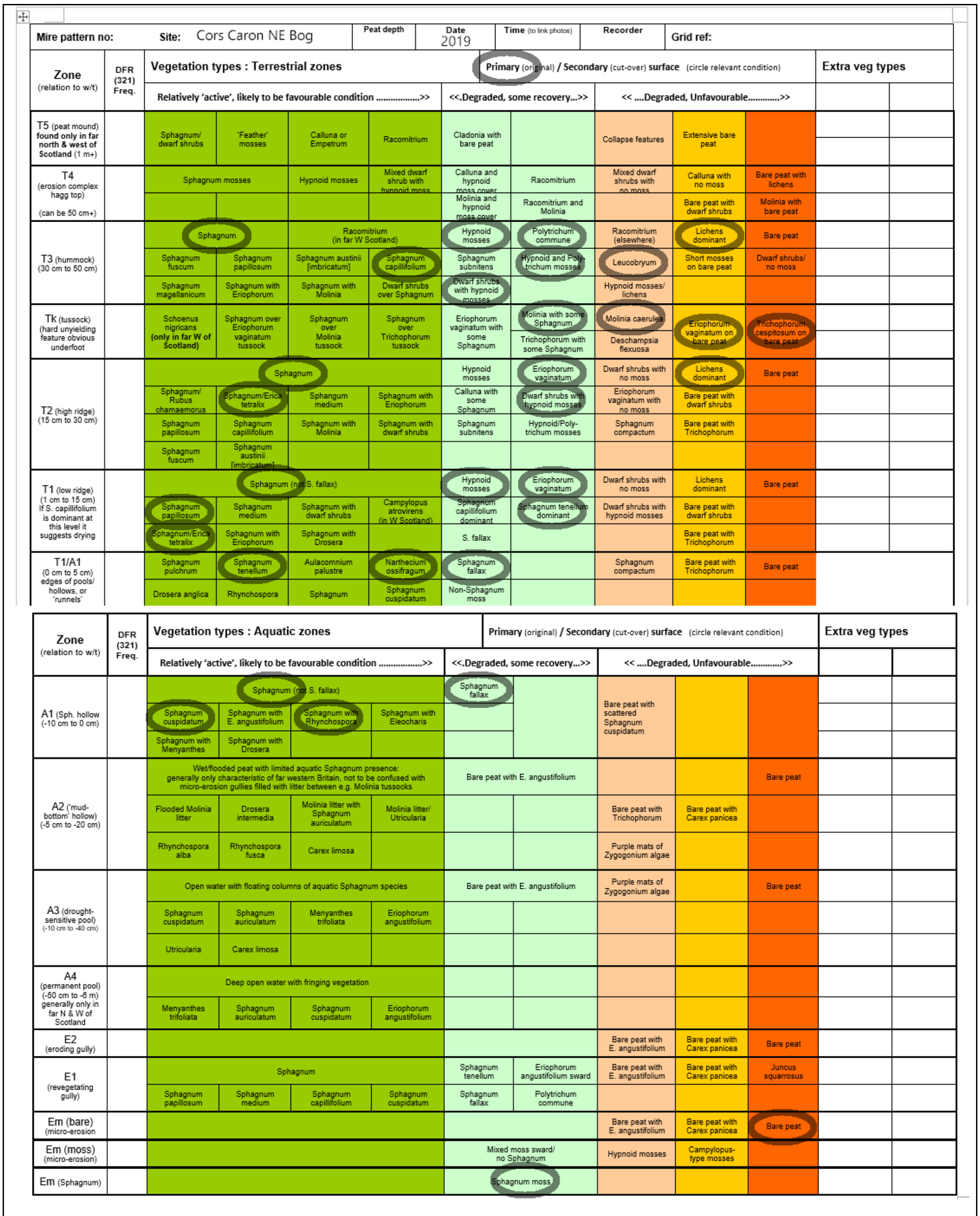
Site: Carmel		**Date:** .28/8/2019	**Microtope no:** .Tx 3		**Location:** .Carmel Point 8		
Zone	**DFR**	**Microtope synusial species composition**					
Tk	F	Molinia caerulea	F	Trichophorum cespitosum	R	Erica tetralix	F/D
		Sphagnum fallax	R	Sphagnum tenellum	R	Eriophorum angustifolium	R
T1	D	Molinia caerulea	F	Trichophorum cespitosum	R	Eriophorum vaginatum	F
		Erica tetralix	R	Sphagnum fallax	F/D	Eriophorum angustifolium	F
T1/A1	R	Sphagnum fallax	D				

Figure 6. Example of a completed synusial form for *ecological* characterisation. Data gathered by David Reed, Natural Resources Wales.

5. Consolidation and conversion of matrix sheets

5.1 Having completed field survey it will often be found that the five matrix sheets obtained for a single polygon or texture are not identical. A new consolidated sheet should therefore be prepared by combining records from all five sheets into one condition matrix. This process is repeated for all polygons/textures.

5.2 There are many ways to display these consolidated sheets. One approach, with Photoshop, involves copying oval shapes and placing them over all relevant synusial boxes (see Figure 7).



Mire pattern no:	Site: Cors Caron NE Bog	Peat depth	Date 2019	Time (to link photos)	Recorder	Grid ref:

Zone (relation to w/t)	DFR (321) Freq.	Vegetation types : Terrestrial zones				Primary (original) / Secondary (cut-over) surface (circle relevant condition)					Extra veg types	
		Relatively 'active', likely to be favourable condition ....>>				<<.Degraded, some recovery...>>		<< ....Degraded, Unfavourable............>>				
T5 (peat mound) found only in far north & west of Scotland (1 m+)		Sphagnum/ dwarf shrubs	'Feather' mosses	Calluna or Empetrum	Racomitrium	Cladonia with bare peat		Collapse features	Extensive bare peat			
T4 (erosion complex hagg top) (can be 50 cm+)		Sphagnum mosses		Hypnoid mosses	Mixed dwarf shrub with hypnoid moss	Calluna and hypnoid moss cover	Racomitrium	Mixed dwarf shrubs with no moss	Calluna with no moss	Bare peat with lichens		
						Molinia and hypnoid moss cover	Racomitrium and Molinia		Bare peat with dwarf shrubs	Molinia with bare peat		
T3 (hummock) (30 cm to 50 cm)		Sphagnum		Racomitrium (in far W Scotland)		Hypnoid mosses	Polytrichum commune	Racomitrium (elsewhere)	Lichens dominant	Bare peat		
		Sphagnum fuscum	Sphagnum papillosum	Sphagnum austinii [imbricatum]	Sphagnum capillifolium	Sphagnum subnitens	Hypnoid and Polytrichum mosses	Leucobryum	Short mosses on bare peat	Dwarf shrubs/ no moss		
		Sphagnum magellanicum	Sphagnum with Eriophorum	Sphagnum with Molinia	Dwarf shrubs over Sphagnum	Dwarf shrubs with hypnoid mosses		Hypnoid mosses/ lichens				
Tk (tussock) (hard unyielding feature obvious underfoot		Schoenus nigricans (only in far W of Scotland)	Sphagnum over Eriophorum vaginatum tussock	Sphagnum over Molinia tussock	Sphagnum over Trichophorum tussock	Eriophorum vaginatum with some Sphagnum	Molinia with some Sphagnum	Molinia caerulea	Eriophorum vaginatum on bare peat	Trichophorum cespitosum on bare peat		
							Trichophorum with some Sphagnum	Deschampsia flexuosa				
T2 (high ridge) (15 cm to 30 cm)		Sphagnum				Hypnoid mosses	Eriophorum vaginatum	Dwarf shrubs with no moss	Lichens dominant	Bare peat		
		Sphagnum/ Rubus chamaemorus	Sphagnum/Erica tetralix	Sphangum medium	Sphagnum with Eriophorum	Calluna with some Sphagnum	Dwarf shrubs with hypnoid mosses	Eriophorum vaginatum with no moss	Bare peat with dwarf shrubs			
		Sphagnum papillosum	Sphagnum capillifolium	Sphagnum with Molinia	Sphagnum with dwarf shrubs	Sphagnum subnitens	Hypnoid/Polytrichum mosses	Sphagnum compactum	Bare peat with Trichophorum			
		Sphagnum fuscum	Sphagnum austinii [imbricatum]									
T1 (low ridge) (1 cm to 15 cm) If S. capillifolium is dominant at this level it suggests drying		Sphagnum (not S. fallax)				Hypnoid mosses	Eriophorum vaginatum	Dwarf shrubs with no moss	Lichens dominant	Bare peat		
		Sphagnum papillosum	Sphagnum medium	Sphagnum with dwarf shrubs	Campylopus atrovirens (in W Scotland)	Sphagnum capillifolium dominant	Sphagnum tenellum dominant	Dwarf shrubs with hypnoid mosses	Bare peat with dwarf shrubs			
		Sphagnum/Erica tetralix	Sphagnum with Eriophorum	Sphagnum with Drosera		S. fallax			Bare peat with Trichophorum			
T1/A1 (0 cm to 5 cm) edges of pools/ hollows, or 'runnels'		Sphagnum pulchrum	Sphagnum tenellum	Aulacomnium palustre	Narthecium ossifragum	Sphagnum fallax		Sphagnum compactum	Bare peat with Trichophorum	Bare peat		
		Drosera anglica	Rhynchospora	Sphagnum	Sphagnum cuspidatum	Non-Sphagnum moss						

Zone (relation to w/t)	DFR (321) Freq.	Vegetation types : Aquatic zones				Primary (original) / Secondary (cut-over) surface (circle relevant condition)					Extra veg types	
		Relatively 'active', likely to be favourable condition ....>>				<<.Degraded, some recovery...>>		<< ....Degraded, Unfavourable............>>				
A1 (Sph. hollow (-10 cm to 0 cm)		Sphagnum (not S. fallax)				Sphagnum fallax		Bare peat with scattered Sphagnum cuspidatum				
		Sphagnum cuspidatum	Sphagnum with E. angustifolium	Sphagnum with Rhynchospora	Sphagnum with Eleocharis							
		Sphagnum with Menyanthes	Sphagnum with Drosera									
A2 ('mud-bottom' hollow) (-5 cm to -20 cm)		Wet/flooded peat with limited aquatic Sphagnum presence: generally only characteristic of far western Britain, not to be confused with micro-erosion gullies filled with litter between e.g. Molinia tussocks				Bare peat with E. angustifolium				Bare peat		
		Flooded Molinia litter	Drosera intermedia	Molinia litter with Sphagnum auriculatum	Molinia litter/ Utricularia			Bare peat with Trichophorum	Bare peat with Carex panicea			
		Rhynchospora alba	Rhynchospora fusca	Carex limosa				Purple mats of Zygogonium algae				
A3 (drought-sensitive pool) (-10 cm to -40 cm)		Open water with floating columns of aquatic Sphagnum species				Bare peat with E. angustifolium		Purple mats of Zygogonium algae		Bare peat		
		Sphagnum cuspidatum	Sphagnum auriculatum	Menyanthes trifoliata	Eriophorum angustifolium							
		Utricularia	Carex limosa									
A4 (permanent pool) (-50 cm to -6 m) generally only in far N & W of Scotland		Deep open water with fringing vegetation										
		Menyanthes trifoliata	Sphagnum auriculatum	Sphagnum cuspidatum	Eriophorum angustifolium							
E2 (eroding gully)								Bare peat with E. angustifolium	Bare peat with Carex panicea	Bare peat		
E1 (revegetating gully)		Sphagnum				Sphagnum tenellum	Eriophorum angustifolium sward	Bare peat with E. angustifolium	Bare peat with Carex panicea	Juncus squarrosus		
		Sphagnum papillosum	Sphagnum medium	Sphagnum capillifolium	Sphagnum cuspidatum	Sphagnum fallax	Polytrichum commune					
Em (bare) (micro-erosion								Bare peat with E. angustifolium	Bare peat with Carex panicea	Bare peat		
Em (moss) (micro-erosion)						Mixed moss sward/ no Sphagnum		Hypnoid mosses	Campylopus-type mosses			
Em (Sphagnum)						Sphagnum moss						

Figure 7. Consolidated matrix sheet for Cernydd Carmel raised bog, Wales, in this case for an area that was a complex mixture of primary and secondary bog surface. The high proportion of ovals within the poor categories of condition highlight the degraded nature of the bog at the time of survey (restoration actions have since been undertaken). Data gathered by David Reed, Natural Resources Wales.

5.3 Having generated the full set of consolidated matrix sheets for the site, these can then be related spatially to the site as a whole by linking each consolidated matrix to its relevant polygon or texture. The matrix then gives a direct indication of whether there are features of concern within any particular parts of the site as well as indicating the nature of those concerns.

5.4 Having identified any features of concern, restoration targets can be set. These should require movement of recorded features towards the left across the matrix in post-restoration surveys, away from 'traffic-light' columns indicating poor condition towards those indicating good condition – or at least towards improving condition.

5.5 Should a more analytical approach to the data be desired, it is possible to convert the condition matrix sheets into 'quadrats' in which each consolidated polygon/texture matrix becomes a 'quadrat' while the individual recorded synusial boxes become 'pseudospecies' within that quadrat.

5.6 These matrix quadrats and their pseudospecies are thereby converted into a format which can be explored using a range of analytical techniques.

6. Analysis of condition matrix and synusial quadrat data

6.1 *Analysis – Ordination or Classification*

6.1.1 Various options are available for those wishing to analyse the condition matrix data in more detail, though in general the interest will be in generating better spatial understanding of different condition-states and therefore production of mapping units will be the main focus of interest.

6.1.2 Map units are by definition based on agglomeration of data into defined clusters (the mapping units). This contrasts with methods of gradient analysis which are the more widely used approaches employed in journal papers written by anglophone authors where correlations between different factors are sought but the objective is not then to generate distinct units for spatial expression in map form.

6.1.3 This difference in approach was codified by Whittaker (1973) in his seminal volume "*Ordination and Classification of Communities*", in which ordination based largely on gradient analysis was compared and contrasted with classificatory approaches in which communities were described on the basis of defined mappable groupings. In essence, ordination methods arose from post-war use of computers to calculate complex multi-dimensional relationships between species and environmental gradients, then express these as distribution plots in multi-dimensional space. While revealing relationships between species and environmental factors, this process does not explicitly generate discrete vegetation assemblages which can be mapped.

6.1.4 In contrast, during the years prior to WW1 a systematic approach to the process of classifying vegetation assemblages into discrete mappable units was devised and widely adopted across Europe (Braun-Blanquet, 1932). The method, termed phytosociology (the sociology of plant species), is now the standard approach to vegetation description across much of Europe and further afield, with the result that standardised mapping units exist and vegetation maps are available for much of Europe.

6.1.5 More recently in Europe, the synusial concept of Gams (1918) has been revived and incorporated into the phytosociological approach, giving rise to synusial phytosociology (Gillet and Galandat, 1996), in which synusiae consisting of micro-habitats and associated species assemblages are recognised as the building blocks of all ecosystems. Indeed, using these building blocks it is possible to construct an entire inter-connected landscape hierarchy, as illustrated by Gillet and Galandat (1996) and, for example, Lindsay *et al*., (1988) and the Bogs SSSI Guidelines (JNCC, 1994).

6.1.6 The present Handbook assumes that spatial expression of habitat condition in map form is of most interest to readers of the Handbook. The description below is therefore largely focused on the process of converting condition-matrix data into a format suitable for analytical approaches that can generate mapping units.

6.2 *Conversion of condition matrix data to 'quadrat' format*

6.2.1 The matrix data can be converted to more conventional quadrat format within a spreadsheet by treating both the zones and the synusial vegetation boxes as pseudospecies. Each matrix sheet is assigned a single column in the spreadsheet, while all possible zones and synusial vegetation boxes are listed in the first left-hand column and the recorded items are then listed in their appropriate place in the quadrat column.

6.2.2 Jack Cook of Aberystwyth University has produced a macro-enabled Excel spreadsheet that mirrors the condition matrix sheet and converts any input records into Excel quadrat format. The form requires relevant input to any cell shaded pale blue, then the relevant matrix boxes are simply clicked, before finally clicking the button to convert the data into conventional quadrat format. You can also use the Excel spreadsheet to produce a pdf version of the matrix sheet for digital archive purposes. This macro-enabled input system can be downloaded from the IUCN UK Peatland Programme website here: Matrix to Quadrat converter.

6.2.3 When the spreadsheet is downloaded to your Downloads folder and unzipped, Microsoft may then prevent you from opening the spreadsheet directly (because of the macros). Copy the spreadsheet to somewhere other than the Downloads folder before attempting to open it. It is important to note that the macros must then be enabled if requested by Excel. Also, some organisational servers do not permit macro-enabled Excel spreadsheets to function. Permission may thus need to be obtained from your IT department in order to allow these particular macros to function - or alternatively run the spreadsheet on a non-institution device.

6.2.4 Having converted the matrix data into conventional quadrat format, it is then possible to subject the data to analytical investigation. If generation of actual mapping units is the objective of analysis – as is likely to be the case in the use of the condition matrix – then classification methods of analysis such as TWINSPAN would be the more appropriate approach, rather than ordination methods such as principal components analysis (PCA).

6.2.5 This manual is not an instruction guide to the use of TWINSPAN but certain aspects of that programme are worth highlighting because misunderstandings about the purpose and function of TWINSPAN are widespread.

6.2.6 First and foremost, Mark Hill created TWINSPAN (Hill, 1979; Kent and Coker, 1992) as a method for first-stage rough sorting of data, the results of which would then be subject to further sorting *based on ecological knowledge and understanding*. It is expected that the final output will not be taken as the final word but rather a starting-point from which the roughly-sorted groupings are then examined for similarities between groups or differences within groups, or spotting mis-classified samples that in ecological terms make more sense if placed in another grouping.

6.2.7 TWINSPAN is, technically speaking, a polythetic divisive classification system. In simple terms, this mean that the whole dataset is assessed for its composition and the two most different samples, and the two most different species-pairs, are used as the limits of a dispersed distribution plot of all other samples and species. TWINSPAN then divides this first agglomeration of data into two groupings, or 'end-groups' based on difference within the agglomeration – which may mean that the two resulting groups contain very different numbers of samples.

6.2.8 These two end-groups are then analysed in the same way and sub-divided to create a total of four end-groups and so the process goes on until either the number of defined 'levels of division' (defined as a parameter at the start of the programme) is reached, or until an end-group contains a minimum number of samples (again, defined as a parameter at the start).

6.2.9 Typically, the number of defined 'levels of division' lies between 5 and 7, whilst the minimum number of samples in an end-group is around 5. However, it is important to understand that reaching the defined levels of division does not mean that the analysis has reached the necessary level of ecological division. In a large dataset, some end-groups may still contain a large number of samples that contain important ecological differences within the end-group, differences that can be brought out by running the programme again but using a larger number of divisions.

6.2.10 Equally, it may be found that some end-groups quickly reach the minimum number of samples but the resulting end-group makes less sense as a mapping unit than if the final end-group is re-combined with its twin at the next level up in the division hierarchy (technically a 'dendrogram') or even higher up the divisions, to create an ecologically meaningful mapping unit. Thus the ecologically meaningful output from TWINSPAN may result in a dendrogram that ends at different levels but may also involve moving some mis-classified samples from one group to another in order to make more ecological sense.

6.2.11 It is also possible to separate out the nanotope zones and analyse these separately from the synusial matrix boxes, thereby creating a classification of microtopographic combinations, thus giving a picture solely of the physical 'texture' of the area (*e.g.* a mapping area consisting of dominant Tk tussocks and frequent Em micro-erosion with non-*Sphagnum* moss). This can then be represented as one map layer, onto which another map layer can be draped using vegetation-based mapping units created from the synusial matrix boxes.

6.2.12 A practical example of both the condition matrix and use of TWINSPAN to generate condition mapping can be seen in the report produced for the EU-funded New LIFE for Welsh Raised Bogs Project.

7. Summary steps for matrix use

7.1 *Desk study*

7.1.1 Define area of interest using aerial/satellite imagery.

7.1.2 Define areas of texture using eyeball, zoom or segmentation.

7.1.3 Draw polygon boundaries round identified textures, or select single texture layers.

7.1.4 Establish an appropriate number of viewpoints for each texture type.

7.1.5 Prepare black-and-white matrix sheet for each viewpoint, indicating, where appropriate or possible, provisional estimates of zone frequencies.

7.1.6 Where possible, note whether the texture is primary, secondary (*i.e.* regenerating surface) or both in nature and note appropriately on the form.

7.1.7 Work out optimal route between viewpoints, given available time and resources.

7.2 *Field survey*

7.2.1 Position a visible object (tripod, rucksack, etc.) at the first viewpoint.

7.2.2 Take photo(s) of the viewpoint texture, ensuring photos will be suitably labelled.

7.2.3 Walk in an outward spiral from the viewpoint, testing microtopography elements using a moisture probe to obtain a sense of how frequent each element is within the texture.

7.2.4 Note/confirm frequency of zonal elements in Column 2 of the matrix form.

7.2.5 For each zonal element, circle **every** example seen during the spiral walk-around of the vegetation assemblages listed within that row of the matrix sheet.

7.2.6 Where a **structural** element (*i.e.* a damage feature) also gives an appropriate reading for a **hydrological** element using the moisture probe, record the appropriate boxes in both zonal-feature rows and a comment made in the Notes section.

7.2.7 If desired, record synusial quadrats for each texture.

7.2.8 Move on to next viewpoint.

7.3 *Post-field survey steps*

7.3.1 If more than one viewpoint is recorded for a texture polygon, consolidate all records from that polygon into a single consolidated sheet for that texture, using the colour-coded matrix sheet in order to display the 'traffic-light' condition of that texture.

7.3.2 Compare consolidated sheets to determine where polygons may represent the same texture and combine these into a single mapped texture.

7.3.3 Note particularly the synusial boxes lying within the various degraded 'traffic-light' sectors and devise appropriate conservation measures to address these.

7.3.3 If so desired, use the IUCN Conversion Routine to convert matrix data to pseudospecies quadrat data, then analyse appropriately.

7.3.3 Where a previous matrix survey has been carried out for the same area (for example prior to restoration intervention), compare matrix sheets from the two time periods to look for change. Typically, improvement results in movement of circles to the left of the matrix, an overall reduction in **structural** elements and an increase in **hydrological** elements.

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ANNEX 1. Identification of hydrological and structural elements

A1.1 **Hydrological elements** of the microtopography are ecological zones distributed vertically within the microtopography in relation either to the upper limit of the high-moisture region within the peat or, in the case of aquatic elements, in relation to the average position of the bog water table.

A1.2 The narrow vertical range of these elements has been demonstrated by various authors since at least the turn of the last century (e.g. Weber, 1902; Sjörs, 1948; Ratcliffe and Walker, 1958; Lindsay, Riggall and Burd, 1985; Moen, 1985, Minayeva *et al*., 2017). Ivanov (1981) states that:

> *"The maximum difference in mean long-term [water] levels which does not lead to a change in the quantity or floristic composition of mire plant communities is very small. [..] For several varieties of moss cover it is less than 4-5 cm. Changes of that magnitude in mean long-term [water] levels are sufficient to produce important changes in the floristic composition of the moss cover."*
>
> *Water Movement in Mirelands, p.199*

A1.3 Hydrological elements are key components in the self-regulating mechanism of peat bog systems and are thus characteristic of peat bogs in a natural condition. In the face of environmental change brought about either by natural or anthropogenic effects, these elements may re-arrange themselves in order to minimise the impact of such change and thereby permit continued formation of peat. Consequently presence of these elements does not always mean that the bog is in good condition, but if a bog is in good condition it will always possess, and be dominated by, some or all of these hydrological elements.

A1.4 **Structural elements** are mostly associated with various forms of degradation. They are visually evident structures or micro-structures that generally result from breakdown of the natural set of hydrological elements originally present on the bog. The moisture meter is thus **not** used in order to determine presence of such structures.

A1.5 However, structural elements still possess a zone of high moisture although this zone may lie deeper in the peat than was originally the case. For example, ground that was originally *T1 low ridge* may become *Em micro-erosion bare* but the upper limit of the high moisture zone may fall only a centimetre or so (such is the water-retaining ability of peat), with the result that the moisture probe still records the micro-erosion as T1 low ridge. This provides an indication of the recovery potential for that particular element – conditions exist for it to re-develop a T1 community. In such circumstances it is useful to record **in the NOTES section** that the micro-erosion element retains a moisture zone equivalent to T1 low ridge.

A1.6 The following seeks to provide as much guidance as possible about the various hydrological and structural elements as an aid to their identification.

A1.7 Hydrological elements

A1.7.1 The spatial relationship between all hydrological elements used in the condition matrix are shown in Figure A1. Each element is subsequently described in more detail.

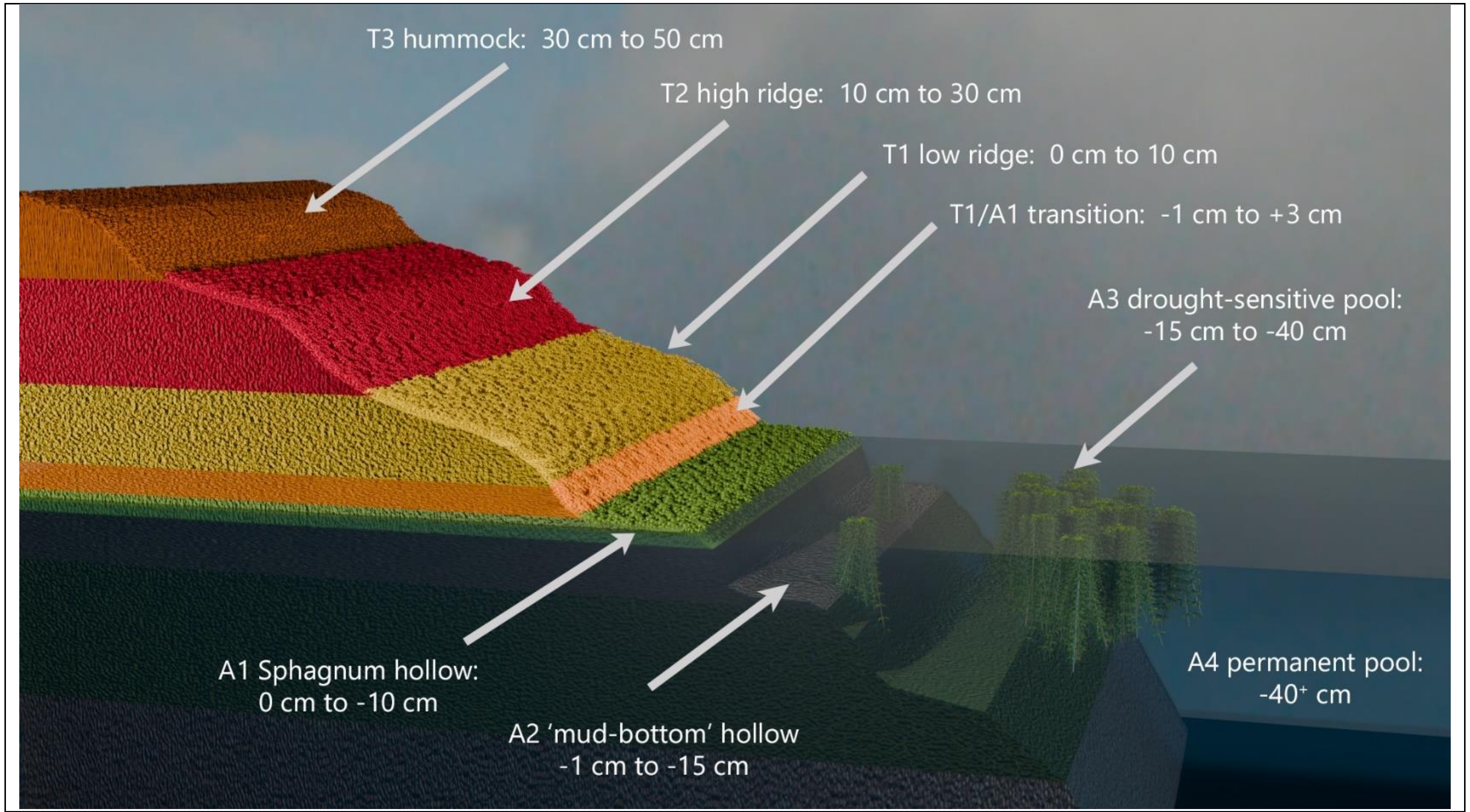

Figure A1.1 Spatial arrangement of hydrological elements in a highly patterned bog system. Positive height values relate to height above the zone of high moisture content, as measured using a moisture meter. Negative values refer to depth below water surface.

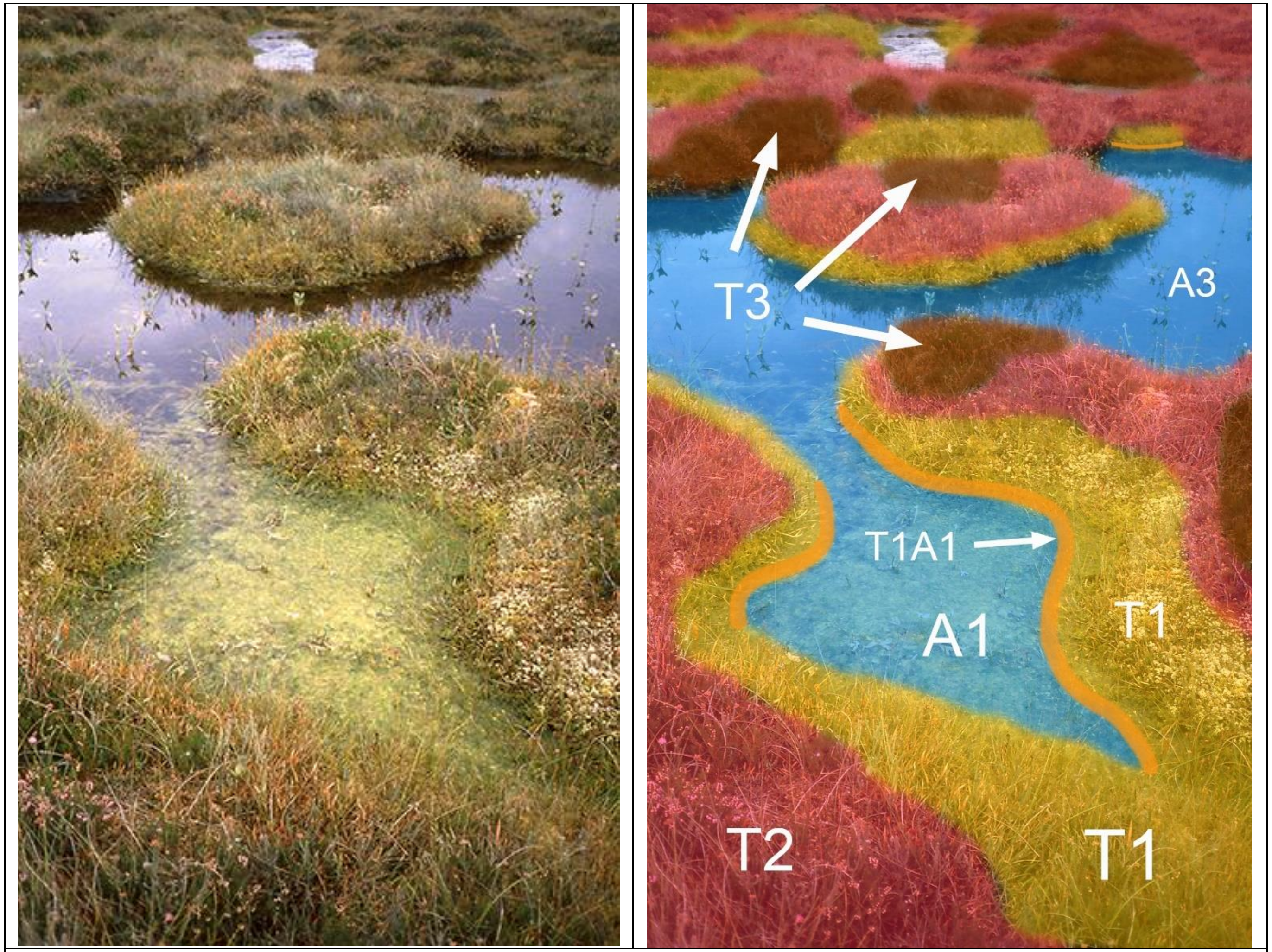

Figure A1.2. (Left)An example of several zones within a pool system in the Flow Country, northern Scotland. (Right) Zones highlighted by colour-coding and labelling

A1.7.2 T3 Hummock

A1.7.2.1 The driest zone within a natural microtopography, hummocks are typically characterised by species capable of enduring dry conditions (such as various dwarf shrubs), of drawing up water from the high-moisture zone (such as tightly-packed *Sphagnum fuscum* or *Sphagnum capillifolium*), or species intolerant of waterlogging (such as *Calluna vulgaris*).

A1.7.2.2 T3 hummock is the zone within which dwarf shrubs other than *Erica tetralix* are likely to be most abundant, as well as non-*Sphagnum* mosses. *Drosera rotundifolia* is the only sundew regularly found in this zone so can often be used as an ecological indicator. The most typical *Sphagnum* species now is *Sphagnum capillifolium*, though *Sphagnum papillosum* may sometimes form large hummocks, while it is still possible to find examples of the (now) rarer *Sphagnum austinii* and *Sphagnum fuscum*.

A1.7.2.3 Bogs dominated by the T3 hummock zone are unlikely to be entirely healthy so it is useful to look for evidence of harm, though climate change may ultimately cause a general shift towards the T3 hummock zone as part of the self-regulating dynamic of peat bog systems.

A1.7.2.4 It is important not to confuse T3 Hummocks with Tk tussocks. The former are created by mosses and are soft and yielding whereas tussocks are created by vascular plants and are hard unyielding structures. Furthermore, it is also possible to assume incorrectly that large dense clumps of *Calluna vulgaris* are hummocks but investigation may reveal that the apparent mounded shape is nothing more than the foliage of *Calluna*.

Figure A1.3. T3 hummock assemblages of two rarer hummock-forming *Sphagnum* species. (Left) *Sphagnum austinii* with *Cladonia* and *Drosera rotundifolia*. (Right) *Sphagnum fuscum* with *Calluna vulgaris* and *Drosera rotundifolia*.

A1.7.3 T2 High ridge

A1.7.3.1 This is often the default zone for many UK bogs that are not dominated by tussocks and micro-erosion or more extensive gully erosion, largely because the long history of land use has rendered them drier than might otherwise be the case.

A1.7.3.2 Under more natural conditions such sites could be expected to have equal dominance of T2 high ridge and T1 low ridge as well as frequent A1 hollows if not actual pools, but in many cases the hollows/pools are now empty areas of bare peat while the T1 low ridge zone has become much reduced in extent.

A1.7.3.3 *Sphagnum capillifolium* may form extensive swards here, as will *Sphagnum papillosum* and sometimes *Sphagnum medium* (formerly *S. magellanicum*). The overall species assemblage consists of species more typical of the bog (rather than heathland) environment so cotton grasses, *Erica tetralix* and *Narthecium ossifragum* become more common.

Figure A1.4. (Left) T2 high ridge assemblage with *Sphagnum capillifolium*, *Sphagnum medium*, *Sphagnum papillosum*, *Narthecium ossifragum and Eriophorum angustifolium*, with *Calluna vulgaris*-dominated T3 in the background. (Right) *Andromeda polifolia* within a T2 carpet of *Sphagnum papillosum*.

A1.7.4 T1 Low ridge

A1.7.4.1 Displaying the most 'bog-like' of all the zones, T1 low ridge supports the majority of species that are considered to be most characteristic of the bog environment. The greatest variety of *Sphagnum* species and vascular plants can be found here, although the most characteristic species are *Sphagnum papillosum* and *Erica tetralix*.

A1.7.4.2 On a natural bog this zone experiences the greatest fluctuation in water table because it receives water from both T3 and T2 zones, but then sheds it into the various aquatic zones. There is thus a mild flushing effect from extra nutrients coupled with markedly fluctuating oxygen levels as the water table rises and falls.

A1.7.4.3 On truly natural bogs, the T1 low ridge zone is extensive and renders the bog surface extremely soft though still capable of being walked on

Figure A1.5. A mix of *Sphagnum* species in the T1 low ridge zone, including *Sphagnum papillosum*, *Sphagnum medium*, *Sphagnum tenellum*, *Sphagnum pulchrum* and *Sphagnum cuspidatum*, together with *Narthecium ossifragum* leaves and a small *Drosera rotundifolia*.

A1.7.5 T1A1 transition

A1.7.5.1 This is an extremely narrow but distinctive zone where the terrestrial zone meets the aquatic zone. It is most characteristically occupied by either *Sphagnum tenellum* or *Sphagnum pulchrum*, though *Sphagnum cuspidatum* is also often present and other T1 *Sphagnum* species may extend into this zone.

A1.7.5.2 The zone is often rich in *Drosera anglica, Narthecium ossifragum* and *Rhynchospora alba*.

A1.7.5.3 It is also a zone that often begins to re-develop as a secondary community in the lowest parts of the microtopography when damaged bog is undergoing spontaneous recovery or recovery begins as a result of restoration intervention. *Sphagnum tenellum* mats will often develop over wet bare peat in this way.

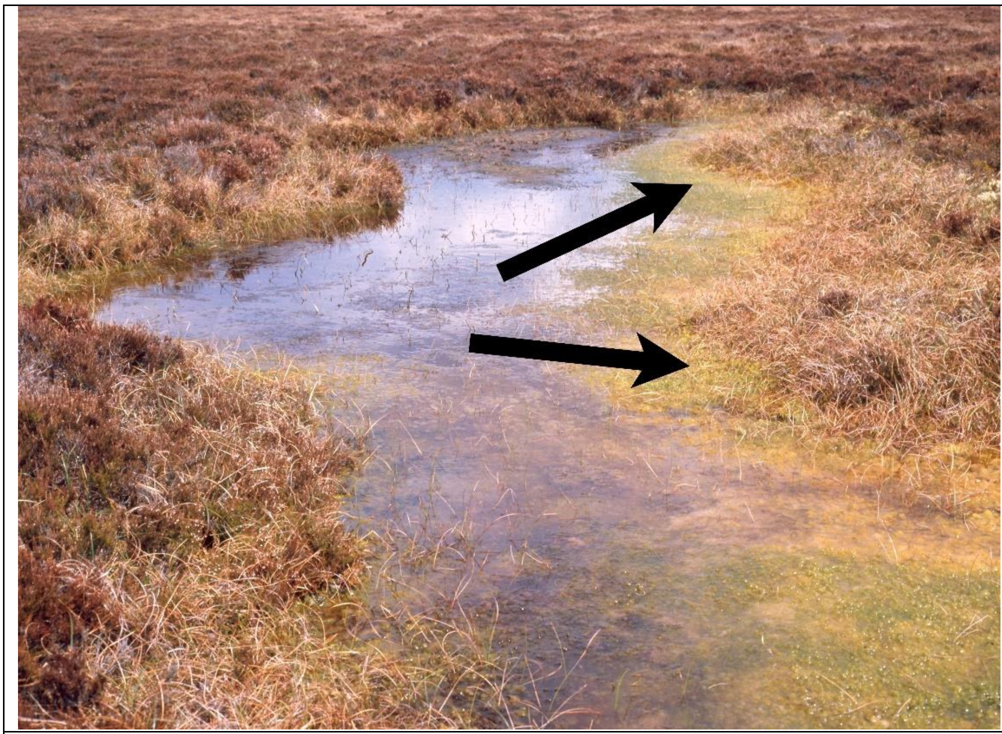

Figure A1.6. Distinctive yellow band indicating the T1A1 zone around the margin of a bog pool.

A1.7.6 A1 *Sphagnum* hollow

A1.7.6.1 The *Sphagnum* carpet of an A1 *Sphagnum* hollow may appear to be an invitingly smooth green surface to walk on, but it is the first aquatic zone and the *Sphagnum* carpet is merely in effect floating in the bog water table. It is therefore not safe to walk on.

A1.7.6.2 A1 *Sphagnum* hollows are typically dominated by a single species of *Sphagnum* - either *Sphagnum cuspidatum* or, in the case of secondary regeneration in, for example, old peat cuttings, then *Sphagnum fallax*. Vascular plants such as *Drosera anglica*, *Eriophorum angustifolium*, *Rhynchospora alba*, *Menyanthes trifoliata* or *Eleocharis multicaulis* may be scattered sparsely across the *Sphagnum* carpet but rarely at any density.

A1.7.6.3 The densely-packed but floating mass of *Sphagnum* provides a large number of niches for certain groups of aquatic invertebrates, in particular water beetles. These invertebrates are an important source of food for breeding waders.

A1.7.6.4 *Sphagnum* hollows rarely exceed a few metres in their long axis and are thus often not immediately obvious on Google Maps, but if zoomed in far enough they will appear as pale patches within the darker tone of the bog vegetation. In the case of regenerating peat cuttings, if cutting was carried out on an industrial scale then such areas may be very extensive.

Figure A1.7. A1 *Sphagnum* hollow

A1.7.7 A2 mud-bottom hollow

A1.7.7.1 This zone is something of a misnomer because there is no mud on a peat bog, but the term was coined in Sweden and has become part of the established terminology. It refers to shallow hollows that either have a bare-peat base or, in the west of the UK, have a base of *Molinia caerulea* leaves that have blown in during the autumn.

A1.7.7.2 These shallow hollows provide habitat for species such as *Drosera intermedia*, *Rhynchospora alba* and *Rhynchospora fusca*, as well as a variety of aquatic invertebrates. *Utricularia* species may also be found here, but *Sphagnum* is rather sparse, consisting of small pockets of *Sphagnum auriculatum* and scattered *Sphagnum cuspidatum*.

A1.7.7.3 On aerial imagery these hollows will appear as black features with some light patches where there is vegetation. It is difficult on aerial imagery to distinguish between healthy mud-bottom hollows and empty bare-peat former bog pools resulting from various forms of damage. However, features that are healthy A2 hollows will have their long axis oriented parallel with the slope contours and will show <u>no signs of linking up</u> with adjacent features downslope.

Figure A1.8. A2 mud-bottom hollow with *Rhynchospora fusca*

A1.7.8 A3 Drought-sensitive pools

A1.7.8.1 Drought-sensitive bog pools have a significant depth of water - sufficient for waterfowl to swim, for example – but the bottom of the pool remains visible. In severe drought, these pools may become dry, though beneath a thin crust the base will still be extremely soft and saturated.

A1.7.8.2 A3 drought-sensitive pools support a limited range of plant species – mainly *Menyanthes trifoliata* and *Eriophorum angustifolium*, with occasional floating masses of *Sphagnum cuspidatum* and loose assemblages of *Sphagnum auriculatum*.

A1.7.8.3 Being shallow and with a dark base and sides, these pools warm up rapidly in sunny weather and are thus favoured by larger aquatic invertebrates such as the larger water beetles and nymphs of large dragonflies and damselflies. They are also used by smaller waterfowl such as teal.

A1.7.8.4 Again, these features appear black in aerial imagery and cannot easily be distinguished from empty bare-peat 'pans' characteristic of some degraded pool systems. However, they can again be distinguished from actively eroding systems by the absence of evidence for interconnections between such features, especially interconnections evidently leading downslope.

Figure A1.9. A3 drought-sensitive pools. (Left) A pattern of A3 pools. (Right) *Sphagnum cuspidatum* floating above the pool bottom.

A1.7.9 A4 permanent pools

A1.7.9.1 These pools are sufficiently deep to appear 'bottomless' and may be as much as 3-4 metres deep. They typically occupy the crown of a bog unit and are relatively un-oriented or have only a limited distinction between their long axis and short axis.

A1.7.9.2 Such pools are mostly devoid of vegetation though may have floating columns of *Sphagnum cuspidatum* or patches of *Menyanthes trifoliata*. Their main source of biodiversity comes from their aquatic invertebrate assemblages and the use of the pools by waterfowl such a Greenland white-fronted geese, either for roosting or feeding.

A1.7.9.3 Permanent pools may be large enough for wave action or sky reflections to show up on aerial imagery, which then indicates that the pools are water-filled and not large bare-peat expanses within erosion complexes. In the absence of such signs, lack of downslope connections between these large black features would suggest that the system may be intact.

Figure A1.10. A4 permanent pools

A1.8 structural elements

A1.8.1 Peat mounds

A1.8.1.1 These are natural features although their origin is still rather a puzzle. They resemble large mounds known as ‘palsas’ in Fennoscandia but palsas rely on a permafrost ice-core for their formation whereas ‘peat mounds’ contain no ice. Peat mounds are distinguished by being markedly taller than typical hummock heights, and range from more than 1 m up to 3 or 4 metres tall.

1.8.1.2 The most favoured theory for their formation is that peat mounds form as a result of regular use by seabirds – in particular gulls and skuas –bringing their food to a high point, thereby fertilizing the peat of this high point and encouraging further growth.

1.8.1.3 It is certainly true that the national distribution of peat mounds to some extent corresponds with that of the national skua population. The most extreme mounds are found in Shetland, particularly around Ronas Hill, although they are also found in the Outer Hebrides and, as smaller less frequent examples, throughout Caithness and Sutherland. Use by larger gulls may explain the distribution beyond that of the skua population.

GOODE AND LINDSAY

PLATE 4.—Large circular pools on a level expanse of watershed mire. Pools are up to 1 m deep, with steep edges. Ridges have pronounced hummocks of *Rhacomitrium lanuginosum*. Large peat mounds can be seen on the horizon. Blar-nam-Faoileag.

Figure A1.11. Distant view of large **peat mounds** in the Outer Hebrides, from Goode & Lindsay 1979
Available from: https://repository.uel.ac.uk/item/86qw6

A1.8.2 Tk Tussocks

A1.8.2.1 Tussocks are formed by a few species (*Eriophorum vaginatum*, *Trichophorum cespitosum*, *Molinia caerulea* and *Deschampsia flexuosa*) when they are no longer competing with a vigorous *Sphagnum* carpet – because the *Sphagnum* has been lost through drainage, burning, stock trampling or pollution.

A1.8.2.2 Tussocks are now one of the commonest structural features of bog systems but with full zoom in Google Maps it is still not possible to see the presence of tussocks, even large tussocks, so they must be identified in the field.

A1.8.2.3 Tussocks vary in size from thigh-high *Molinia caerulea* tussocks some 30 cm in diameter to small *Trichophorum cespitosum* tussocks a mere 5 cm high and diameter. Whatever their size, they are nevertheless solid features which can be felt underfoot.

A1.8.2.4 As vegetation recovers and moss species begin to re-establish a ground cover, and particularly as *Sphagnum* is re-established, the tussock becomes overgrown and increasingly less solid until eventually it no longer registers as a tussock underfoot.

A1.8.2.5 Tussocks are almost invariably set within an EM micro-erosion network, though this network may be in various stages of revegetation which can eventually reach the point where the original presence of the micro-erosion network is no longer evident.

Figure A1.12. (Top left) Recently burnt **Tk tussock** of *Eriophorum vaginatum*. (Bottom left) Older *Eriophorum vaginatum* **Tk tussocks** becoming overtopped by vegetation. (Right) **Tk tussock** of *Trichophorum cespitosum* in **EM micro-erosion bare**.

Figure A1.13. (Top) *Eriophorum vaginatum* **Tk tussocks** after burning. (Bottom) *Trichophorum cespitosum* **Tk tussock** within an **E2 regenerating erosion gully**.

A1.8.3 Em micro-erosion bare

A1.8.3.1 Micro-erosion is an almost universal accompaniment to tussock formation, where loss of *Sphagnum* between the tussock-forming plants results in an inter-connected network of bare-peat channels running between the tussocks. While it actually represents a drainage network, in appearance it may seem to represent the basal plain of the peat surface upon which the tussocks are distributed.

A1.8.3.2 As such, this micro-erosion network is typically no deeper than the height of the accompanying tussocks and is therefore not generally visible using aerial imagery. If the drainage network channels become wide enough it may be possible to see an anastomosing network of channels when viewed at extreme zoom in Google Maps, but generally this is not the case. If channels become wide enough to be seen clearly using aerial imagery, this usually represents E1 or E2 erosion gullies rather than Em micro-erosion.

A1.8.3.3 In general, Em micro-erosion has no clear direction of flow within the network pattern. Although there will be a direction of flow it will not be visible unless observed during rainfall or unless the micro-erosion network lies on a distinct slope.

Figure A1.14. Initiation of **Em micro-erosion bare** following burning (detail), consisting of the bare peat surface between the many burnt *Eriophorum vaginatum* tussocks.

Figure A1.15. Initiation of **Em micro-erosion bare** following burning (general view), consisting of the bare peat surface between the many burnt *Eriophorum vaginatum* tussocks.

Figure A1.16. EM micro-erosion bare between tussocks of *Trichophorum cespitosum* (tawny colour) and *Eriophorum vaginatum* (pale green.

Figure A1.17. EM micro-erosion bare between a mixed sward of *Eriophorum vaginatum* tussocks and *Eriophorum angustifolium* growing on the wet bare peat.

Figure A1.18. EM micro-erosion bare in a more intense form but still not yet forming erosion gullies and still only sometimes visible on Google Maps, though probably readily detectable using detailed aerial photography or drone imagery.

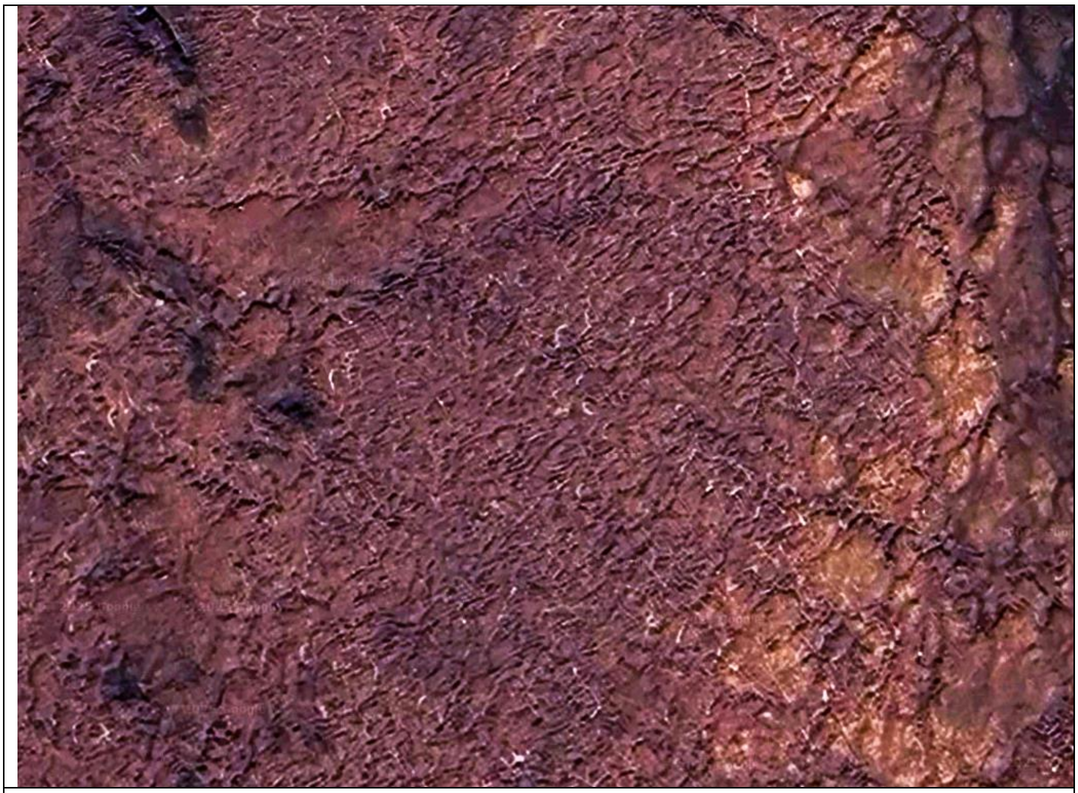

Figure A1.19. Aerial view near Gairloch, west-coast Scotland, from Google Maps) of **EM micro-erosion bare** of the type shown in Figure A1.18. Note the somewhat un-oriented nature of the pattern in the centre of the image.

Figure A1.20. EM micro-erosion bare between tussocks after exceptionally heavy rain, highlighting the interconnected drainage system of the micro-erosion network.

A1.8.4 Em micro-erosion - moss

A1.8.4.1 Unless Em micro-erosion bare intensifies to become active erosion gullies, in time there is a tendency for the bare peat micro-erosion network to become colonised by non-*Sphagnum* mosses. Initial colonisers are often very small acrocarpous mosses (*i.e.* single-stem, largely unbranched mosses with upright growth-form) such as *Pohlia nutans*, *Campylopus pyriformis* or *Campylopus flexuosus*. If the peat is relatively dry, colonisation by prostrate mat-forming (pleurocarpous) mosses such as *Hypnum jutlandicum* may occur in the absence of further burning. Indeed *Hypnum jutlandicum* can become so vigorous that it begins to overwhelm shorter tussocks, creating a series of moss hummocks with dense tussock cores.

A1.8.4.2 Development of a moss cover over the bare peat of the micro-erosion network helps to retain moisture within the peat and raise humidity levels in the micro-environment between the tussocks. Such conditions can then enable *Sphagnum* to become re-established, leading to the next phase of recovery.

Figure A1.21. Tk tussocks with Em micro-erosion moss – small green acrocarpous mosses

Figure A1.22. Tk tussocks with Em micro-erosion moss –
Hypnum jutlandicum - pleurocarpous mat-forming moss

Figure A1.23. Tk tussocks with Em micro-erosion moss – late stage of development
Hypnum jutlandicum and *Pleurozium schreberi* forming thick mat between old tussocks.

A1.8.5 Em micro-erosion - *Sphagnum*

A1.8.5.1 When conditions between the tussock of micro-erosion are sufficiently damp, either as a result of initial colonisation by non-*Sphagnum* mosses or simply because of the shade provided by overhanging leaves of the tussock-forming species, *Sphagnum* can become established within the micro-erosion network.

A1.8.5.2 Typically the first *Sphagnum* coloniser is *Sphagnum fallax*, but *Sphagnum tenellum* (in the case of wet bare peat) and *Sphagnum capillifolium* (where the peat is drier) may also act as colonisers of the micro-erosion network.

A1.8.5.3 As *Sphagnum* infills the micro-erosion network and begins to overwhelm tussocks, the increased degree of waterlogging created by the *Sphagnum* sward and the increased competition for light as the *Sphagnum* sward accumulates around and through the tussock, causes the tussock-forming species to abandon the dense tussock growth-form and develop a looser form of growth. Over time, therefore, the dense tussocks become increasingly soft underfoot and are eventually subsumed beneath fresh peat accumulation.

Figure A1.24. Tk tussocks with Em micro-erosion *Sphagnum*

A1.8.6 T4 erosion hagg top

A1.8.6.1 Where the natural peat land surface has been degraded and become riven with gullies (haggs) of larger or smaller scale, the ground immediately adjacent to these gullies adopts a distinctive character. In the UK, the nature of this character depends on where within the UK this phenomenon occurs, but in all cases the vegetation is associated with a **face of bare peat**, ranging from vertical to gently-sloping, immediately beneath vegetated hagg-top.

A1.8.6.2 In the far north and west of the UK, hagg tops are characterised by large 'pillows' of *Racomitrium lanuginosum* together with *Cladonia* lichens and dwarf shrubs of dry conditions such as *Erica cinerea*, *Calluna vulgaris* and *Vaccinium vitis-idaea.*

A1.8.6.3 In the Pennines and the Southern Uplands of Scotland, as well as in central parts of Wales, hagg tops are characterised more by dense *Calluna vulgaris*, *Empetrum nigrum*, *Vaccinium myrtillus*, *Hypnum jutlandicum* and *Cladonia* lichens, though *Racomitrium lanuginosum* can also occur.

A1.8.6.4 In the South West of England and Wales, hagg tops tend to be dominated by *Molinia caerulea*, although Pennine-type assemblages also occur.

A1.8.6.5 Where erosion systems are re-wetting and active bog is regenerating, 'legacy' hagg tops can generally be observed, contrasting markedly with the active bog vegetation and highlighting the fact that active erosion was once present at this location.

Figure A1.25. T4 erosion hagg tops (arrowed)

Figure A1.26. T4 erosion hagg tops (arrowed)

Figure A1.27. 'Legacy' T4 erosion hagg top with E1 regenerating bog vegetation at its base.

A1.8.7 E2 active erosion gully

A1.8.7.1 Erosion gullies are generally characterised by the presence of bare-peat walls lining a channel that cuts into the underlying peat body. Such gullies may have a distinct slope, in which case the channels all tend to point downslope, but if the erosion has occurred across a broad plateau then the patterns tends to be that of a maze without evident orientation until the edge of the plateau is reached, at which point the channels become oriented downslope.

A1.8.7.2 A key feature of this type of ground is that there are few barriers to water flow. Either the plateau network permits water to interconnect and flow unimpeded through the maze, or the gullies formed on slopes provide a route for rapid water flow downslope. This is the fundamental distinction between a natural bog system, in which structures are oriented in such a way as to inhibit water movement, and a damaged system where water flow is largely un-impeded.

A1.8.7.2 Once erosion becomes visible in Google Maps imagery, seen as black or dark grey features in either a linear, if ragged, form cutting downslope, or alternatively as a maze of black channels without evident direction, the system has developed E2 active erosion gullies.

A1.8.7.2 Although there is a continuum from micro-erosion to full erosion gully, in general micro-erosion will be no deeper than shin deep. Once gullying becomes deeper than this it can be regarded as E2 active erosion gully. However, where large expanses of bare peat have become exposed, leaving just scattered tussocks or perhaps patches of vegetated ground less than shin-height above the bare peat expanses, these areas can also be classed as E2 active erosion gully.

Figure A1.28. E2 active erosion gully (arrowed)

Figure A1.29. E2 active erosion gully – Barvas Moor, Outer Hebrides.

Figure A1.30. E2 active erosion gully as wide 'flats' on Carn nan tri tighearnan,

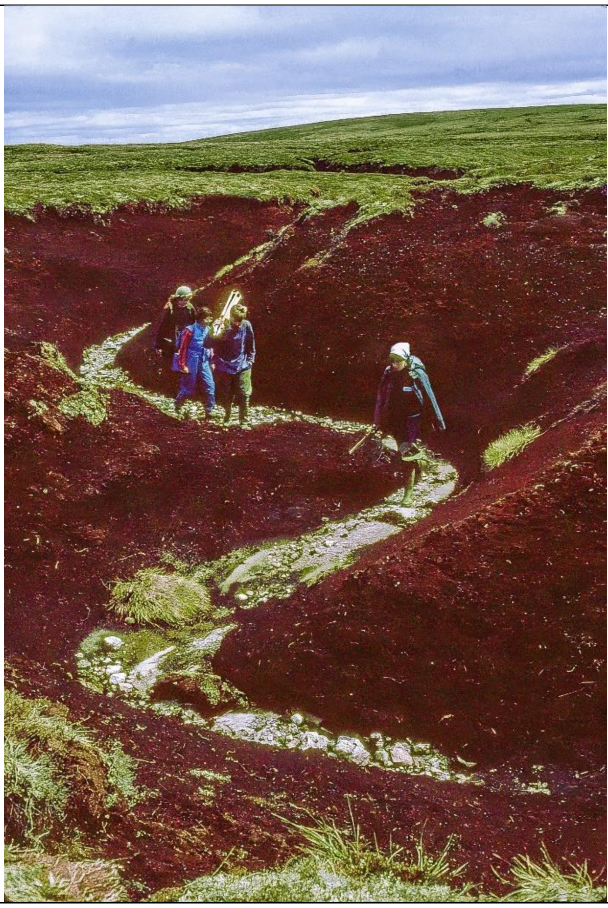

Figure A1.31. Deep E2 active erosion gully exposing underlying glacial till, Pennines.

Figure A1.32. Aerial imagery of E2 active erosion gullies (Google Maps)

A1.8.8 E1 regenerating erosion gully

A1.8.8.1 It is not unusual to find that the floor of an erosion gully has become littered with blocks of peat which have fallen from the gully sides and which then pond and impede water flow. In time, this can lead to a secondary vegetation forming along the gully floor. Active restoration intervention can also simulate this process, speeding up development of a secondary active, peat-forming vegetation within the gully.

A1.8.8.2 Colonisation of the gully floor by species such as *Eriophorum angustifolium*, *Juncus squarrosus*, *Juncus effusus* and *Polytrichum commune* can also create significant surface 'roughness' and slow water flow as well as providing anchor points for *Sphagnum* species to become established.

A1.8.8.3 The commonest *Sphagnum* coloniser of revegetating gullies is *Sphagnum fallax*, though *Sphagnum medium* and *Sphagnum capillifolium* are also capable of growing down the walls of erosion gullies to begin coating the gully floor with a carpet of *Sphagnum*. Once this has happened, *Sphagnum papillosum* and *Sphagnum tenellum* may also begin expanding the carpet.

A1.8.8.4 On the other hand, if *Sphagnum fallax* becomes the dominant coloniser, although its rapid growth can rapidly begin to infill the gully, it seems that it becomes much harder for other *Sphagnum* species to become established within the *Sphagnum fallax* carpet. Eventually, however, colonisation of other species will doubtless occur from the increasingly wet margins of the gully tops, and in most cases there are already patches of these other species where they have perhaps fallen into the gully as part of a collapse feature.

A1.8.8.5 The floors of regenerating gullies generally show up as cream or very pale green on Google Maps aerial imagery. This same tone, though usually slightly pink-white, can indicate exposed glacial till where the peat has been entirely lost from the gully floor, so care must be taken when interpreting aerial imagery. If the gully is wide and filled with vegetation, this will normally appear as pale-bright green, though if the vegetation is dominated by *Juncus effusus* or *Eriophorum angustifolium* it will instead have a tawny tint.

Figure A1.33. E1 revegetating erosion gully, with extensive swards of *Eriophorum angustifolium* (chestnut colour) and patches of *Sphagnum* (pale yellow). Barvas Moor, Outer Hebrides.

Figure A1.34. Deep E1 revegetating erosion gully, still with some underlying glacial till exposed. Fallen blocks of peat assist with the process of revegetation.

Figure A1.35. Extensive revegetation consisting mainly of *Sphagnum* in an E1 revegetating erosion gully.

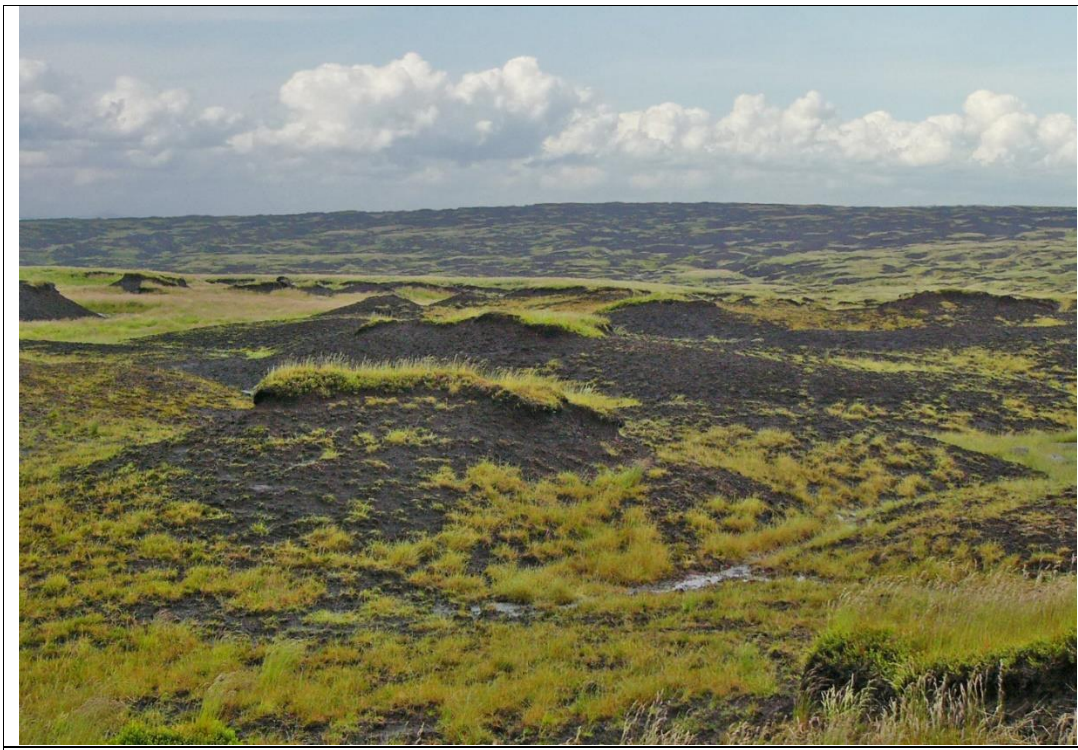

Figure A1.36. Deep, extensive erosion in the Peak District of northern England, but even before restoration intervention there was some E1 revegetation of these wide gully expanses.

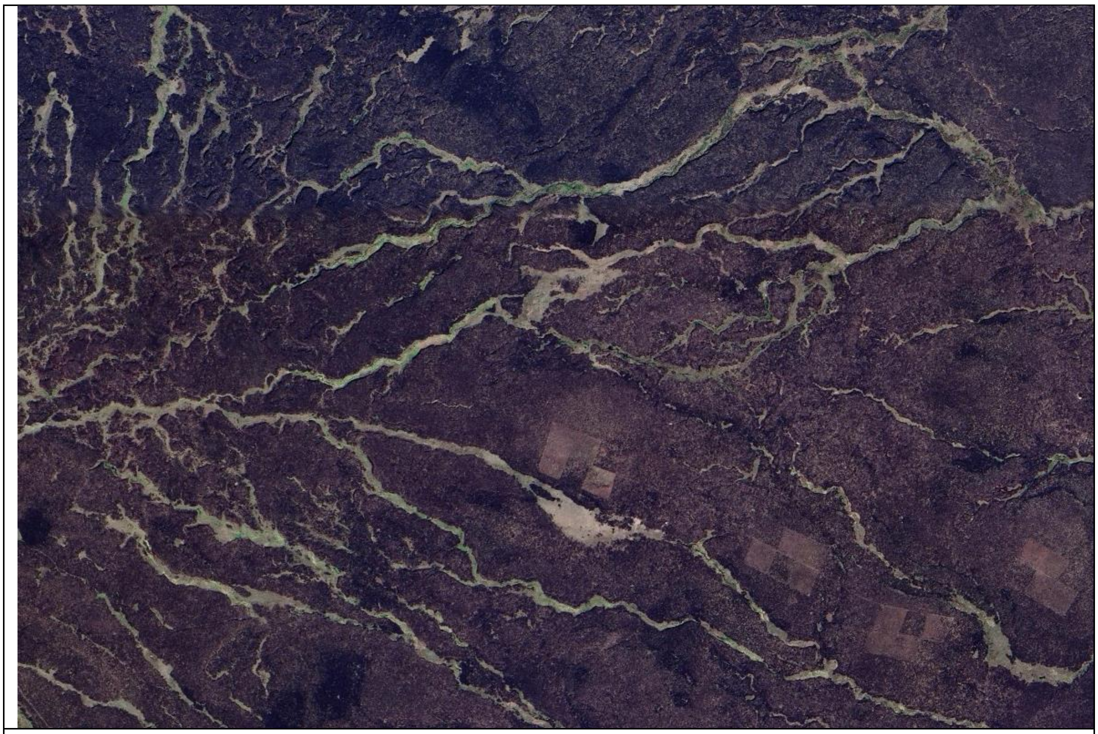

Figure A1.37. Pale-shaded E1 revegetating erosion gullies on Hard Hill, Moor House National Nature Reserve, north Pennines.

ANNEX 2. Identification of species used in the condition matrix

A2.1 The condition matrix is mainly focused on identifying indicators of poor quality rather than assessing the relative qualities of good-condition bogs (for the latter objective it is more appropriate to employ synusial quadrats). As such, the matrix requires identification of only relatively few key species or species groups, some of which are exclusive to poor-condition sectors of the matrix while others occur across the range of conditions.

A2.2 In terms of species that are exclusive to the good-condition sector, the matrix allows for the recording of various *Sphagnum* species as well as a few other valuable indicator species. If the surveyor is confident in their *Sphagnum* identification they can note the presence of, for example, *Sphagnum austinii*, but for surveyors who are not confident in their *Sphagnum* identification there are also options within the good-condition sector simply to note the presence of *Sphagnum*. This will be sufficient.

A2.3 A very small number of *Sphagnum* species feature within the poorer sectors of the matrix, either because their presence in a particular zonal element is 'out of place' or because they are mostly associated with areas of damage. It is helpful though not essential to be able to distinguish these species.

A2.4 The following seeks to provide as much information as possible about the various species or species groups that are featured within the matrix. The matrix generally uses scientific names so it is helpful to become familiar with such usage.

A2.5 Species and species groups are arranged in alphabetical order.

A2.6 *Andromeda polifolia* – bog rosemary (‘dwarf shrub’)
Absent from SW England and extending no further north than the Forth Valley in Scotland, this dwarf shrub can grow to knee height but is often much shorter. It is entirely restricted to the bog environment though can grow on dry damaged bogs.

Its long narrow grey-green leaves are inrolled along their margins, hiding a silvery-white underside to the leaf. The pale pink flowers and the delicate nature of the plant led Linnaeus to name it after the original beauty in the mythical story of beauty and the beast because he saw a lizard squatting on the moss carpet next to the plant

Figure A2.1. *Andromeda polifolia* – bog rosemary

A2.7 *Arctostaphylos uva-urs*i – bearberry ('dwarf shrub')
A low-growing, often creeping, dwarf shrub of high-altitude or far-northern bogs. Its most distinctive feature is the reticulate network of veins on the underside of the small stiff leaf.

Figure A2.2. *Arctostaphylos uva-ursi* - bearberry
Photo credit: Douglas Goldman

A2.8 Aulacomnium palustre

Often seen as pale yellow patches or individual small 'caterpillar-like' plants mixed within *Sphagnum* carpets, *Aulacomnium palustre* is a small acrocarpous moss (*i.e.* largely single-stemmed and with upright growth) some 2-3 cm long generally found on damper *Sphagnum*-rich areas. The leaves often have a somewhat crinkled look, which distinguishes it from most other pale acrocarpous mosses, but the truly distinctive feature is the thick brown woolly covering (tomentum) of the stem beneath the leaves – a feature that is evident to the unaided eye.

Almost the only time when *Aulacomnium palustre* forms a distinctive region of its own within a bog microtopography is where bog pools are used by waterfowl. The nutrient load generated by such usage sometimes creates a ring of *Aulacomnium palustre* around the pool edge in the T1A1 transition zone. It can thus be a useful indication that particular pools are used extensively by waterfowl.

Figure A2.3. *Aulacomnium palustre*
Photo credit: **James Lindsey at Ecology of Commanster**

A2.9 *Calluna vulgaris* – heather

Calluna vulgaris is a dwarf shrub most characteristic of dry heath environments – the common name being derived from this fact. It is the only member of the genus *Calluna* within the broader family of the *Ericaceae* – the 'Heaths'. As such, it has a distinct leaf arrangement unique to *Calluna* whereby the leaves are small overlapping scale-like structures resembling the overlapping scales of a reptile.

The flowers are small, bright pink and are distributed densely along the length of the uppermost branches. This characteristic distinguishes the plant from *Erica tetralix*, a true bog plant capable of tolerating waterlogged roots, which has pale pink flowers bunched only at the very tip of its largely unbranched stems.

Figure A2.4. (Top) *Calluna vulgaris* (heather) showing the arrangement of flowers and (Bottom) the overlapping scale-like leaves.

A2.10 *Campylopus atrovirens*

A moss of far western bogs, it forms dark green, almost black, cushions on wet peat surfaces. The tightly-packed, upright nature of the stems forming these cushions results in the cushions looking and feeling like dark bottle-green velvet. It typically occurs close to the water table so is most characteristic of the T1 low ridge zone or the T1/A1 transition zone.

This moss should not be confused with the closely related (though invasive) *Campylopus introflexus*, which looks similar when wet but each leaf of the latter species has a white hair extending from the leaf tip. When *Campylopus introflexus* is dry – which it often is because it is characteristic of damaged, dry bare peat – the leaf-hairs cross at the centre of the moss tip to form a white star shape.

See: https://www.britishbryologicalsociety.org.uk/wp-content/uploads/2020/12/Campylopus-atrovirens.pdf

Also: https://www.britishbryologicalsociety.org.uk/wp-content/uploads/2020/12/Campylopus-introflexus.pdf

A2.11 *Campylopus* -type mosses

This is a group of relatively tall acrocarpous mosses (*i.e.* largely single-stemmed mosses with upright growth-form) that resemble *Campylopus flexuosus* and are thus somewhere between half and the full height of a little finger. This includes a number of *Campylopus* species, along with several *Dicranum* species, and others that have a similar appearance. The important point is that these are not prostrate mat-forming species, especially as the latter tend to be found in rather drier conditions than is generally the case for these acrocarpous species. The example given here is *Campylopus flexuosus*.

Figure A2.5. *Campylopus flexuosus*

A2.12 *Carex limosa* – mud sedge

Although generally a species of poor fens, *Carex limosa* occurs in bog pools in the far west of Scotland – indeed its presence is an indicator of hyper-oceanic bog conditions. It is distinctive because of the upward curving growth-form of the leaves and the small nodding fruits which have a pale brown outer covering (glume). It is generally restricted to A2 mud-bottom hollows and A3 drought-sensitive pools.

Figure A2.6. (Top) Upward curving *Carex limosa* leaves in an A2 mud-bottom hollow - arrowed. (Bottom) Nodding female fruits of *Carex limosa* with male flowering spike to the far left.

A2.13 *Carex panicea* – carnation sedge

A sedge found only on damaged ground in a peat bog in the far north-west of the UK, the distinctive blue-green colour of the sparse leaf rosette usually stands out against the dark brown of the bare peat on which it is most often found. The blue-green colour of the leaves gives the plant its common name – carnation sedge – because it is the same colour as seen on the stems and leaves of carnation flowers. The fat pale fruits are also very distinctive.

The species grows best in poor fens, where the foliage becomes taller and more luxurious, as seen in the main example below, but in its typical habitat within damaged bog, it is more usual to find a simple sparse rosette of leaves often without a flowering spike.

Figure A2.7. (Left) *Carex panicea* blue-green foliage from a poor fen. (Top right) Typical sparse rosette on bare peat in damaged blanket bog. (Bottom right) Distinctive fat fruits of *Carex panicea* (Photo: Andrea Moro : Creative Commons Attribution-Share Alike 3.0 Unported)

A2.14 – *Cladonia* – lichen

The *Cladonia* genus of lichens is the commonest form of lichen found on bogs. There are several species which may be encountered although by far the commonest and most visible (because it forms large clumps) is *Cladonia portentosa* (formerly *C. impexa*). It forms a multi-branched mass grey-white without any clear orientation to the branching. A similar species is *Cladonia arbuscula*, which has a slightly more pale green tint and the ends of the branches all curl in one direction. Both are species of relatively dry conditions.

Various small single-stem cup-shaped, pointed or bulbous-ended Cladonias may also be encountered – all associated with very dry peat – but none form extensive mats or clumps.

Cladonia uncialis, on the other hand, resembles small, upright, pale grey-green single roe-deer antlers and is associated with wetter conditions, though only very rarely forms extensive clumps.

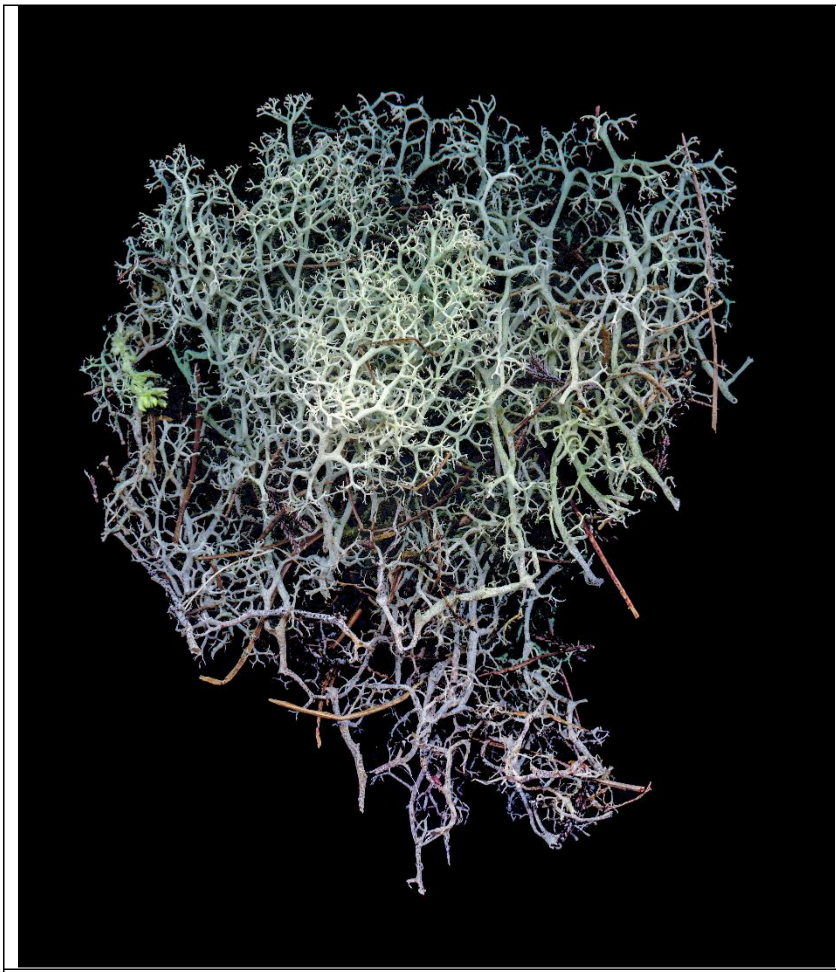

Figure A2.8. *Cladonia portentosa* (formerly *C. impexa*)

A2.15 *Deschampsia flexuosa* – wavy hair grass

One of the few true grasses found on bogs, *Deschampsia flexuosa* is nevertheless only found on damaged sites, particularly where there has been regular burning together with a degree of base-enrichment. Thus it occurs on damaged peatlands in limestone districts, or where base-rich water emerge onto otherwise base-poor blanket bog. In the absence of a vigorous *Sphagnum* carpet and in the presence of burning, *Deschampsia flexuosa* is a tussock-former.

The leaves of *Deschampsia flexuosa* are narrow and thread-like, resembling those of *Eriophorum vaginatum*, which can make the two difficult to distinguish when both species occur together, although the triangular cross-section of the *Eriophorum* leaves can help distinguish one tussock from another. The flowering head (panicle) of *Deschampsia flexuosa* has a distinctive open appearance with single pale florets at the end of each branch, and the central stem within the panicle has a characteristic 'wiggly' shape.

Figure A2.9. *Deschampsia flexuosa* – wavy hair grass

A2.16 *Drosera* – sundew

There are three species of *Drosera* in UK and Ireland – *Drosera rotundifolia*, *Drosera anglica* and *Drosera intermedia*. Each has its centre of distribution in a different microtopographic zone (see diagram).

Drosera is carnivorous, an adaptation developed in order to obtain sufficient nutrients in the nutrient-poor bog environment, trapping its invertebrate food on short tentacles which are tipped with a dew-like sticky sugar solution. The leaf blade is bright green whilst the tentacles and dew-drops are red. Once prey is trapped, the leaf curls round it and enzymes then digest the body contents. The leaf finally uncurls and allows the empty husk of the prey to blow away in the wind.

Darwin was fascinated by Drosera, eventually writing a book about this unusual group of plants.

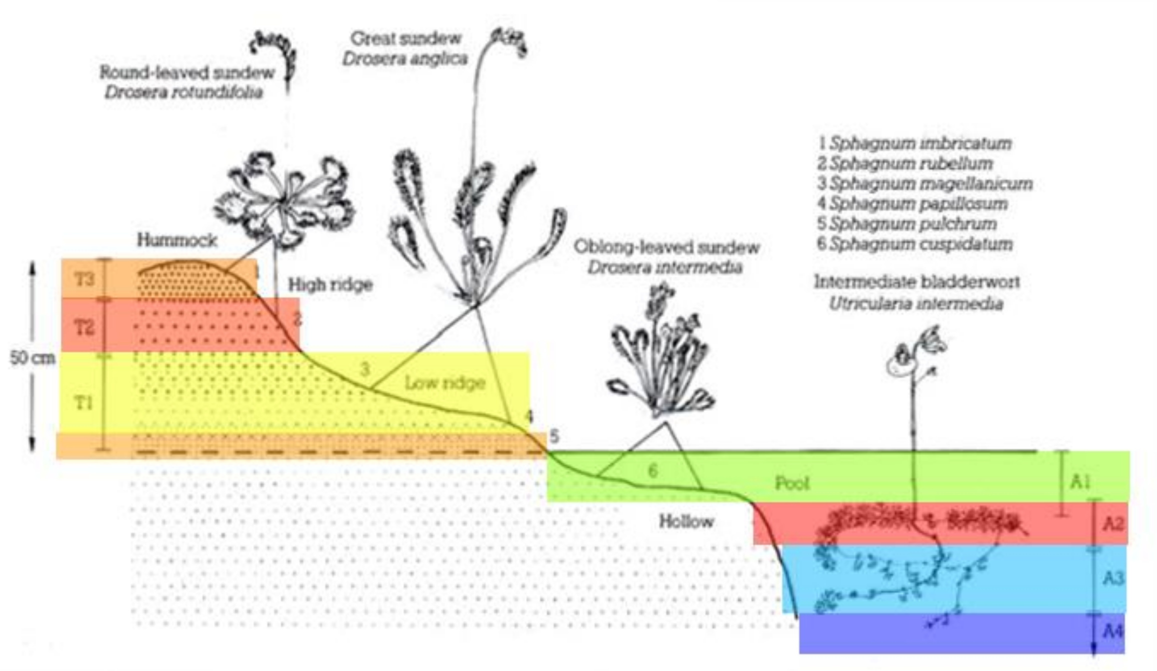

Figure A2.10. Typical distribution of *Drosera* species, and Utricularia, within the natural zonation of a bog.

A2.17 *Drosera anglica* – great sundew

The largest of the UK sundews, *Drosera anglica* has long flat leaves shaped rather like an ice-lolly stick, and can grow to the length of a finger. It is a plant of pool and hollow margins as well as damp *Sphagnum* carpets, so is characteristic of the T1A1 and T1 zones, though also grows on A1 *Sphagnum* hollows and can be found in A2 mud-bottom hollows and occasionally as high up the zonation as T2 high ridge.

Forming a ring around the margins of aquatic zones, the plant is ideally placed to trap emerging aquatic invertebrates and can capture even very large adult dragonflies as they emerge from the larval stage.

Entirely dependent upon the peat bog environment, although originally widespread across the UK, this species has undergone a dramatic decline in distribution as peat bog sites have been degraded, damaged or destroyed.

Figure A2.11. *Drosera anglica* – great sundew

A2.18 *Drosera intermedia* – oblong-leaved sundew
Drosera intermedia is a plant of wet or shallow-flooded bare peat. As such, it is not restricted to the bog environment. It can form extensive mats on wet heath and so is relatively widespread in the south of England, but in the strictly bog environment it relies on the presence of A2 mud-bottom hollows and so has its centre of distribution in far western and northern parts of Britain which is where such features are most common. Being semi-aquatic, *Drosera intermedia* can trap aquatic prey as well as aerial prey.

This species can be confused with young *Drosera anglica* plants but the latter has leaves that taper very gradually and never have the marked bulbous rounded tip of *Drosera intermedia*, while the flowering spike of *Drosera anglica* emerges from the centre of the leaf rosette whereas that of *Drosera intermedia* emerges from beneath the rosette in a distinct curl. *Drosera intermedia* also tends to have a greater density of sticky gland hairs, often resulting in a quite striking mass of cherry/blood red colour, whereas the larger leaf of *Drosera anglica* means that the red of the sticky glands is more balanced by the green of the leaf.

Drosera intermedia can be distinguished from *Drosera rotundifolia* because the round lobe of the *Drosera intermedia* leaf tapers into the leaf stem (petiole) whereas there is an abrupt angle between the round lobe and the petiole in *Drosera rotundifolia*. The two are also usually separated by habitat, with *Drosera rotundifolia* occupying drier parts of the microtopography while *Drosera intermedia* is restricted to wetter parts. However, this niche distinction becomes less clear on wet heath.

Figure A2.12. *Drosera intermedia* – oblong-leaved sundew (Left) Distinctive leaf shape tapering into leaf stem petiole. (Right) Characteristic sward of *Drosera intermedia* in A2 mud-bottom hollow.

A2.19 *Drosera rotundifolia* – round-leaved sundew
The most widespread species of sundew in the UK, *Drosera rotundifolia* can also be found on wet heath and wet nutrient-poor substrates such as gravel tailings. On bogs, its centre of distribution is T3 hummocks and T2 high ridge, though it can also be found on T1 low ridge and even occasionally on A1 *Sphagnum* hollows.

The species is distinguished by its rounded leaf which is attached at an abrupt angle to the leaf stem (petiole). Its leaf is quite small so cannot trap large aerial insects or even larger spiders or beetles, but it is capable of capturing ants, small flies, small spiders and mites.

Figure A2.13. *Drosera rotundifolia* – round-leaved sundew

A2.20 'Dwarf shrubs'

This term covers any and all woody shrubs that typically grow no taller than knee height on bogs, although some grow instead as low creeping mats while heather (*Calluna vulgaris*) may reach chest height on very dry ground. Presence of one or more such species counts as 'dwarf shrubs'. Seedlings of trees or bushes (e.g. birch, or Rhododendron) do not count.

In the UK, the list of typically relevant dwarf shrubs is quite short, comprising:

Bog rosemary	*Andromeda polifolia*	A2.6
Bearberry	*Arctostaphylos uva-ursi*	A2.7
Heather	*Calluna vulgaris*	A2.9
Bell heather	*Erica cinerea*	A2.23
Cross-leaved heath	*Erica tetralix*	A2.24
Bilberry	*Vaccinium myrtillus*	A2.44
Cranberry	*Vaccinium oxycoccos*	A2.45
Cowberry	*Vaccinium vitis-idaea*	A2.46
Bog bilberry	*Vaccinium uliginosum*	A2.47
Crowberry	*Empetrum nigrum*	A2.22

These species are individually described in the indicated sections.

A2.21 *Eleocharis multicaulis* – common spike rush

Not a member of the rush family (Juncaceae) despite its common name, but rather a member of the sedge family (Cyperaceae), *Eleocharis multicaulis* is restricted to the far north of the UK within the bog habitat although it can be found growing in fens elsewhere. On bogs it grows, often as dense mats, on *Sphagnum* carpets within the A1 *Sphagnum* hollow zone or sometimes on the A2 mud-bottom hollow zone. If these zones are absent, then so too with be *Eleocharis multicaulis*.

It has a few short rush-like leaves but the most visually evident feature is the flowering spike which is topped by a small brown flowering spikelet (strictly, a collection of tiny spikelets), which typically grows no taller than a hand-span.

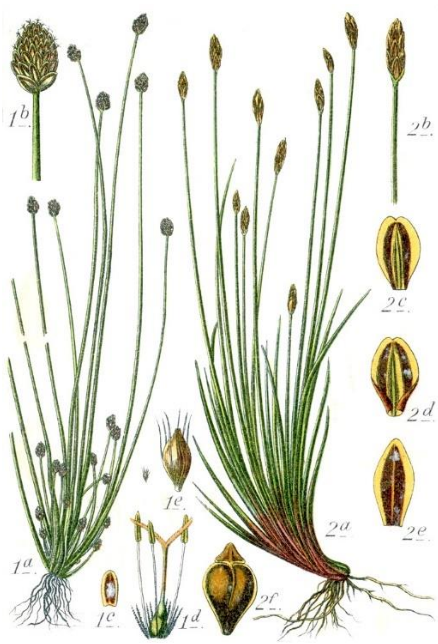	
Eleocharis multicaulis – common spike rush Figure from *Deutschlands Flora in Abbildungen* at http://www.biolib.de	A2 mud-bottom hollow with *Rhynchospora alba* (white-beaked sedge) in the centre and *Eleocharis multicaulis* to the right of the image.

Figure A2.14. *Eleocharis multicaulis* – common spike rush

A2.22 *Empetrum nigrum* – crowberry

This is a low-growing shrub, more commonly seen as a branching mat sprawling across the vegetated surface rather than as an upright plant. Its most distinctive features are the vivid green of its fat stubby leaves and, most distinctively, a white line running the underside length of each leaf.

Figure A2.15. *Empetrum nigrum* – crowberry : showing the white line on the underside of each leaf, and the berry, which is often black.

A2.23 *Erica cinerea* – bell heather

Erica cinerea is a species of very dry peat in areas where the climate is constantly damp – in other words it likes 'dry feet but wet hair'. It is distinguished from *Calluna vulgaris* by its needle-like leaves and clusters of flowers at the tip of the topmost stems. It is distinguished from *Erica tetralix* (cross-leaved heath) firstly by habitat (because the latter species is characteristic of wet ground) but also by the bunches of needle-like leaves in *Erica cinerea* whereas *Erica tetralix* has just four leaves arranged in a cross at each leaf node.

Figure A2.16. *Erica cinerea* – bell heather : note the bunches of needle-like leaves.

A2.24 *Erica tetralix* – cross leaved heath

The most characteristic dwarf shrub of good-condition bog, its glaucous (grey-blue-green) leaves and pale pink flowers positioned in small bunches at the top of the stems help to pick out areas of wet *Sphagnum*-rich bog. Its scientific and common name both refer to the fact that its leaves are arranged in groups of four, in a cross, at each node along the stem. The leaves are also distinctive in having a fringe of hair-like glands around the leaf margin. The plant typically does not grow much taller than shin-height.

Unlike *Calluna vulgaris* which is a heathland plant rather than a bog plant, *Erica tetralix* can tolerate waterlogged roots and so is a good indicator of both good-condition T1 low ridge zone and to a lesser extent the T2 high-ridge zone within the bog environment.

Figure A2.17. *Erica tetralix* – cross leaved heath

A2.25 *Eriophorum* – cotton grasses
The cotton grasses are neither related to cotton nor, are they grasses. *Eriophorum* species are part of the sedge family (Cyperaceae) and can thus be distinguished from grasses by the triangular flowering stems typical of the sedge family – best felt by rolling the flowering stem between the fingers.

The two *Eriophorum* species that occur on bogs in the UK are the common cotton grass (*Eriophorum angustifolium*) and hare's-tail cotton grass (*Eriophorum vaginatum*). The two look very different in many ways. *Eriophorum angustifolium* occurs as individual plants (though sometimes as an open sward) with no more than three or four leaves forming an open star shape. The leaves are V-shaped and around 4 mm in width, tapering gradually to a solid triangular tip. In contrast, *Eriophorum vaginatum* tends to grow as a mass of leaves, each of which is thread-like and solid, with a vaguely triangular cross-section. It also has just a single 'cotton' seed-head at the end of each flowering stem whereas *Eriophorum angustifolium* develops multiple 'cotton' seed-heads.

Eriophorum vaginatum is almost exclusively terrestrial in nature, whereas *Eriophorum angustifolium* tends towards wetter parts – its autumnal chestnut sward colour helping to pick out wetter (and thus often better) parts of the bog.

Figure A2.18. A mixed sward of *Eriophorum angustifolium* (broader leaves) and *Eriophorum vaginatum* (tufted hair-like leaves.

A2.26 *Eriophorum angustifolium* – common cotton grass

Eriophorum angustifolium has the widest ecological range of the cotton grasses, being found in fens and bogs and from T3 hummock-tops to A4 permanent pools. Its adaptability undoubtedly comes in part from its extremely long roots which have air-transport cells (aerenchyma) that can transport oxygen to roots deep in the peat. As a result, *Eriophorum angustifolium* tends to be more frequently found in wetter parts of a bog than is the case for *Eriophorum vaginatum*, and is a frequent early coloniser of the wet bare peat at the bottom of erosion gullies.

Eriophorum angustifolium has multiple flower heads which then become obvious when the cotton-like seed heads develop. It also has the typical narrow but V-shaped leaf of sedges (rather than the flat leaf of true grasses). The leaf is as long as those of *Eriophorum vaginatum* but because it is also wider for almost all its length (it ends in a solid triangular tip) the individual leaves are more individually visible even though any one plant produces only a few leaves. When young the leaf is a deep mid-green but as it ages the upper part becomes a deep chestnut colour.

Figure A2.19. *Eriophorum angustifolium* – common cotton grass

A2.27 – *Eriophorum vaginatum* : hare's-tail cotton grass
Probably the commonest of the three *Eriophorum* species found on British and Irish peatlands, yet the name 'common cotton grass' refers to another member of this group of plants (*Eriophorum angustifolium*). *Eriophorum vaginatum* is called hare's-tail cotton grass because it has only a single white bobble of 'cotton' fruit at the tip of its flowering stem, resembling a hare or rabbit's tail, whereas common cotton grass has multiple 'cotton' heads.

Not only are cotton grasses not a member of the cotton family, they are also not grasses. They are instead members of the sedge family (Cyperaceae), which gives their flowering stems a triangular shape in cross-section, easily felt when rolling the flowering stem between the fingers. This can also be felt with the leaves of *Eriophorum vaginatum* because they are solid, very narrow and thread-like.

On undamaged bogs *Eriophorum vaginatum* grows as loose collections of leaves emerging through the *Sphagnum* carpet, but if this *Sphagnum* is lost then (like *Molinia*) *Eriophorum vaginatum* will develop a tussock growth-form. If the bog is burnt, this tussock growth-form becomes even more pronounced and dense, creating hard tussocks which may range from small hard lumps underfoot to a mass of knee-high tussocks which, though solid and densely-spaced, are too wobbly to walk on.

Figure A2.20. *Eriophorum vaginatum* tussocks with regenerating *Sphagnum* infilling the Em micro-erosion between. Note the single flowering heads of the *Eriophorum*.

Figure A2.21. *Eriophorum vaginatum* tussock following burning.

Figure A2.22. *Eriophorum vaginatum* tussocks growing amidst dense *Calluna vulgaris*.

A2.28 'Feather mosses'

There are two basic categories of moss – technically 'acrocarpous' and 'pleurocarpous'. Acrocarpous mosses are generally upright single-stem plants, resembling miniature trees, while pleurocarpous mosses are broadly mat-forming and multi-branched.

'Feather mosses' includes all forms of pleurocarpous moss, although typically consists of the most branched species which resemble miniature multi-branched ferns. A typical example would be *Hylocomium splendens*, which is one of the most branched and fern-like of all mosses likely to be encountered in a bog environment.

Figure A2.23. *Hylocomium splendens* in commune of Salles-la-Source, Aveyron, France.

Feather mosses typically occur on relatively dry substrate within a damp climate, thus having 'dry feet but damp hair'.

A2.29 *Hypnoid* mosses

This group of mosses consists of pleurocarpous mosses (*i.e.* mat-forming prostrate growth form) that are not so extremely multi-branched as the feather mosses. The defining type is *Hypnum jutlandicum* (formerly *Hypnum cupressiforme*) but any moss that adopts the same prostrate, moderately-branched growth-form belongs to this category. It thus includes such species as *Pleurozium schreberi* and *Pseaudoscleropodium purum*.

Figure A2.24. *Hypnum jutlandicum* – note the curled leaves and prostrate branched growth-form. Other 'Hypnoid mosses' have a similar prostrate, moderately-branched growth-form.

A2.30 *Juncus squarrosus* – heath rush

A true rush of the family Juncaceae, *Juncus squarrosus* is distinctive because of the way in which its flattened rosette of stiff tube-like leaves crowd out any other species from the immediate vicinity of the plant.

Juncus squarrosus is most typical of the thinnest peats and even mineral ground, so is most often found in blanket bog environments as part of the initial colonising vegetation established at the bottom of erosion gullies. Its presence is thus usually an indication of very thin peat. Indeed its common name of heath rush indicates that it is most typically associated with the thin peats of upland and lowland heath rather than true bog.

Figure A2.25. *Juncus squarrosus* – heath rush

A2.31 – *Leucobryum glaucum*

This is an acrocarpous moss (*i.e.* single-stemmed and with upright growth-form) that forms tight glaucus (grey-blue-green) mounds. It is common in dry birchwoods on the margins of raised bogs where it may even sometimes form round balls of moss. Elsewhere, it is generally a sign of dry peat, though it may occasionally form hummocks on more westerly bogs.

The leaves are tightly packed around the stem and feel quite solid, almost like hard plastic, while the plants themselves are almost always tightly packed together to the point where it is often difficult to pull the mound apart. Although the image below may also resemble the moss *Aulacomnium palustre*, that species is much softer and more yellow-green, and never forms dense hummocks. The stems illustrated here are the length of a little finger.

Figure A2.26. *Leucobryum glaucum*

A2.32 ***Menyanthes trifoliata* – bog bean**

Despite its common name, *Menyanthes trifoliata* is not a member of the bean family (Fabaceae) but is instead a member of the daisy family (Asteraceae). The scientific name – *trifoliata* – gives a good indication of its most distinctive feature which is the three-lobed nature of *Menyanthes trifoliata* leaves, which typically emerge from bog pools or *Sphagnum* hollows.

Figure A2.27. *Menyanthes trifoliata* – bog bean

A2.33 *Molinia caerulea* – purple moor grass/flying bent

Molinia caerulea is a natural component of areas which experience water seepage (*i.e.* flush fens and stream margins). This is often strikingly visible on aerial photographs taken in early spring or mid-late summer when *Molinia* is bright green while the surrounding bog vegetation is a tan/brown colour. Such distinctions are lost in late spring/early summer when everything turns a general green. *Molinia* is distinguished from other grasses found in this general habitat by its hairy ligule and tall flowering spike (thigh-high) topped with purple-brown florets that tend to be pressed to the flowering spike rather than spreading.

Molinia is a deciduous grass, shedding its dead leaves in autumn. These leaves are grey-cream-white, lightly curled and tend to blow across the ground during gales, thus explaining its common name of 'flying bent'. The stark white appearance of *Molinia* during autumn and winter is usually very evident on aerial imagery

Molinia is a natural component of bogs in the far north-west of Scotland (and Ireland) where it occurs as individual leaves growing through the *Sphagnum* carpet. In the absence of a vigorous *Sphagnum* layer, and in particular following burning, *Molinia* adopts a dense tussock growth-form. Tussock growth-form on a *bog* surface is thus a sign of damage, whereas in some natural fen systems lacking a vigorous moss layer this growth-form may also be adopted.

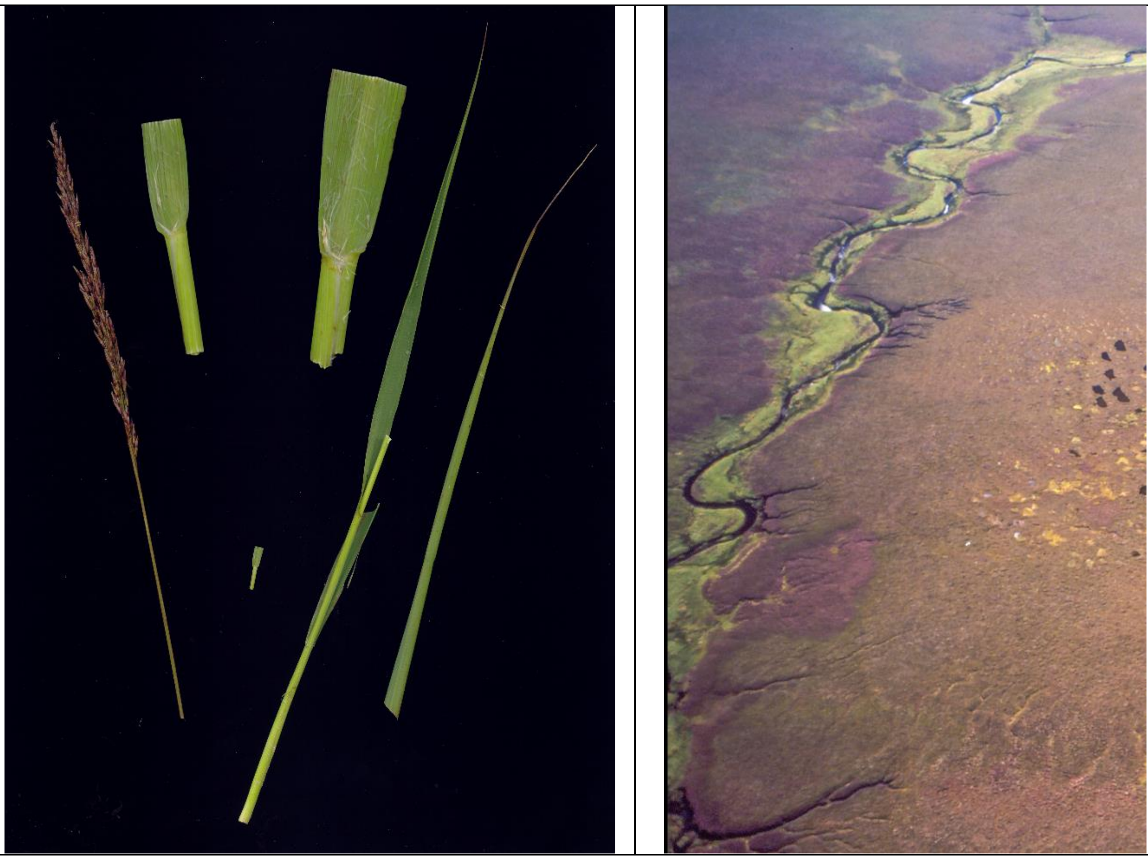

Figure A2.28. (Left) *Molinia caerulea* displaying hairy ligule. (Right) *Molinia*-rich vegetation along a stream course.

A2.34 *Narthecium ossifragum* – bog asphodel

In German this plant is called 'moor lily', and indeed at one time it was a member of the Liliaceae family but it now has its own taxonomic family – the Nartheciaceae. The three distinctive features of this plant are that the leaves are flat, mid-green and cutlass-shaped, the flowers are a brilliant yellow that are visible from a distance against the darker colours of a bog, and the seed-head is a vivid orange.

Narthecium ossifragum thrives in areas of water seepage, so although it is common as individual plants across bogs in good condition, it forms dense mats where there is significant surface-water movement. It tends to be restricted to a zonal range of T2 high ridge down to the T1A1 transition zone, though it may also be found in A1 *Sphagnum* hollows and A2 mud-bottom hollows.

The scientific name *ossifragum* means bone breaker, which is the old country name originating from the belief that sheep grazing on *Narthecium* developed brittle bones. While lack of calcium in bog vegetation is probably a major factor, photosensitization in lambs and kidney problems in certain breeds of cattle have both proved to be issues for livestock.

Figure A2.29. *Narthecium ossifragum* – bog asphodel. (Left) Cutlass-shaped leaves. (Top) *Narthecium* in flower. (Bottom) *Narthecium* seed head.

A2.35 *Polytrichum commune*

Polytrichum commune is an acrocarpous moss – *i.e.* it is single-stemmed with upright growth-form. It resembles a bottle brush, with stiff dark green narrow triangular leaves sticking out almost at right angles from the pale brown stem. It often forms rounded 'cushions', or 'pillows' created by a mass of stems but these are always loose and easily parted or crushed, unlike the rather firmer hummocks typical of *Sphagnum*.

Other *Polytrichum* species are similar in form but much smaller, with only the extremely short *Polytrichum juniperinum* forming extensive mats – typically on dry (often burnt) bare peat.

Polytrichum commune occurs naturally towards the margins of bogs, where there is an increase in nutrients and to some extent increased tendency for water seepage or occasional shallow flooding. It is therefore generally an indicator of mild enrichment – perhaps from animal dunging or from burning. It is also common in regenerating peat cuttings and regenerating erosion gullies.

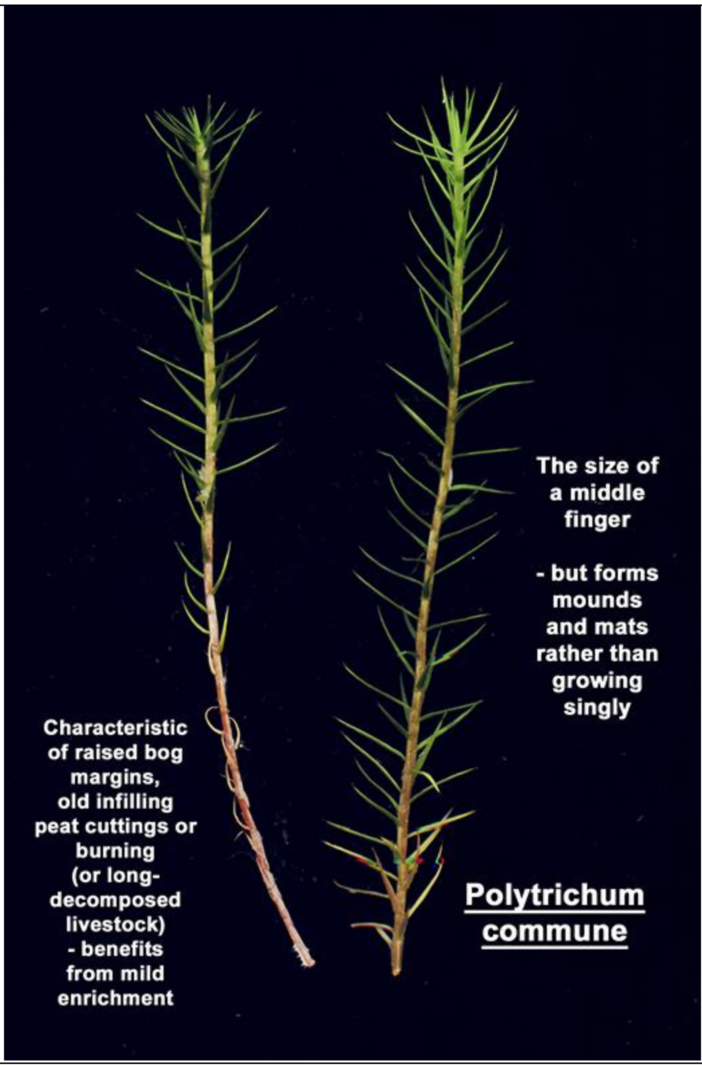

Figure A2.30. *Polytrichum commune*

A2.36 – *Racomitrium lanuginosum* – woolly hair moss

A pleurocarpous moss (i.e. mat forming and often branched) that falls into the 'Hypnoid moss' category rather than the 'feather moss' category because it is not sufficiently branched for the latter category. *Racomitrium lanuginosum* tends to form large hummocks.

Its specific name of '*lanuginosum*' refers to its wool-like appearance resulting from the long white hair protruding from the end of each leaf. When the moss is dry, its many large hummocks look greyish-white and can resemble a herd of sheep from a distance. Close-to, the hummocks look grey-green with a white coating when dry, but become a luminous glaucus green (a blue-grey-green mix) when wet.

The moss is also distinctive because it has what appear to be nodules at each branching node along the moderately-branched stem.

Figure A2.31. (Top) *Racomitrium lanuginosum* with inset showing white hairs at the end of each leaf. (Bottom left) *Racomitrium* hummock with *Erica cinerea*. (Bottom right) *Racomitrium* covering T4 hagg top.

A2.37 *Rhynchospora* – white- or brown-beaked sedge
Two species of *Rhynchospora* occur in the UK and Ireland – *Rhynchospora alba* (white-beaked sedge) and *Rhynchospora fusca* (brown-beaked sedge). The common names make clear the characteristics of these two sedge species – namely that one has a white floret at the tip of its flowering stalk while the other has a larger bunch of brown florets.

Both species are characteristic of the shallower aquatic zones, but *Rhynchospora alba* is most commonly found in the range of T1A1 transition down to A2 mud-bottom hollows whereas *Rhynchospora fusca* is much more restricted to A2 mud-bottom hollows. *Rhynchospora fusca* also has a much more restricted distribution on bogs in the UK, being limited to bogs of the far north west, whereas *Rhynchospora alba* is found in good-condition bogs throughout the UK, albeit with a somewhat western bias.

Figure A1.32. (Top) *Rhynchospora alba* (Bottom) *Rhynchospora fusca*

A2.38 *Rubus chamaemorus* – cloudberry

A plant more typical of non-peat montane areas in northern Scotland but found extensively on good-condition blanket bog further south. Its leaves resemble those of rhubarb leaves, though very much smaller, while the white flower turns into a pale orange multi-faceted berry (strictly an aggregate fruit of drupelets). It typically grows beneath an open dwarf-shrub canopy through a moss layer, though can also grow in the open within a moss layer.

Figure A1.33. *Rubus chamaemorus* leaves and fruits

A2.39 *Schoenus nigricans* – black bog rush

Normally a species of somewhat base-rich flushes and valley fens (it is common in the central water-track of Thursley NNR in Surrey), *Schoenus nigricans* occurs on a few bog systems in the far north-west of Scotland but is more usually recorded from the bogs of Western Ireland – extra nutrients being supplied by drifting sea-spray.

It is a member of the sedge family (Cyperaceae) rather than the rush family (Juncaceae), but resembles soft rush (*Juncus effusus*) in its tall flowering stem with a dense flowering head above which a long spike protrudes. In the case of *Schoenus* this spike (bract) is much shorter than the spike above the flower in *Juncus*. The obvious distinction between *Juncus effusus* and *Schoenus nigricans* is that the flower of *Schoenus* is dark brown, almost black, whereas that of *Juncus* is pale brown. *Schoenus* also has a mass of long, rather stiff but wiry leaves whereas *Juncus* has only the green flowering stem.

Figure A1.34. *Schoenus nigricans* – black bog rush

A2.40 'Short mosses'

This refers to a number of small acrocarpous mosses (*i.e.* upright single stems) that may be found growing on bare peat. It includes species such as *Polytrichum juniperinum*, various *Campylopus* species, *Dicranum* species *Pohlia* species, and various others typically found on bare peat. This group is distinguished from the mat-forming pleurocarpous mosses because these 'short mosses' are generally associated with more degraded conditions than those associated with the mat-forming 'hypnoid' and 'feather' mosses.

Figure A1.35. Examples of 'short (acrocarpous) mosses'. (Top) *Pohlia* type (Bottom) *Campylopus* type.

A2.41 *Sphagnum*

Sphagnum is a genus of moss possessing a structure like no other moss. It has an upright central stem from which horizontal branches radiate like spokes of a wheel. These branches are densely covered with rows of overlapping leaves. Less obvious is the fact that from the same connecting point of every 'spreading' branch there are also one or more much thinner 'pendant' branches hanging down the stem – while the stem itself has a scattering of leaves directly attached to the stem (stem leaves). Crowning the stem is a bunch of buds which will subsequently form new branches as the stem grows. This crown is termed the 'capitulum'.

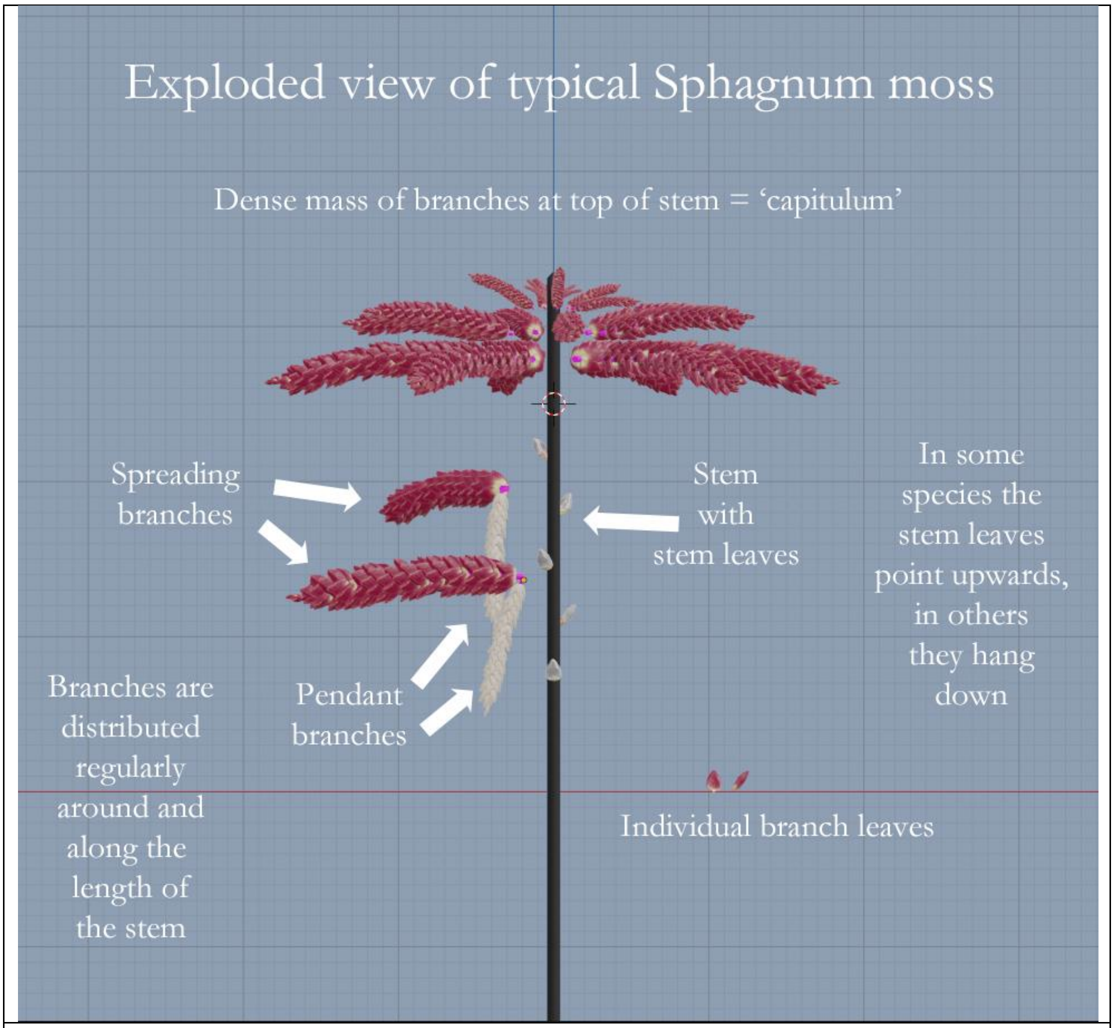

Figure A1.36. Key structural parts of a *Sphagnum* plant.

The characteristic features of individual *Sphagnum* species are too involved to go into here. The reader is directed to the IUCN UK Peatland Programme's *Sphagnum World* which provides detailed descriptions of several species: https://storage.net-fs.com/hosting/6147066/20/

A2.42 *Trichophorum cespitosum* – deer (hair) grass

Originally known as 'deer-hair grass' because of the colour it takes on in autumn, *Trichophorum cespitosum* is more commonly referred to now simply as 'deer grass' although the original name is a real guide to the colour to look for in autumn and winter – namely a rich russet/tawny colour.

As with the *Eriophorums*, this is not in fact a grass but is instead a member of the sedge family (Cyperaceae). Unlike the cotton grasses, *Trichophorum cespitosum* does not have separate leaves and flowering stems. It instead has a green stem topped by an extremely small brown flowering spike. Once this has set seed it drops off leaving only the stem, thus making it easy to confuse with the leaves of *Eriophorum vaginatum*. The sure way to distinguish these two is to look at the base of the stem, where a small finger-like ligule can be seen in *Trichophorum* but is absent on *Eriophorum* leaves.

In autumn and winter, *Trichophorum* leaves also turn that russet/tawny colour, often with a rather zebra-stripe look, whereas *Eriophorum vaginatum* leaves just turn rather whitish-pale. *Trichophorum* flowering stems are also stiffer than *Eriophorum vaginatum* leaves and thus create tussocks that are 'stiffer, neater and more regular' than the often more straggly appearance of *Eriophorum vaginatum* tussocks at the end of the growing season.

Trichophorum cespitosum is also a tussock former, growing as single dispersed stems within a vigorous moss carpet but taking on the tussock growth-form if there is no such carpet, forming increasingly dense tussocks if also subject to burning.

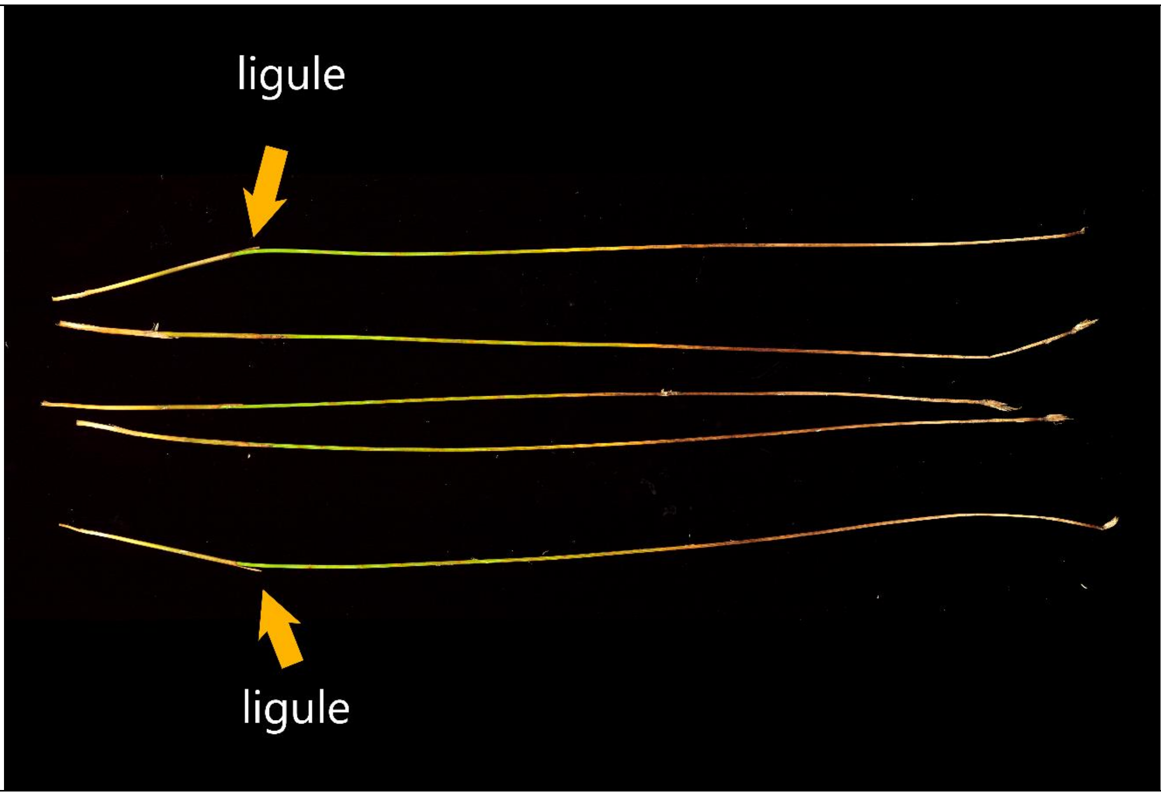

Figure A1.37. *Trichophorum cespitosum* flowering spikes, indicating the small ligule towards the base.

Figure A1.38. *Trichophorum cespitosum* florets, plus the 'zebra striping' as the stem dies back in late summer.

Figure A1.39. *Trichophorum cespitosum* tussock in early-summer before turning tawny-russet.

Figure A1.40. Tawny-russet *Trichophorum cespitosum* tussocks within an *Eriophorum* sward.

Figure A1.41. *Trichophorum cespitosum* tussock in 'Em bare/Carex panicea' micro-erosion.

A2.43 *Utricularia* – bladderwort

The Utricularias are aquatic carnivorous plants that trap aquatic invertebrates within small bladders – thus the common name. They are not always easy to see within the mass of other plant material that may be floating in bog pools, although their small aerial flowers, looking like tiny snapdragon flowers, may be spotted just above the water surface.

Figure A1.42. *Utricularia minor* – lesser bladderwort

Picture credit: Kristian Peters Creative Commons Attribution-Share Alike 3.0 Unported

A2.44 *Vaccinium myrtillus* – bilberry
Favouring somewhat drier ground, *Vaccinium myrtillus* grows on the dry margins of peat cuttings and more extensively on the drier heath-like blanket bogs of the Pennines. Its most distinctive feature is the ridged green photosynthetic stem, while the leaves are not as stiff and 'waxy' as other *Vaccinium* species, and have tiny 'pie-crust' teeth around the leaf margin.

Figure A1.43. *Vaccinium myrtillus* – bilberry – note the green photosynthetic stem

A2.45 *Vaccinium oxycoccos* –cranberry

A tiny creeping dwarf shrub with leaves barely 0.5 cm long. It can easily be missed when it is tangled amongst and obscured by other taller vegetation. It produces abundant maroon-coloured berries, though these are not what are used to create cranberry sauce – that comes from the larger American cranberry *Vaccinium macrocarpon*.

Figure A1.44. *Vaccinium oxycoccos* - cranberry

A2.46 *Vaccinium vitis-idaea* – cowberry

A very short shrub with stiff leaves that are slightly curled under around the margins. The defining feature of *Vaccinium vitis-idaea* is that there are small dots (pits) scattered across the underside of the leaf. A plant of somewhat drier ground, and also commoner at higher elevations, and most characteristic of central and eastern upland bogs.

Figure A1.45. *Vaccinium vitis-idaea* - cowberry
Picture credit: Hans Hillewaert

A2.47 *Vaccinium uliginosum* – bog bilberry

Another more eastern and upland dwarf shrub which has the centre of its distribution in Fennoscandia. It has a more rounded leaf than *Arctostaphylos uva-ursi* but has something of the same reticulate venation on both upper and underside of the leaf. The leaf has a matt texture whereas *Arctostaphylos uva-ursi* has a very shiny surface.

Figure A1.46. *Vaccinium uliginosum* – bog bilberry
Picture credit: Banangraut Creative Commons Attribution-Share Alike 3.0 Unported

A2.48 *Zygogonium* – purple algae

This represents a group of algae that typically form a crust on dry bare peat that is sometimes flooded. No individual algal entities can be seen, but the peat develops a general purple-ish tone. It is useful to know that this is present because it indicates at least some regular ponding of water on this area.