Working Towards the Development of Ecohydrological Guidelines for Blanket Bogs and Allied Minerotrophic Habitats (Phase 2)

PHASE 2 REPORT

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NON-TECHNICAL SUMMARY

All countries of the UK have ambitious targets for the restoration of degraded peatland. The development of Ecohydrological Guidelines for Blanket Bog and Associated Habitats is seen as an important element of any strategy that aims to restore degraded upland mires. This is a multi-year project which was initiated by the UK TAG Wetland Task team and is being led by the Environment Agency, in partnership with Scottish Environmental Protection Agency, Natural Resources Wales, Natural England, DAERA-Northern Ireland, and NatureScot.

As a background to the rationale for this project a brief review has been made of the early literature dealing with the various concepts of peatland terminology, including the development of the term ‘blanket bog’ by Godwin in the 1930s and 1940s, and other terms such as ‘basin peats’, ‘valley bogs’, and later subdivisions of blanket bog into ‘pool-and-hummock complexes’ and ‘bog-slope communities’ by Tallis in the 1980s. Also in the 1980s, Lindsay and co-workers identified several sub-types of blanket bog: watershed, saddle, valleyside and spur bogs, based on their topographic positions. Later, the Wetland Framework was developed by Wheeler, Shaw and Tanner (2009) as an alternative way of characterising wetlands, using a ‘layered’ approach to view the different ecohydrological units of a wetland. Whilst it was initially aimed at lowland minerotrophic wetlands, the possibility was raised that a similar approach might help to identify different units of upland and ombrotrophic wetlands.

One of the central aims of this pilot study has been to use the Wetland Framework approach to try to characterise the range of habitats and topographical conditions associated with the vegetation types and peat surfaces found on upland blanket mires. This has been done using data gathered during field investigations at a range of sites from several regions: central and northern Wales, the Southern Pennines, the Forest of Bowland, the Northern Pennines and the Roman Wall Country of Northumberland and Cumbria. These datasets have been used, in combination with selected data extracted from published sources, to begin to develop a typology of upland mire habitats by identifying their water supply mechanisms (WETMECs).

Field data have been analysed and interpreted using multivariate clustering and ordination procedures and univariate correlations, and the outputs from these were used alongside schematic sections for each site to develop a conceptual understanding of the various mires encountered. Insights gained from this process enabled the recognition of relationships between peat surface topography, sub-peat topography, and vegetation types. This has led to an informal characterisation of peatland surface configurations in relation to the topography of the landscapes in which they occur, and the development of a series of WETMECs. Vegetation types as observed during this work have also been described.

In the original ‘Wetland Framework’ study, WETMECs were mainly conceptualisations of different water supply mechanisms. However, in upland ombrogenous contexts, because of the ubiquity of precipitation, they may be better regarded as conceptualisations of different water drainage mechanisms. In general, peat tends to accumulate most readily in poorly-drained locations; topography exerts a very strong influence upon drainage and drainage patterns, and thus helps to determine both the development and configuration of ombrogenous peat surfaces.

Ombrogenous surfaces appear to be broadly divisible into two groups: those in which the peat surface topography was largely independent of the sub-peat topography, and those where the surface topography largely followed that of the underlying mineral ground. These latter were often on slopes whilst the former generally occupied ‘flat’ surfaces or hollows, which were ‘water-collecting’, primarily through topographically-impeded drainage. This corresponds very roughly to an older subdivision of ‘hill peats’ *versus* ‘basin peats’; here they have been categorised as hill bogs and topogenous bogs.

Hill bog surfaces roughly follow the slope of the underlying terrain and correspond to much of the ombrogenous peat that covers huge expanses of upland Britain. In contrast, topogenous bogs have formed on more-or-less flat surfaces in both lowland and upland situations, whilst a few examples of topogenous bogs have developed on gentle slopes in broad, shallow valleyheads in upland locations. In other situations, ombrogenous surfaces have formed within basins or partial basins, the latter with a lip at a lower level on one side, giving rise to either an asymmetric dome or a flat or gently sloping surface. In some locations topogenous bogs have developed within troughs between low ridges or hills, sloping in either one or both directions, and usually supporting rather wet surface conditions. A particular feature of many of the Border Mires of the Roman Wall Country has been the accumulation of peat across ridges and hollows to varying depths, sometimes completely obscuring these, whilst in other situations the underlying mineral slopes or ridge may contribute to the shape of the mire surface.

Broadly speaking, the topographical character of peat deposits relates to the conformation of the catotelm (lower peat layer), whilst WETMECs relate primarily to surface conditions and the acrotelm (surface peat layer). Five main Ombrogenous WETMECs have been recognised:

- **WETMEC O1**: Ombrogenous Crowns – the uppermost, water-shedding surfaces of autonomous peat deposits (often slightly domed), usually with M18 vegetation and often with well-developed hummocks.
- **WETMEC O2**: Deep Ombrogenous Slopes – often peripheral to a Crown or on ‘steps’ within steeper hill peat, and typically with M19 vegetation.
- **WETMEC O3**: Hill Bogs – fairly thin ombrogenous peat on moderate to fairly steep slopes, following the topography of the underlying mineral ground, and usually supporting M19, M20, or M25 vegetation.
- **WETMEC O4**: Ombrogenous Percolation Troughs – located in topographical troughs and valleyheads and mainly developed over former shallow lakes or some form of fen. Support M18, M19, M20, M2 and M21 vegetation.
- **WETMEC O5**: Ombrogenous Flow Tracks – the bottoms of valleyheads and troughs, often on fairly deep peat, and on some hillslopes. Similar to WETMEC 19: Flow Tracks, of the Wetland Framework, but without a significant minerotrophic component.

In addition, two erosion features have been recognised: **Hill Bog Gullies** are a conspicuous erosional feature of many sites, incised into Hill Bogs of varying depths and slopes. **Summit and ‘Flat Area’ Gullies** are associated with shallow slopes, and cover large areas of summit or near-summit situations, typically resulting in a ‘hagged’ surface or sheet erosion.

Narrow soakways and water tracks are widespread around the margins of some of the peat deposits considered here, where they can form some sort of ‘lagg’. These are generally minerotrophic, and many are best considered a form of WETMEC 19: Flow Tracks, though the margins of some sites may be influenced by examples of percolating groundwater (WETMEC 18), and occasionally WETMEC 17 (Groundwater-flushed Slopes).

It is important to recognise that the WETMECs identified as part of this project represent sub-divisions of a continuum of variation, and individual WETMECs are likely to intergrade. Whilst they are provisional, they serve as a useful initial attempt to distinguish between different upland ombrogenous mire types, which can be built upon in future work. Similarly, the categories of Topogenous Bog and Hill Bog undoubtedly intergrade to some degree, but they do show differences in vegetation composition, surface configuration, sub-surface topography and, to a degree, stratigraphy and probably hydrodynamics.

Some deficiencies in this pilot study should be noted: fieldwork was carried out during the winter, thus precluding the collection of summer hydrological, hydrochemical, and vegetation data. Also, hydrometric data from dipwells were lacking because very few upland sites have such installations, and those that do were either not in appropriate locations, had only just been installed, or the data could not be obtained. Importantly, many regions of the UK that support extensive ombrogenous peat deposits were not visited as part of this study.

Future studies of ombrogenous bog habitats in other parts of the UK, both upland and lowland, are likely to result in the modification of these WETMECs, and the identification of other WETMECs or sub-types, and also other surface conformation types. Whilst upland blanket mires have been the focus of this project, there is likely to be much value obtained from broadening this work to include comparisons with lowland ombrogenous peatlands.

Obtaining access to data held by research groups and conservation organisations should be prioritised as part of any further phases of this project. Initial contact with potential data holders is considered to be best carried out by staff from within the various country agencies, as they are generally more likely to be able to develop a level of trust with the data holders. Consequently, a strategy to facilitate data sharing between stakeholders has been proposed, with a number of appropriate steps suggested. These include identifying potential data sharing partners; determining which agency staff would be best placed to contact partners; explaining the rationale behind this project; determining data types, degrees of restriction, payment needs, and lead-in time requirements; and examining funding mechanisms for payments. The highest priority datasets have been listed, as have organisations generally thought likely to hold relevant data.

It would also be extremely useful to create a UK-wide GIS catalogue of peatland NVC vegetation surveys, peat depth surveys, locations of peat stratigraphic data, and hydrological monitoring points, so that the overlaps and gaps can be seen clearly.

Suggestions for future phases of this project (should funding be made available) include:

a) for late 2023 / early 2024 – refining the fieldwork protocol to streamline data collection; initiate planning for fieldwork opportunities for summer 2024; carry out a brief literature review of recent relevant research; create a photographic resource of different peat types to assist with future surveys.

b) for summer 2024 – expand the dataset through a combination of fieldwork and acquiring external data, to include field investigations of regions not examined during this phase of the project, *e.g.* Scotland (Flow Country, Hebrides, Central Highlands, Silver Flowe, Dumfries & Galloway, Scottish Borders); Wales (all regions); Northern Ireland; England (Northumberland 'hill bog' examples, North York Moors, North Pennines, Dartmoor, Exmoor, Bodmin Moor).

1 INTRODUCTION

Recent policy drivers for the UK include Scotland's National Peatland Plan (Scottish Natural Heritage, 2015) and the England Peat Action Plan (Defra, 2021), which emphasize the importance of healthy peatland ecosystems to maintain a carbon store, amongst other wider environmental benefits. All countries of the UK have ambitious targets for the restoration of degraded peatland, and peatland research is identified as a target in the UK Net Zero Research and Innovation Framework (2021).

The development of Ecohydrological Guidelines for Blanket Bog and Associated Habitats is seen as an important element of any strategy that aims to restore degraded upland mires. This is a multi-year project which was initiated by the UK TAG Wetland Task team and is being led by the Environment Agency, in partnership with Scottish Environmental Protection Agency, Natural Resources Wales, Natural England, DAERA-Northern Ireland, and NatureScot.

1.1 Rationale

Two main considerations have influenced the approach to this project.

1) As was demonstrated by Phase 1 of the project, the amount of relevant data already available from upland mires in Britain is small. More could probably be obtained from a small number of sources that were unexplored in Phase 1, though some of these are of uncertain value and were considered likely to be difficult to locate or obtain. In view of this, it was suggested that there was a need for new fieldwork to obtain simple but appropriate data which would support an approach broadly comparable with that already used in a consideration and analysis of lowland wetlands (Wheeler, Shaw & Tanner, 2009).

2) The stipulated timeframe of Phase 2 of this project, within which to undertake fieldwork, data collation, data analysis, and to develop both a revised typology for blanket mires and allied minerotrophic habitats, and ecohydrological guidelines for vegetation of these habitats, was relatively short. In consequence, the acquisition of new data needed to be targeted on a fairly small number of contrasting field locations, to be compatible with the time frame.

Consequently, it was proposed that the fieldwork would be focussed mainly on a subset of blanket bog landscapes, as represented by four contrasting 'blanket bog' regions within England and Wales: the Roman Wall Country of Northumberland and Cumbria, Forest of Bowland, Southern Pennines, and locations in central and northern Wales, with some additional examination of the Stainmore area of the Northern Pennines if fieldwork constraints allowed.

From this starting point characterisation, it would then be possible to gather additional ecohydrological information from other regions of the UK in later phases of the project.

1.2 Aims

The overall aim of this project has been to use a combination of new field data and existing information to:

- Characterise the range of habitat and topographical conditions associated with the main distinctive floristic units and surfaces found on blanket bogs and allied minerotrophic habitats in the areas examined. The floristic units were those of the sub-communities of the *National Vegetation Classification*, but in addition attention has been given to other *widespread* species combinations, and peatland surfaces, that are not well accommodated within the *NVC* units, where these have been encountered.
- The datasets gathered have been examined in order to <u>initiate</u> the development of a novel typology of these upland mire types, by the identification of distinctive water-supply mechanisms and categories (WETMECs), as was done for lowland wetlands by Wheeler *et al.* (2009). These have related both to ombrogenous surfaces and to associated minerotrophic mires, depending on what was encountered in the field examinations.

The longer-term aim for the overall project is to examine data from the full range of mire types associated with blanket bog landscapes throughout England, Scotland, Wales and Northern Ireland, in order to develop a comprehensive typology of, and ecohydrological guidelines for, blanket mires and allied minerotrophic habitats. This would include gathering additional new field data and acquiring existing relevant datasets from partner organisations and research groups.

Issues relating to difficulties in obtaining relevant datasets were identified in Phase 1 of this project and as a consequence an additional aim of this phase of the project has been to develop a strategy for the acquisition and incorporation of data from other priority sites in later phases of the project, including a wide range of geographically distinct sites throughout England, Wales, Scotland and Northern Ireland.

The data gathered during the current phase of the project will contribute substantially to achieving the full project ambition; at this early stage it is difficult to state with any accuracy what proportion of the overall project will be achieved during Phase 2, but it may be somewhere between 10% and 30%.

2 BACKGROUND

According to Godwin (1981), 'blanket bog' was part of a peatland terminology that had been "hammered out by Professor A.G. Tansley, Hugo Osvald and myself during our meetings in 1935, and subsequently brought into general use." Hitherto, Tansley (1911) had used the term 'moor' to accommodate what came to be regarded as 'blanket bog', but then came to eschew this usage on the grounds that 'moor' had wider and ambiguous connotations (Tansley, 1949). Nonetheless, W.H. Pearsall, probably the doyen of moorland ecologists in the 1940s – and one-time Professor of Botany at the University of Sheffield – considered that 'blanket bog' also was "a conveniently vague term for peat-forming vegetation" in these moorland locations (Pearsall, 1950, *p.* 152).

Pearsall commented further that "The waterlogged peats are of two main types: (i) bog peats and (ii) flush peats. The bog peats are widespread, covering the majority of stable upland soils and characteristic of those of slight slope. They fall into two topographic types: those found on concave lowland forms, valley bottoms or lake basins, which have sometimes been distinguished as *basin-peats*, and, in contrast, those on long slopes and gentle ridges, for which Dr. H. Godwin coined the name *blanket bog*, a term expressive of the way in which the peat covers all stable features of the original surface. Strictly speaking, basin peats are part of the blanket bog in the uplands and it is only useful to separate them because they have, at times, a somewhat different and longer history as well as differences in present vegetation." To which could now be added 'differences in conservation management requirements'.

Pearsall did not explain why he considered that "strictly speaking, basin peats are part of the blanket bog in the uplands", but this view is suggestive of an all-accommodating notion of 'blanket bog', one which not only blankets physically some of the topographical features of the landscapes where it occurs, but which also provides a conceptual blanket across real ecohydrological differences that exist within some of these peatland areas, and which may even discourage exploration of these.

Subsequently, working at Moor House, Johnson & Dunham (1963) – who generally followed Pearsall on matters peaty – did not encompass their examples of 'basin peats' within 'blanket bog', but regarded them as discrete entities with different developmental histories. They referred to their areas of 'basin peat' as 'valley-bog deposits' which were embedded within a wider expanse of 'blanket peat'. One of these deposits, rather ingenuously named 'Valley Bog', occupied a basin formed within a small boulder-clay–dammed valleyhead and had clearly developed by the terrestrialisation of a shallow lake, with some 7.4 m of fen and bog peat superposed upon lake muds. By contrast, their profiles of what they called blanket peat indicated that these had formed essentially by paludification (though these authors used neither terrestrialisation or paludification as working terms). Subsequent vegetation survey of the area (Eddy, Welch & Rawes, 1969) showed that the vegetation of these two categories was different too: their vegetation nodum from Valley Bog was subsequently encompassed within M18 by Rodwell (1991), whilst much of the vegetation on 'blanket peat' was encompassed within M19. The blanket peats were shallower than those of Valley Bog but of variable thickness, and included deeper deposits in shallow hollows that, other than their depth, were not very different from surrounding examples. Johnson & Dunham considered that "these profiles are regarded as thickened blanket peat rather than small valley-peat deposits." It was thereby established that, whilst variable, at least two distinct categories of ombrogenous mire could be recognised in these upland peatland landscapes, and not just on topographical grounds. Subsequently Tallis (1985b) recognised two types of 'blanket bog' – " pool-and-hummock complexes and bog-slope communities". He indicated that "the latter show little microtopographical differentiation of the bog surface". Any categorisation of upland peatlands should be able to distinguish at least these types of mire.

In the 1980s, Lindsay and some co-workers identified several types of blanket bog. These were watershed, saddle, valleyside and spur bogs (Lindsay *et al.*, 1988). These were essentially locational units based on the topographical position of the mires in the landscape and offered few insights into how, or even if, they could be distinguished on their intrinsic features, other than their topographical location. A similar approach had been used earlier with regard to the categorisation of lowland fens based on landscape position and topography, which represented a top-down approach to the recognition of categories based on expert judgement. This approach, although ostensibly 'simple' is nonetheless difficult to use, because of the enormous variation in actual landscape topography and the concomitant difficulty of definition, and because some of the topographical units are often, in the field, nested within others. The various issues and considerations involved have already been examined in detail (Wheeler *et al.*, 2020) and do not need to be discussed further here.

Wheeler, Shaw & Tanner (2009) developed an alternative approach to the characterisation of lowland wetlands, which was essentially based on a bottom-up and 'object-oriented' protocol*, viz.* the identification and comparison of salient ecohydrological properties of wetlands, or different parts of wetlands, based on field data from samples of stands of different vegetation types. The resulting characterisation was neither perfect nor comprehensive, but it did provide a meaningful way forward in the recognition of distinctive ecohydrological units within the wetlands examined. These units were termed 'WETMECs'. These units related almost exclusively to lowland[1] wetlands (the Malham Tarn wetlands were an exception) and dominantly to minerotrophic examples ('fens'), but Wheeler *et al.* (2020) raised the possibility that a similar approach might help to identify upland and ombrotrophic units based on the salient properties of selected field examples. The main constraint on examining this possibility was a general lack of the synoptic field data comparable to those which had been acquired for lowland fens.

As a possible way forward, it was suggested that the potential of this approach could be tested in the first instance by the rapid acquisition of field data for a number of upland sites. A selection of sites for examination was chosen, almost all of them in the Pennines, to represent a series from the Peak District north to the Borders. Three sites were also examined in Wales, at the suggestion of Natural Resources Wales. Constraints of time and timing meant that this work had to be done over a very short period during the winter of 2022–23, which is not the most propitious period for field investigations in upland mires. This work should therefore be seen as a pilot study, intended to examine the potential of the 'Wetland Framework' approach for the characterisation of upland wetlands especially, but not exclusively, ombrogenous examples.

A wide-ranging review of many characteristics of blanket peat and related deposits was provided by Wheeler *et al.* (2020) and will not be repeated here, but attention is drawn to some material that is particularly pertinent to the present project or which is additional to that presented in the earlier report.

2.1 The pre-peat upland landscape

In some upland areas, the start of the development of a peatland cover occurred round about the Boreal–Atlantic transition (*c.* 7500 BP) but more widespread development seems to have occurred near the start of the sub-Boreal period (*c.* 5000 BP) and has continued since then (see Table 1 for a summary of these periods and their approximate timings). There had been some development of peat deposits earlier in the post-glacial period, but mostly in particularly poorly-drained locations, such as the 'Valley Bog' at Moor House (where the basal muds were pollen-dated to the Boreal period by Johnson & Dunham (1963)). The pre-peat landscape seems generally to have been forested, particularly with birch and pine (Tallis & Switsur, 1983), though in the Moor House area some of the highest summits may have been above the treeline. Thus for much of the Mesolithic period, any ecohydrological enquiry into wetlands in the uplands would necessarily have focussed on much the

[1] In England and Wales the term 'lowland' is informally used to refer to land below about 300 m aOD and below the limit of enclosure.

same features as is currently the case in mineral soil-based areas of the lowlands, *viz.* slope processes, surface water supply (including patterns of rain-generated run-off, the location and impacts of watercourses, alluvial deposition *etc.*) and groundwater outflows.

Table 1. Approximate correlations between subdivisions of the late-glacial and post-glacial periods.

	Approx date (BP)	Archaeological Period	Blytt & Sernander period[2]	Godwin Pollen Zone[3]
Post-glacial (Flandrian)	1000	Post Medieval	Sub-Atlantic	VIII
	2000	Early Medieval Romano-British		
	2500	Iron Age		
	3000	Bronze Age	Sub-Boreal	VIIb
	4000			
	5000	Neolithic	*Elm Decline*	
	6000	Mesolithic	Atlantic	VIIa
	7000			
	8000	Late	Boreal	VIa, VIb VIc
	9000			V
	10000	Early	Pre-Boreal	IV
Late Glacial (Devensian)	11000	Late Upper Palaeolithic	Upper Dryas	III
	12000		Allerød	II
	13000		Lower Dryas	I

The rôle of groundwater in the early development of the peatland surfaces is less clear. Johnson & Dunham (1963) reported early development of peat (Boreal V) at the base of a short, steep slope of Quarry Hazle sandstone, and attributed this to early waterlogging caused by springs from the base of the sandstone. More generally, and largely following Pearsall (1950), they identified the occurrence of 'flush peat deposits', including 'lime-rich flushes', 'base-rich flushes' (especially associated with the Quarry Hazle sandstone, and 'iron-rich flushes', which occur where springs drain over a blanket bog surface (though it is doubtful whether, in such situations, such surfaces were truly ombrogenous[4], or ever had been, unless the springs were of recent origin). It is likely that groundwater conditions were important in the early development of some peatland sites, and some evidence is available for this from Ringinglow Bog (Conway, 1947), but in general present-day investigators of blanket peats pay little attention to the hydrogeological context of their chosen sites. This may well be because there is often little reason to suspect much in the way of telluric outflows into such systems. Peripheral springs and seepages are known from some sites and there may be minerotrophic 'windows' within the hill

[2] The Blytt-Sernander classification is a series of north European climatic periods or phases based on the study of Danish peat bogs by Axel Blytt (1876) and Rutger Sernander (1908).

[3] Pollen zones are a system of subdividing the last Glacial Period and Holocene (post-glacial) paleoclimate using data from pollen cores, developed in the UK by Sir Harry Godwin.

[4] This was a matter on which Johnson & Dunham seem to have been rather fussy. They usually used the term 'blanket *bog*' to refer specifically to ombrogenous peat and 'blanket *peat*' to encompass the entire peat profile, including any lower minerotrophic layers.

peat of others, as recognised by Pearsall (1950), but in general most sites appear, on the basis of their vegetation, to be largely ombrotrophic. It is, of course, possible that some groundwater outflows may occur beneath and into the peats without much affecting surface hydrochemistry or vegetation but still contributing to the water balance. The extent to which this may occur depends, of course, not just on the existence of suitable outflows but also on the hydraulic conductivity of the overlying peat.

2.2 Formation and accumulation of ombrogenous peats

2.2.1 Peat accumulation

Peat is generally regarded as a sedentary (rather than sedimentary) deposit and is usually found more-or-less *in situ* in the place where it formed. There are obvious exceptions to this generalisation. One is that compaction of a layer of peat beneath an accumulating mass of superposed material may result in some (usually fairly small) measure in its vertical displacement downwards from its point of formation. More significantly, in systems where accumulating peat is underlain by loose sediments, or even 'water', peat may also gradually subside or settle into that material, and this can sometimes result in a considerable vertical displacement. On sloping ground, accumulating peat may gradually move downslope in consequence of solifluction or erosion and, rarely, but more dramatically, in some instances by peat slides and bog bursts. Even in topogenous troughs there may be some mass movement of peat down a slight slope, perhaps evidenced by water-filled cracks across the direction of movement, as has been reported from Muckle Moss (Pearson, 1960). Peat and vegetation erosion or detachment can also occur in some lacustrine situations, and lead to the redistribution of this material, often as re-deposited sediments. It is nonetheless the case that peatland ecologists and stratigraphers generally recognise the essentially sedentary character of peat, and assume that it originally formed more-or-less where it was subsequently found and examined.

Box 1. Processes of Peat Formation and Accumulation

This identifies some of the terms and categories used to conceptualise the processes by which peat formation may occur. Some of the categories have variable definitions and may overlap.

Terrestrialisation

Terrestrialisation is a rather clumsy but apt term used to refer to the infilling of bodies of open water with sediments and peat, and their conversion into a more terrestric surface. The process is often centripetal (*i.e.* it advances from the margins of the lakes towards their centre) and the sequence of events often can be expressed by distinctive horizontal zonations of vegetation around the water bodes. The typical sequence is often given as: aquatic > swamp > fen > fen woodland, going then either to mixed deciduous woodland or ombrogenous bog (Walker, 1970). In reality, there is little reason to suppose that most such successions ever develop into mixed deciduous woodland, at least autogenically (it may occur in consequence of lowering water tables); moreover, the actual sequences and transitions are a good deal more complicated than is implied by this. Also, when the water body is shallow, it may be possible for swamp development to occur across most of its area without a significant initial aquatic phase. The process can also be modified by any allogenic changes to the water level, in which an increase may prolong the open-water phase and a decrease reduce it.

Topogenous accumulation

Topogenous essentially means 'created by the topography' and is used mostly to refer to topographical situations in which water collects. Here 'topogenous accumulation' is used to refer both to peat accumulation in poorly-drained hollows and similar which have not contained open water (and for which 'terrestrialisation' is thereby inappropriate) and also to ongoing peat accumulation on top of a terrestrialised surface, usually in response to an increase in water level within the hollows. Likely causes of on-going water level rise in such situations may be strongly context-dependent, and depend *inter alia* upon the connectivity of the hollows to external surface water and groundwater sources and sinks. In the case of basins that are in large measure isolated hydrologically from any such influences, the position of the water table is likely to be determined by the balance between precipitation and evapotranspiration, and a cumulative increase in water stored from any precipitation surplus. However, such hollows may also show an autogenic rise in their water table because accumulation of sediment and peat in the bottom of the basin is likely to displace some of the existing water upwards. This process enables the ongoing accumulation of peat over and above its former water level or that of any former, terrestrialised lake, and may continue until any water table rise is balanced by increased drainage from the hollow.

The impact of the water level change depends upon its magnitude. In some instances it can result in open water becoming perched upon existing peat and susceptible to (secondary) terrestrialisation; in others it just makes an existing peat surface wetter. The upper topographical limit of formation of minerotrophic peat (fen) is usually fixed by the position of the telluric water table. Above this, precipitation is likely to be the dominant water source and favour the development of an ombrotrophic surface when in sufficient supply. Where such topogenous accumulation results in the significant formation of peat on hitherto 'dry' slopes of the hollows *etc*, either directly by an increase in the water table or indirectly by impeding any natural down-slope drainage, it effectively represents a form of 'paludification'.

Paludification

The process by which drier ground has progressively become wetter is effectively the opposite of terrestrialisation and is often referred to as *paludification*. However, the term *paludification* is rather ill-defined and has been used with differing compass by different authors. At its broadest, it sometimes seems to be used to refer to any wetland development that is not obviously due to terrestrialisation – and even this distinction may sometimes be difficult to make, because processes that can lead to paludification can sometimes, by raising the water level, also result in 'terrestrialisation' or 'topogenous accumulation'. In this broad sense, 'paludification' can be used to encompass extensive wetland development in a variety of contrasting contexts, from ombrogenous uplands to coastal floodplains, each involving rather different processes. But because of this, in terms of area covered, in this broad sense paludification has been a much more widespread process in Britain than terrestrialisation.

In a narrower sense, paludification can refer more specifically to processes in which wetting is induced by a rise in groundwater conditions, or by increasingly impeded drainage, including topogenous peat accumulation down-slope. This may be induced by largely pedogenic processes, such as podsolisation, and can result in the formation of an ombrogenous peat with little by way of minerotrophic organic material to separate it from the underlying mineral ground.

Crenication

The term *crenication* suggested here is derived from the Greek *κρήνη*, a spring, fountain or seepage, and refers to surfaces kept wet by groundwater outflows. Of course, such outflows can occur into topogenous hollows and limnic systems, but crenication is used here to refer to outflows that help to keep sloping surfaces wet and form part of the concept of soligenous slopes. Such surfaces can occur quite widely, but tend to be localised, in 'blanket peat' landscapes. Most, if not all, of the 'lime-rich flushes' and many of the 'iron-rich flushes' reported from areas of blanket bog by workers such as Pearsall (1950) and Johnson & Dunham (1963) can be regarded as crenication surfaces, and usually can be distinguished quite readily from ombrogenous peat surfaces.

Slope Irrigation

As used here, *slope irrigation* refers to down-slope flow of surface water. In upland ombrogenous areas this is often dominantly rain-generated run-off, which may be sourced both from upslope ombrogenous and mineral surfaces. It can also include downwash from crenication outflows. In lowland contexts 'slope irrigation', if it occurs at all (as a peat-forming process), tends to be confined to discrete water flow paths (soakways and water tracks) or to unusual combinations of topographical circumstances, but in the wetter uplands it is potentially of more pervasive importance in peat formation – though here too it may be particularly evident in soakways and 'peaty flushes'. Some 'peaty flushes' are reported to have a subterranean origin in which water flow along the interface between the blanket peat and underlying mineral ground, and presumably thereby somewhat enriched ionically, can sometimes rise to the surface of ombrogenous peat deposits by means of peat pipes or similar (Johnson & Dunham, 1963)

In essence, peat accumulates in locations where the rate of production of plant material consistently exceeds its rate of decomposition. Waterlogged environments often favour this process, and the wetness of the substratum often determines the extent, character and depth of any peat that forms over it, though these relationships may not be exact. 'Wet' conditions are generally determined by rates of water supply in relation to water loss. High rates of water supply are provided by high precipitation values (*meteoric* water) or by surface water flows or groundwater outflows (*telluric* water sources). Rates of loss are determined mostly by evapotranspiration and by drainage. Drainage is strongly influenced by the topography of the landscape, and poorly-drained hollows may store some water input surplus and hence be particularly 'wet'. In the lowlands of England and Wales, where there may be little or no precipitation surplus, any 'permanent' wetlands on sloping ground are normally irrigated by surface water flows or, particularly, by groundwater outflows. In the wetter uplands, the precipitation : evaporation balance may be such that peat can also develop on sloping ground irrigated more-or-less directly and exclusively by meteoric inputs. Such peat is often described as being *ombrotrophic*, in contrast to the *minerotrophic* peat associated with telluric water supply (Box 2). In the uplands of England and Wales, ombrotrophic peat is generally far more widespread and extensive than is minerotrophic peat, but the latter can occupy a wider range of topographical contexts.

It is important to recognise that, reflecting its sedentary character, the accumulation of peat is essentially a vertical and upwards process. Other things being equal, minerotrophic peat usually accumulates more-or-less to the level of the telluric water table (though in certain circumstances it may lead to an increase in the level of this, sometimes to a significant degree). Likewise, ombrotrophic peat usually accumulates, often atop minerotrophic peat, to the point of which the maintenance by precipitation of surface conditions wet enough to sustain further peat accumulation becomes balanced by drainage or erosion, because of the increasing height or slope of the deposit. Nonetheless, ‘hydroseral succession’ is often popularly seen as a lateral rather than a vertical process, probably reflecting the dominance of the notion of centripetal invasion of, and succession within, open water. But, subject to the caveats mentioned above, peat does not normally spread laterally. What may spread, and account for the increasing horizontal extent of a peat deposit, are conditions appropriate for peat formation and its accumulation *de novo.* In some situations, particularly in terrestrialising lakes, this process may be strongly aided and abetted by the lateral growth into open water of the colonising plant species as, very often, where they are able to invade and grow their peat is also able gradually to accumulate. In other situations, the growth of existing plants, and the accumulation of their peat, can help to create conditions appropriate for peat initiation next to them without direct lateral growth of the plants themselves, for example by promoting waterlogging upslope.

Box 2. Ombrotrophy and Minerotrophy

The Swedish ecologist G.E. Du Rietz developed the ideas of some earlier workers and suggested that the primary division of “the main formation of boreal mires” was between those that were ombrotrophic and those that were minerotrophic (Du Rietz, 1949, 1954). These primary categories were separated by the ‘mineral soil water limit’ (*mineralbodenwassergrenze*), so that ombrotrophic mires were fed directly and exclusively by precipitation (and were called ‘bogs’) whilst minerotrophic surfaces were fed also to some extent by telluric water (and were called ‘fens’).

This subdivision has received widespread use, perhaps partly because it is conceptually neat and because it gives appropriate emphasis to the status and extent of ‘bogs’ – which are very extensive in some boreal and temperate regions. However, it is questionable whether it constitutes the most ‘fundamental’ subdivision of peatlands, even if it is with regard to water source. Wheeler & Proctor (2000) and others have pointed out that the main floristic and hydrochemical split in peatlands is between ‘base-poor’ and ‘base-rich’ circumstances with a diffuse separating point of about pH 5.5 of the mire water, and concluded that ““although many workers have come to accept Du Rietz’s ‘fundamental’ subdivision of mires into bog *versus* [rich + poor] fen as a major difference in water *source*, it represents neither a basic edaphic distinction, nor a fundamental split of floristics (on which it was ostensibly based).”

A consequence of this is that, although Du Rietz’s ‘bog–fen’ split may be conceptually clear with regard to water source, it can be difficult to determine in the field. In practise, assessments of the status of a peat surface as minerotrophic or ombrotrophic seems generally to be made on topographical grounds (does it seem that the surface is above the likely influence of telluric water?) or floristic ones. The latter was, effectively, the approach used by Du Rietz for whom the *practical* split between ombrotrophic and minerotrophic surfaces was based on the *mineralbodenwasser*<u>**zeiger**</u>*grenze* (‘mineral soil water ***indicator*** limit’) – that is, the presence or absence of plants thought to indicate minerotrophic conditions. This approach is hostage to the potential circularity of a rationale which provides an indicator value of plant species for minerotrophy but without an independent assessment of this, and by the possibility that ‘biological inertia’ may permit some ‘minerotrophic species’ to persist on a surface that is actually ombrotrophic, or because they are rooted into a lower layer of minerotrophic peat. Specific indicator species for ombrotrophic conditions have not been identified, moreover the indicator value of plants for minerotrophy can vary considerably geographically. For example, *Sphagnum magellanicum* and *S. papillosum* are both important peat-forming (‘bog-building’) species in some British mires that are generally considered to be ombrotrophic, but in parts of Scandinavia they are confined to minerotrophic conditions and are regarded as indicative of these.

Proctor *et al.* (2009) considered that the chemical composition of mire water was “the only independent evidence of the ombrotrophic origin of the surface water of a mire… This therefore offers the only ultimate criterion of ombrotrophy”. However, this remains difficult to establish – Proctor (1992) found difficulty in identifying consistent hydrochemical differences between examples of weakly minerotrophic and ombrotrophic mires, primarily on account of the regional variability of the hydrochemical signature for ombrotrophy, perhaps due mainly to regional variation in the ionic composition of rainfall.

A corollary of these observations concerning the weak hydrochemical and floristic boundary between ombrotrophy and minerotrophy is that for many practical purposes it may be of little consequence if, in some locations, an ombrotrophic surface is fed in part by weakly minerotrophic water. In the present project, it has been assumed that any minerotrophic enrichment of 'ombrotrophic' surfaces is of consequence only if it is expressed in terms of local floristic change that points towards this.

2.2.2 Topographical contexts of ombrogenous peat accumulation

The accumulation of peat is strongly related to its topographical circumstances. At Moor House, Johnson & Dunham (1963), following Pearsall (1950) and others, commented that "Bog-peats are widespread in the Pennines and can be divided into two topographic types; those found in concave hollows and old lake basins are called valley-bog deposits[5] while those which occur on convex slopes, ridges and flat benches are called blanket-peat deposits." Tallis (1969), examining the blanket bog vegetation of the Berwyn Mountains, up to around the 800 m contour, showed schematically that peat depths were greatest (> 2.5 m) at "the lowest points of broad gently concave ridges where water might be expected to collect and stagnate" and thinnest on steep slopes (up to 26°), and that this correlated with the composition of the vegetation. However, there was also an effect of altitude and exposure, and generally peat formation appeared to have been slow on the higher-level summits and ridges.

The situations of ombrogenous peat formation reported from the Berwyn Mountains occur widely in other upland locations, along with others not identified specifically by Tallis (1969). These include near-flat surfaces which, although generally not extensive in the uplands, do occupy hill plateaux and valleyside benches in places. More widespread are gently sloping, partly irregular surfaces, such as flank parts of the upper reaches of the River Tees (Turner *et al.*, 1973). Valleyheads, troughs and basins, both large and small, often provide poorly-drained hollows in the uplands, and can contain ombrogenous peat deposits: some of the accumulations in the East Moors of the Peak District occupy what are, in effect, broad, shallow valleyheads (Conway, 1947; Hicks, 1971). In the 'corrugated' relief of the 'Roman Wall Country' of the English Borders, ombrogenous peat depressions of various shapes and sizes occur, from more-or-less closed basins to open troughs. Such hollows often provide the *locus* of 'basin peat' formation. Some such examples may have originated by the terrestrialisation of (usually shallow) open water, others by topogenous accumulation of peat, and they are often flanked by sloping surfaces of ombrogenous peat that appear to have originated by processes including paludification and slope irrigation, and locally, crenication (Box 1).

2.2.3 Peat accumulation sequences

In those upland areas where it has been examined, there appears to have been a general upslope sequence of peat initiation (*e.g.* Tallis, 1964b), in which peat started to form first in poorly-drained hollows, then on the adjoining slopes and last on the ridges. A similar acropetal sequence has been demonstrated from some lowland ombrogenous deposits over undulating terrain (*e.g.* Chat Moss, Hall, Wells & Huckerby, 1995) (Figure A. 23; Annexe 2, section 11.2.4). Thus, the greater depth of peat found in some 'water-collecting' positions may be both because such locations were more conducive to peat accumulation and because peat formation started earlier within them than on adjoining interfluves (Tallis, 1964b).

In general, it is easy to understand why peat accumulates readily in waterlogged, poorly-drained hollows. It is less obvious why it should also accumulate in water-shedding areas, except those subject to slope irrigation of some sort. 'Soligenous deposits' have been reported as part of the basal layer of some sloping peat deposits (Johnson & Dunham, 1963; Bostock, 1980) but they seem by no means to be universal (though detailed studies on the basal layer of amorphous peat below ombrogenous slopes are sparse). The acropetal sequence of peat initiation on slopes above water-collecting situations raises the possibility of some influence of the topogenous accumulation onto the slope above, in which peat accumulation may impede drainage of water immediately upslope and thus encourage paludification by that means. It is, however, difficult to envisage such a process operating on the scale required to account for the long sequence of shallow, sloping peat beneath Red Sike Moss (Turner *et al.*, 1973), nor how it would account for sloping peat initiation in locations where a lower 'water-collecting'

[5] In fact, more generally these have been called 'basin peats'

hollow is absent. Smith & Taylor (1989) have suggested that in such situations long-term biopedological processes may be more important than the telmatological processes associated with waterlogging, and result in what are effectively peaty podsols or peaty gleys with an over-extended peat surface layer.

2.3 Configurations of ombrogenous peat deposits

All accumulations of peat may modify to some extent the topography of the surfaces upon which they developed, but a particular feature of ombrotrophic peat in some situations is that it can form surfaces and structures that seem in large measure to be independent of the underlying relief. In these circumstances, the configuration of the ombrotrophic surfaces is determined usually by the patterns of drainage of precipitation excess from the accumulating peat mass, interacting with the existing topography of the peat and, very often, underlying or adjoining mineral surfaces.

2.3.1 Ombrogenous peat on hillslopes

Perhaps the simplest and most distinctive situation in which ombrogenous peat forms in the uplands is upon steeper hill slopes, where a shallow peat[6] has formed in which the topography of its surface may parallel closely that of the sub-peat topography, perhaps thickening somewhat across shallow depressions or where the slope decreases and thinning where the slope steepens, thereby partly ironing out minor irregularities in the sub-peat surface and justifying the name of 'blanket peat'. Such surfaces cover large expanses of hillslope in upland England and Wales and are subdivided by streams and valleys of varying magnitude and sharpness. Some, perhaps much, of the existing surface water drainage may have been established during the early part of the post-glacial period and persisted during the subsequent development of an extensive peatland cover, though in places itself becoming covered by peat. Johnson & Dunham (1963) observed layers of clay and sand within the hill peat in some locations, and concluded that these represented flooding episodes from streams which originated on mineral ground above the peat deposits. However, areas of peatland have also developed their own drainage systems and in some instances may have modified pre-existing drainage patterns. A consequence is that, whether pre-existing or endotelmic, many areas of sloping ombrogenous peatland have become divided by watercourses into more-or-less separate units, and this subdivision may often persist across peatlands at the foot of the slope, which may themselves be of greater depth and different character. This can be seen particularly clearly in the subdivision of the Silver Flowe peatlands (in Galloway), by streams that mostly originate on the hillsides above the mires, into units sufficiently discrete to have been given their own names (Boatman, 1983).

2.3.2 Ombrogenous peat on 'flat' surfaces

In contrast to hillslopes, perhaps the simplest situation in which ombrogenous peat has accumulated 'independently' of the underlying relief is where it has developed over more-or-less flat surfaces of low permeability, such as on the fen peats of clays or former lakes, or on extensive floodplains or coastal plains. Examples of this type of development were once widespread in the lowlands, but in some instances little now remains of the former ombrogenous peat, either because of natural processes (sea-level rise), drainage and conversion into agricultural land, or in some cases, turbary. Extant examples have also mostly been modified by similar developments, especially around their margins, so that it can be particularly difficult to determine what was their natural conformation, especially around their edge.

One of the best remaining examples of lowland ombrogenous peat on a flat surface is provided by Cors Caron (Tregaron Bog) in Wales, which consists of three main domes of ombrogenous peat separated by watercourses. Childs & Youngs (1961) recognised that standard drainage equations could be used to account for the size and shape of the ombrogenous peat deposit at this site, an insight which was developed by Ingram (1982) "who reproduced a simple steady-state equation from the groundwater literature and showed how it can be used to model bog shape and size" (Belyea & Baird, 2006). In this,

[6] Peat depths have been divided into informal categories for the purpose of this project (see definitions in Annexe 1).

drainage occurs only around the margins of the peat deposit, so that wettest conditions are generally in locations furthest from the margins which, in the case of a deposit of circular plan will be more-or-less in the centre, and the deepest peat occurs there. This can produce a more-or-less symmetric half-elliptical 'dome' of peat. At Cors Caron a section across the south-eastern dome broadly corresponds with this (Godwin & Mitchell, 1938). However, that of the western bog is rather different. It encompasses an asymmetric dome of ombrogenous peat sandwiched between rising farmland slopes to the north-west and the Afon Teifi to the south-east (Godwin & Mitchell, 1938). The river abruptly delimits, probably truncates, the long south-eastern side of the western bog, and is marked by a particularly steep marginal slope (with a gradient of about 1 in 10) down which much of the bog drains into the river. On the north-western side, however, the bog directly adjoins the hillside and its topography is influenced by this. In places there is no rand or separating lagg, but the bog "passes smoothly on to the hill side. A thin peat deposit slopes slightly up the hill" (Godwin & Conway, 1939). Surface contours provided by these authors indicated that the dome of the bog is located eccentrically towards the north-west margin where, whilst it is some 8 m above the Teifi, it is only about 1 m higher than the bottom of the adjoining hillslope. This illustrates that the conformation of an ombrogenous deposit even on a flat surface can be influenced by the topography of its surroundings. In this regard, it has strong affinities with some of the foot-slope bogs of the Silver Flowe (Boatman, 1983), though these have developed over an irregular and partly sloping sub-peat surface.

Extensive 'flat' surfaces are not widespread in the uplands, but at Widdybank Fell (Teesdale) an outcrop of Whin Sill on the western flank provides a flattish valleyside bench at around 500 m aOD on which has developed a somewhat elongated but clearly domed deposit of ombrogenous peat (Red Sike Moss). A particular feature of this deposit is that, unlike so many 'domed' examples of ombrogenous peat in the uplands it is not joined with ombrogenous peat upslope on the Fell, but forms a more-or-less isolated unit. This is because the adjoining part of Widdybank Fell is formed of Melmerby Scar Limestone, here metamorphosed into fairly free-draining 'sugar limestone', which supports various types of limestone grassland rather than bog. The limestone slope serves to confine the ombrogenous deposit along its eastern margin and groundwater outflows from it help to form Red Sike which, in effect, forms a lagg stream that helps to separate the Moss from the hillside (conceptually comparable to the spring-fed stream along the north side of Malham Tarn Moss). The other sides of Red Sike Moss are unconfined, but are delimited partly by a steep slope down to the Tees, which is covered by a thin veneer of ombrogenous peat. This has a gradient as steep as 1 in 9.

The floor of the upper Tees valley west of Widdybank Fell also provides an example of irregular terrain of fairly low amplitude, more-or-less flat in places and much of it was covered by ombrogenous peat, though mostly now drowned beneath Cow Green reservoir. Before construction of the reservoir, the configuration and stratigraphy of parts of the peat areas was documented by Turner *et al.* (1973). These observed that at Foolmire Moss "the maximum depth of peat is 570 cm in the Far Foolmire area, which in section resembles the characteristic umbrella shape of a raised bog". This impression is created partly because Foolmire Sike cuts across the valley-bottom peat deposit a short distance from the adjoining hill slopes, but Turner *et al.* considered this to be a watercourse of long standing.

It might reasonably be expected that the extensive, tabular plateau of Kinder Scout in Derbyshire, at around 620–630 m aOD, could have provided a flattish surface suitable for the development of some sort of domed deposit of ombrogenous peat, but no detailed peat surface or sub-surface topographical data have been obtained, and the highly dissected and variable surface of peat haggs makes difficult even a simple visual assessment. Nonetheless, if the view of Tallis (1985a & b) and others has substance, that the reticulate dissection of peat surfaces, such as occurs over much of the plateau, represents eroded pool and hummock complexes, this would be compatible with the former occurrence of a particularly wet, possibly slightly domed, surface.

2.3.3 Ombrogenous peat in basins

On a smaller scale, 'domes' of ombrogenous peat of various shapes and sizes can develop in basins. The upland Malham Tarn Moss (c. 380m aOD), also developed largely across a lake–fen surface, provides an example of this. In this case, the eastern margin of the moss is open to, and formed by, Malham Tarn, and is steep and eroded, but the other margins are largely 'confined' by rising upland slopes. Such circumstances often permit the development of a distinct and minerotrophic moat-like 'lagg' zone, fed both by bog drainage and surface flows from the upland slopes, which separates the ombrogenous deposit from its surroundings, and this is clearly the case at Malham, though the prominent lagg along the north side of the moss has undoubtedly been much modified, and has probably been partly created by, and the bog slope down to it steepened by, turbary. Prominent 'laggs' are particularly obvious features of 'confined' ombrogenous circumstances and may be absent from unconfined margins. In effect they represent water-flow paths and their prominence and extent relates very considerably to the topography of the terrain adjoining the bog. On the eastern side of the western bog at Cors Caron, the Teifi provides the functionality which, in other topographical contexts, would be associated with a lagg.

Walton Moss in Cumbria (Barber *et al.,* 1998; Hughes *et al.*, 2000) has developed in a partial basin, and has formed an asymmetric (or 'tilted') dome of ombrogenous peat. It is largely 'confined' on the deeper northern side of the basin but slopes broadly, and increasingly steeply, southwards, with some 5 m depth of peat over the lower lip of the basin (which probably confined the mire at a much earlier stage of development). It then drops away southwards as a thinning deposit of unconfined acidic peat on sloping ground below the mire. Barber *et al.* have suggested that this site provides an example of a largely undisturbed rand and lagg. This may well be correct, but the likely hydrodynamics of the peat suggest that these were not necessarily similar to comparable structures associated with more concentric, confined basins. Nonetheless, there seems no reason to suppose that the deposit of ombrogenous peat is significantly different from that of some other, more complete, basins. It seems to be a case of a partial dome in a partial basin.

Shallow basins of some form are widespread in the uplands and can support areas of fairly deep peat, deeper than that of many hill peats, but often with rather nondescript topographical characteristics. In central Wales, Cors Lwyd occupies a trough-like valleyhead with some 4 m depth of ombrogenous peat that has developed from former lake and fen, and which shows little evidence of any doming (in the sections available from Slater, 1976). In the East Moors of the Peak District, Ringinglow Bog (and White Path Moss) occupies a broad, gently-sloping valleyhead, with the deepest ombrogenous peat forming a very slightly domed deposit some 6 m deep on some of the highest ground (almost 400 m aOD) towards the south-east corner of the mire (Conway, 1947), and in a location that has probably long been particularly ill-drained, being furthest from the main drainage axis and outlet of the valleyhead and close to possible inflows from the adjoining heather moor. Nearby, Lucas Moss occupies a small 4 m-deep hollow at 346 m aOD (Long, 1994), with a more-or-less concentric dome up to about 1 m above the level of the margins. The peat infill of Leash Fen is mainly of ombrogenous peat, not of fen peat[7] (Hicks, 1971). Here peat covers a flattish col, but this seems mostly naturally to have provided a shallow valleyhead draining to the north-west (to Blake Brook) and, except near the southern end, the peat surface slopes, as a gentle half-dome, from the north-east margin (where, along the line of Hicks' section, it is some 6.5 m deep) to the north-west corner, the pattern again being generally deepest furthest from the drainage outlet. Towards the southern end there is a shallow watershed marked partly (on Lidar contours) by a very shallow dome of peat, but as no peat depth data along the length of the mire axis have been published, it is not known to what this corresponds.

2.3.4 Ombrogenous peat surfaces over irregular terrain

The range of topographical circumstances in which ombrogenous peats have developed in the uplands are not so very different from some lowland examples. Wheeler *et al.* (2009) pointed out that many of the larger examples of lowland ombrogenous peat have developed over irregular terrain. The Chat Moss complex has been quite well investigated and provides an instructive example of this. This large deposit (almost 2600 ha), largely of lowland ombrogenous peat, is spread across the interfluve of the rivers Mersey and Glazebrook near Manchester, with unconfined margins that slope quite steeply down towards the rivers. The peat surface is said to vary between 16.68 and 27.21 m aOD (Hall, Wells & Huckerby, 1995). Both Birks (1965) and Taylor (1983) demonstrated considerable variation in the sub-peat relief, over a topographical range of about 6 m (the basin examined by Birks was at least twice this depth below the peat surface, but the lower parts of this were clay-filled). Hall, Wells &

[7] There are groundwater outflows near the margin of parts of Leash Fen, and it has been suggested that groundwater may penetrate its peat, but this evidence seems to be based on modelling and speculation and it is not supported by what (little) is known about the stratigraphy of the mire (Hicks' detailed section related only to part of the site).

Huckerby (1995) generated a terrain model of the sub-peat topography, which indicated a system of hollows, shallow valleys, and ridges. They envisaged a developmental sequence in which organic deposits accumulated initially in the deep hollows, followed by the development of "valley mire communities", presumably in the valleys, followed by the extensive, and eventually over-arching, development of ombrogenous peat. The ridges appear generally the last to have become covered by peat. They commented that "the Chat Moss peats seem to emulate the stratigraphic behaviour of blanket moss systems, albeit at gentler amplitudes of slope", though in fact the sub-peat slopes of upland ombrogenous mires are, in many places, no steeper than those found at Chat Moss. Overall, they considered that the topography of the mineral ground "affects the surface topography of the peats creating the impression of a 'raised mire', whereas in fact the highest central portion is responding to changes in underlying mineral ground topography." Thus, whilst the bones of the sub-peat topography do not protrude above the peat surface, as is the case in some other ombrogenous peatlands, both in the lowlands (*e.g.* Bowness Common and Glasson Moss (Walker, 1966); Brue Valley, Somerset Levels) and the uplands (*e.g.* Malham Tarn Moss, Pigott & Pigott, 1963; Coom Rigg Moss, Chapman, 1964), they are visible beneath it. This may well have been less obvious before the very extensive artificial drainage of the area for turbary and agriculture.

Deep deposits of ombrogenous peat occupy many of the 'basin peat' areas of the Roman Wall Country, forming part of what is the most important series of such deposits remaining in England (the Border Mires), at least of the ombrogenous kind. Chapman (1964a) commented that "the peat deposits in the area fall into two groups; the higher level (1200–1800 ft, 360–550 m) blanket peats with a relatively dry surface which are about 1 m deep, and deeper and wetter areas of peat at lower altitudes (c. 900–1200 ft, 270–360 m) filling the hollows in the underlying topography and often spreading out over the surrounding area. These areas of deeper peat are up to 8 m deep[8] but generally from 2 to 6 m in depth. Their surfaces are mainly composed of *Sphagnum* species and are locally very wet, although pools of water are uncommon" and that, in places at least, "the area consists of several raised bog units united by blanket bog" – a feature which made them difficult to classify.

The Roman Wall Country mires have received surprisingly little published documentation and details of the peat and sub-peat topographies of some examples have been examined as part of the present project. Ombrogenous peat occupies a variety of troughs, basins, half-basins and ridges of various shapes and sizes, and is itself very variably conformed, forming gently-sloping axial deposits in some troughs (Muckle Moss, Pearson, 1960; The Lakes); elliptical domes independent of the basin topography (Hummel Knowe Moss, Clymo, 1980); domes stretched over ridges (Steng Moss, Davies & Turner, 1979) or over both ridges and hollows (Coom Rigg Moss, Chapman, 1964a); ridges of deep peat across a variable sub-surface topography (Butterburn Flow); along with a variety of slopes, tilted domes, partial domes and bulges (Fellend Moss, Davies & Turner, 1979; Walton Moss, Hughes *et al.*, 2000). Some deposits are largely unconfined, some largely confined, and others lie somewhere in between. In some instances, as at Coom Rigg and Butterburn, the ombrogenous peat appears to have become melded into a single, coherent unit across a range of relief. In others, including some examples where differences in relief are greater, separate deep-peat units can be recognised, often connected by thinner ombrogenous peat on the steeper slopes (*e.g.* Grains Head Moss). It is very possible, given time and lack of interference (drainage *etc.*) that some of these systems in the English Borders may develop more by way of an over-arching surface of ombrogenous peat than is currently the case, perhaps comparable to that reported from Chat Moss, and thereby iron out some of the sub-peat topographical wrinkles, but it should be recognised that the extent to which this may be possible is dependent on the balance between peat accretion and decomposition, and the limits that this places on the maximum depth of peat than can accumulate, even in favourable circumstances.

8 Though in fact many are more than 10 m in depth.

2.4 Some characteristics of ombrotrophic peat deposits in the uplands

2.4.1 Characterisations by British Geological Survey and the Soil Survey of England and Wales

The maps of the British Geological Survey show the distribution of peat deeper than about 1 m but do not discriminate different types within it. In some of their *Memoirs* authors refer to the categories of 'hill peat' and 'basin peat', leading to the presumption that there must be some, if unspecified, difference between them. However, a comment of Day (1970) in the account for the area around Bewcastle, which contains a number of the Border Mires, is illuminating. He stated that the separation of hill and basin peat "depends not so much on differences of growth, composition and appearance but rather on their geographical setting."

It may be supposed that the Soil Survey of England and Wales collected numerous cores from peatland sites which would have been relevant to this present enquiry, but few have been published, nor are most others freely available. Without such profiles, their maps of Soil *Associations* are of limited use for this work, not just because of the small scale of the mapping, but also because Soil *Associations* are composite units that can contain a variable range of soil types. Where they are available, Soil *Series* maps may have greater potential value.

In England, two main soil series have been distinguished for raw, acidic peats, Longmoss and Winter Hill, both recognised as oligo-fibrous peat soils. The difference between them, as given by Burton & Hodgson (1987), is that Longmoss series soils "are formed in *Sphagnum* peat" whilst Winter Hill series soils "are developed in mixed *Eriophorum* and *Sphagnum* peat". However, the profile description of Longmoss soil provided by Kilgour (1985 shows only the top 75 cm as fibrous *Sphagnum* peat; below that, to 110 cm depth, was *Eriophorum–Calluna* peat, and, as some peat profiles indicate (see below), the distribution of *Eriophorum* remains in lowland ombrogenous peats can vary considerably, both laterally and vertically, in the upper layers of some deposits. In some other publications of the Soil Survey, Longmoss series soils are equated with 'raised peat', Winter Hill with 'blanket peat' (*e.g.* Jarvis *et al.*, 1984), and with it the presumption that these peatland categories can be identified by other criteria. However, in the Brampton area, Walton Moss is mapped with Winter Hill series soils but is described as a 'raised bog' (Kilgour, 1985).

Longmoss association soils do not appear to occur in Wales, and Winter Hill association soils are highly localised (as mapped). The principal soil series of ombrogenous (and related) peatlands is the Crowdy series, described as "raw oligo-amorphous peat soils… developed in humified peat" (Burton & Hodgson, 1987), their separating feature being their rather amorphous character. The Crowdy series is dominantly a feature of blanket peat but "The famous lowland raised bogs at Borth and Tregaron are included. These have floristic and pedological affinities with blanket bogs, the peat having both amorphous and semi-fibrous layers unlike the dominantly fibrous peats of raised bogs elsewhere."

It thus appears that the Soil Survey's soil series rather encourage the view that they provide little clear basis for the differentiation of different types of ombrogenous peats in England and, especially, Wales, even in those areas for which soil series maps are available. Nonetheless, it may well be the case, at least in parts of England, that some of the greater domes of ombrogenous peat in the lowlands have particularly well-developed *bouffants* of pure-ish *Sphagnum* peat.

2.4.2 Peat profiles (various sources)

Although a considerable number of profiles have been published from ombrogenous 'blanket peats' in various parts of Britain, little attempt seems to have been made to make a systematic synoptic comparison and characterisation of these, or to compare them with lowland ombrogenous peats. Nor is it possible to attempt a wide-scale review as part of this project, but an attempt has been made to examine the reported characteristics of some published peat profiles in the areas which have been examined in the field. It should be recognised that this very much represents 'work in progress', and a more complete examination of available information, along with the extraction of data from less readily-available sources, would be desirable.

The coverage of upland sites by peat profiles, which have often been made for purposes other than examination of mire stratigraphy and development, is patchy. Particularly little attention has been given to shallow upland peats, or to the margins of deeper deposits (Moore, Merryfield & Price, 1984). This may be partly because many peat profiles have been published as adjuncts to pollen analytical investigations, for which deeper deposits may yield a wider age-range of material. This may also explain why only single profiles have been published for some sites. There are also significant areas of ombrogenous peat in the uplands for which peat profiles have not been made (or, at least, not reported). Some upland areas, such as the Stainmore area of the north Pennines, show a clear differentiation of the vegetation cover (Lewis, 1904; Pearsall, 1941) but neither of those authors provided peat profiles or topographical data. The availability of appropriate data has constrained the selection of the examples considered below, but an attempt has been made to include both some well-known stratigraphical information from well-documented sites, along with data from less familiar sources.

The stratigraphical accounts have been divided into those pertaining to 'blanket peats' and those relating to 'basin peats', but it should be recognised that neither category has a clear or agreed compass and that different authors may well have used them rather differently.

2.4.2.1 'Blanket (Hill) Peats'

2.4.2.1.1 Moor House and Upper Teesdale

Johnson & Dunham (1963) described what they regarded as 'blanket peat' at Moor House and provided some detailed peat profiles to accompany this. They stated that "Almost all of the area of the Reserve is covered by blanket peat up to 2500 ft [762 m] OD which varies in thickness from 1 to 12 ft. [0.3 to 3.65 m] thick on flat ground." They reported a broadly consistent profile across their samples:

> "The general sequence of peat layers [from the base upwards] … starts with a thin band of stiff amorphous peat which overlies the mineral substrate. This thin band is overlain by the basal forest layer which varies in thickness over the area and often contains abundant stems, boles and roots of stunted birch trees… Overlying the forest layer a compact, well humified, sticky peat mainly composed of *Eriophorum, Carex, Calluna* and *Sphagnum* is invariably present. This peat varies greatly in thickness on the Reserve and in this region the dominant peat forming plant in it is almost certainly the cotton grass *Eriophorum vaginatum*… *Sphagnum* may or may not be visible to the naked eye but is almost always found to be present on examination of the peat in the laboratory. *Calluna* occurs scattered through this layer and sometimes forms thin bands in the peat."

There were several variants on this overall pattern and, in particular:

> "In many places on the reserve below 2100 ft. [640 m] a thick layer of peat containing the papery rhizomes and leaves of the reed (*Phragmites communis*) have been found. The *Phragmites* (reed–swamp) peat occurs either low in the *Eriophorum–Calluna–Sphagnum* layer or in the underlying forest stratum. The latter association of wood with reeds suggests a fenwood period during peat formation, though the conditions may have been wetter than this in some cases especially where *Phragmites* is found with the bog bean (*Menyanthes trifoliata*) suggesting an aquatic peat and very wet soil conditions."

Unfortunately, Johnson & Dunham did not indicate the topographical circumstances from which their profiles were taken. They also noted that the basal forest layer became thin or absent at high levels, which they suggested might reflect the position of the treeline, but some of their samples without a forest layer were from lower altitudes. (*e.g.* at 1800 ft [549 m] at Bog Hill). Some of their profiles contained a band of macroscopic *Sphagnum*, either forming a band with the *Eriophorum–Calluna–Sphagnum* peat or forming a surface layer, which they suggested might be evidence of on-going active peat formation.

Downstream of Moor House, Turner *et al.* (1973) adopted a rather different approach to categorising the ombrogenous deposits of the upper Tees valley and on Widdybank Fell. They regarded 'blanket peat' as a deposit which covered "a fair proportion of the steeper ground within and around the reservoir basin and also on the Fell…which varies in depth and often merges into the deeper areas of basin peat. This blanket peat tends to be highly humified and, where plant structure can be seen, to consist of *Calluna vulgaris, Eriophorum vaginatum* and *Sphagnum.*" They were able to examine extensive sections of the deposit near the valley bottom that had been exposed by construction of the Cow Green dam and noted that "the peat varied in depth from 0.5 to 1 m and there was a distinct positive correlation between the depth and the amount of birch wood at its base. The deeper the peat, the more wood there was." Almost everywhere, even on the steeper slopes, they symbolised this peat as an *Eriophorum–Sphagnum* mix, and the one profile reported, only about 0.8 m deep, showed a basal layer of organic material and highly humified compact peat, becoming less humified upwards and giving way to a fairly fresh *Sphagnum* peat between about 0.1 and 0.6 cm bgl. They considered that most of the present areas of ombrogenous peat were in existence between about 3000–2500 BP.

Other areas of ombrogenous peat in the upper Tees valley were categorised by Turner *et al.* as "relatively deep peat" and appear not to have been regarded as a form of 'blanket peat'. These authors provided some quite detailed and informative sections across some of the mosses, and two of the best characterised are discussed (and re-drawn) under the heading of 'Basin Peats' (below), but the other sections, not considered here, are also illuminating. The sections of the two mosses considered below make it clear why Turner *et al.* deemed it appropriate to recognise two main types of ombrogenous deposits, with thin blanket peats on mostly steep slopes and developed more-or-less directly upon mineral soil, contrasting with areas of "relatively deep peat" on flatter surfaces, where ombrogenous peat has developed over fen peat (monocot peat with wood fragments) and in places over shallow limnic sediments.

2.4.2.1.2 Southern Pennines

Conway (1954) did some stratigraphical and pollen-based work in the southern Pennines, including samples from flattish areas on top of the hills (Kinder Scout and Bleaklow), where the peat was often deeper than 3 m and on lower hillslopes (Woodhead) where the peat was shallower (*c.* 1.5 m). The summit peats (518 to 640 m aOD) provided evidence of a highly humified basal peat "lacking *Sphagnum* and sometimes containing wood. This layer is rarely over 50 cm thick and usually about 30 cm." It was covered by a fairly uniform peat, ('Lower Peat') usually with microscopic remains of *Sphagnum* and often with a prominence of *Eriophorum vaginatum.* Above this was an "Upper Peat which is much less compact, and usually shows banding, or alternation between fresh Sphagnum peat layers and more humified". By contrast, on the slope at Woodhead (365 m aOD) the shallow profile was "compact throughout and *Eriophorum vaginatum* remains are the chief feature visible in the field. It is in fact the type of peat that has given rise in the older literature to the view that all southern Pennine blanket peat has been formed largely by this species… *Sphagnum* has been present from time to time at the site, but the pollen frequencies show that Ericoids and Cyperaceae (presumably mainly *Eriophorum* spp.) have been far more important here than in the *Sphagnum*-rich peats of the summit areas." In a Kinder Scout core there was a "great frequency of samples with abundant *S. imbricatum*.", below about 0.6 m bgl. However, Tallis (1964c) commented that, based presumably on peat data, "It is almost invariably confined to the deeper, more central peats, and usually occurs remote from the larger drainage systems", though on Featherbed Moss he also reported it towards the slopes (Tallis, 1964d).

Overall, Conway (1954) summarised her findings:

> "that on surfaces above 1200 ft. (370 m.), with poor drainage, peat formation became general at the time of the Boreal–Atlantic Transition, somewhere around 8000 years ago. At the lower altitudes within this range, and at higher altitudes in sheltered or slightly flushed areas, the earliest accumulation of organic matter took place beneath a cover of alder–birch wood of varying density. … The rate of peat formation was slow at first and increased later, but, whereas at lower altitudes the initial rates were very low, and *Sphagnum* peat developed only in recent centuries, if at all, at higher altitudes *Sphagnum* became an important peat builder at an early stage and the rate of growth of fresh *Sphagnum* peat became so great in the last two millennia that the peat blanket tended to develop its own drainage system and became readily subject to erosion. The highly humified 'Cotton-grass peat' described by earlier ecologists (for example, Lewis & Moss in Tansley (1911)) is characteristic of the thinner peat blankets, 2 m. or less in thickness, on the lower and more accessible shoulders between 1200 and 1600 ft. (366–488 m aOD). Cotton-grass remains are, however, evident in the lower half of the thicker peat blanket found higher up. It is the upper half of these deeper peats which characteristically contain *Sphagnum* remains which are so fresh as to be obvious in the field."

Tallis (1964a) examined the stratigraphy of three parts of the southern Pennines, including part of Kinder Scout. He broadly confirmed Conway's finding, but reported more clearly the occurrence of a variable number of distinct bands of less humified *Sphagnum* in the 'Upper Peat', recognising three at Kinder Scout and five at one site on Wessenden Head Moor. These were separated by more humified peat (still usually with some *Sphagnum* remains) and may represent an alternation between wetter and less wet surface conditions. Some of the horizons recognised appeared to correlate with horizons already recognised by Conway (1954). A prominence of *S. imbricatum* remains in a peat examined near Snake Pass was generally, but by no means exactly, associated with the fresher bands of less humified peat (Tallis, 1964c). He also found (Tallis, 1964b) that, along a short transect on part of Wessenden Head Moor, at around 500 m aOD, peat formation everywhere started later than the Boreal–Atlantic transition suggested by Conway, and began earliest in what appears to have been a small valleyhead location, in Pollen Zone VIIa and later on a flanking interfluve (beginning of Pollen Zone VIIb. At Featherbed Moss (Snake Pass) (*c.* 510 m aOD), a similar relationship seemed to apply (Tallis, 1965). Here, along a short (380 m) section downslope from the interfluve, the summit peats contained little *Sphagnum* but this increased in abundance, and to some extent composition, downslope, associated with a drop of only about 2 m. Tallis (1965, 1994) also provided evidence for the possibility that the upper banding of fresh *Sphagnum* peat with more humified material could reflect patterns of climate change during the last 1000 years, but in general conditions appear to have been drier, and peat accumulation rates slower and date of initiation lower, on the crest of the interfluve than on slopes not far below it.

2.4.2.2 'Basin Peats'

'Basin peats' are also ill-defined and can include sites that are not ombrogenous. Even when restricted to ombrogenous examples, such sites are widely variable in their characteristics and stratigraphy.

2.4.2.2.1 Moor House and Upper Teesdale

At Moor House, the stratigraphy of the 'basin peat' deposits at Valley Bog is so different to that of the 'blanket peats' that it is unsurprising that Johnson & Dunham (1963) considered it to be a fundamentally different mire unit. The profile reported by these workers was some 9.3 m deep, of which the bottom 2 m was some form of lacustrine or detrital sediment. Above this was some 3.5 m of monocot peat, with wood fragments and generally small amounts of *Sphagnum.* What appears to be ombrogenous peat occupies the top 3 m of the profile, split fairly evenly between a lower, humified layer of *Sphagnum–Eriophorum–Calluna* peat, and a less humified, more *Sphagnum*-rich peat above this. A subsequent core by Chambers (1978) was broadly similar to this, but showed less clear evidence of the surface ombrogenous layers. Both cores, however, showed a clear layer of *Paludella squarrosa* between 5 and 6 m depth bgl, which can mark the transition to ombrotrophy.

By way of comparison, Red Sike Moss, at the eastern end of the Upper Tees basin, shares some of the properties of Valley Bog, in an attenuated way: it occupies a shallow hollow, has some stratigraphical evidence for (thin) lake or swamp muds and a basal deposit of *Phragmites* peat, usually with some woody fragments and about 1.3m thick in the centre, which thins towards the margins into a well-humified sedge peat. This layer is overlain mostly by a *Sphagnum–Calluna–Eriophorum* peat, though with more pure *Sphagnum* peat in a few places, including a slight hollow. This ombrotrophic layer is typically some 2 m deep, and the total peat thickness reaches about 4 m in the centre of the deposit. As a whole, the mire is isolated, forms a shallow, broadly elliptical 'dome', has a 'lagg' stream along its eastern flank and a *Sphagnum*-rich vegetation which is probably referable to M18. However, the stratigraphy of many of the individual peat profiles is generally within the range of those regarded as 'blanket peat' by Johnson & Dunham (1963).

A similar comment can be made for Foolmire Moss, which occupies irregular but not strongly sloping terrain along the south side of the Tees, and for which Turner *et al.* (1973) have provided a section broadly parallel with the river. Most cores consist of a thick basal layer of monocot peat (*Phragmites* and Cyperaceae) with woody fragments capped by a fairly thin (up to *c.* 1.5 m) layer of *Calluna–Eriophorum–Sphagnum* peat, which may form less than one third of the profile. These profiles are thus indicative of a former riverside fen which has become covered by a fairly shallow depth of ombrogenous peat. The cores from the valley bottom differ from those on the adjoining hillslope in that the latter lack a basal monocot–woody layer but consist just of fairly thin *Calluna–Eriophorum–Sphagnum* peat, of similar thickness to that in the valley-bottom profiles but deposited more-or-less directly on the mineral slopes. The stratigraphy of the valley-bottom peats is clearly different to that of the thinner peats of the hill slopes, but might well come within the range of profiles regarded as 'blanket peat' by Johnson & Dunham (1963).

2.4.2.2.2 Craven District

Harley & Yemm (1942) described a range of features of Thornton Mire, including the topography and peat stratigraphy of the basin. The mire occupies a section of a rather short, narrow and steep-sided col at about 385 m aOD between two 'Yoredale-series limestone' hills (Stake Fell, 487 m aOD, and Addleborough, 357 m aOD), where eastwards-drainage is thought to be impeded by the remnants of a small moraine. There is a quite extensive development of poor-fen vegetation, in places with oxyphilous nuclei, mainly around the margins of the peat deposit, but there is also a large, possibly ombrotrophic, area, with much *Calluna* and some *Eriophorum vaginatum.* This occupies a shallow (up to *c.* 1 m thick) surface of 'acidic peat' over a deeper (*c.* 2 m) layer of 'fen peat', which occupies the floor of much of the basin. A subsequent profile, apparently from outwith the 'ombrotrophic' area has shown some 3 m depth of monocot peat, not strongly humified, layered with somewhat more humified material containing wood fragments (Honeyman, 1985). The start of peat formation was dated to about 8500 BP. The minerotrophic zones are fed by water (both groundwater outflows and surface flows) from the flanking hills; flows from the south are particularly copious and probably account for the eccentric placement of the ombrotrophic area towards the northern margin of the peatland. The surface of the putative ombrotrophic area was generally less than 1 m above that of the surface of adjoining marginal '*Juncus* swamp', but it did have a higher water table. Nonetheless, Harley & Yemm considered that their 'Callunetum' was not entirely ombrogenous, but that there may have been longitudinal seepage of water down the centre of the mire, sufficient to influence the hydrochemistry of some of the pools in that area and the water table associated with what appears to be a shallow ombrotrophic *surface*.

Harley & Yemm also commented that "Despite these special features of the vegetation and hydrography, the Mire bears a striking superficial resemblance to the raised bogs described by Godwin & Conway (1939) and Tansley (1949) … The most striking points of difference between Thornton Mire and the raised bogs described are the slight elevation of the central region, so that the contours are dominated by the east to west slope of the surface, and the absence of a typical raised bog 'regeneration complex'."

A better-known example of 'basin peat' in the north-central Pennines is provided by Malham Tarn Moss (*c.* 375 m aOD) (Pigott & Pigott, 1963). This consists of a thick ombrotrophic peat that has accumulated by terrestrialisation over a former marl-depositing lake, interrupted by mounds of glacial material, one of which (Spiggot Hill) penetrates the surface of the peat. The stratigraphy is variable, but shows about 1 m depth of marl, covered mostly by fen peat with woody remains, often only about 0.5 m thick, but deeper in places, especially towards the margins. This is capped by up to about 6 m of ombrogenous peat, with a thin, well humified basal layer of up to about 0.5 m thickness and a strongly-humified surface cap, but otherwise fairly fresh. The lower half of this deposit appears to have been fairly pure *Sphagnum* (*imbricatum*) peat, whilst remains of *Eriophorum vaginatum* were more prominent in the upper two metres or so. There are two or three (depending on viewpoint) 'domes' of peat, in places mounded across sub-peat topographical highs, in others apparently influenced (perhaps determined) by them, though the occurrence of extensive past turbary hampers any consideration of natural surface contours in parts of the site.

2.4.2.2.3 The Border Mires

In the Roman Wall Country, Muckle Moss (Pearson, 1954, 1960) must clearly be regarded as an example of 'basin peat' and has a distinctive stratigraphy. In the western part of the trough, basal detrital muds, up to about 1 m deep and with macro-remains of a range of hydrophytes and helophytes, are covered by a thin horizon of brushwood peat, mostly apparently with remains of birch, and only some 0.15 m thick, but which also extends to a considerable extent up the slopes of the trough. The woody peat is replaced by a *Sphagnum* peat, more than 10 m deep in the middle of the trough. This generally declines in humification upwards and in places appears to have been too unconsolidated to sample. The lower peats contain frequent remains of *Eriophorum* and ericoid twigs, but these are less prominent in the uppermost 3 m of *Sphagnum* peat. At the margins, there is a cap of *Eriophorum* peat, which wedges out towards the centre of the trough. It is possible, but by no means certain, that this underlies some of the M19 vegetation, mapped as forming an outer-zone around the more central M18.

At least the eastern part of Hummel Knowe Moss also appears to have developed from a shallow lake and has accumulated more than 10 m depth of peat (Clymo, 1980). Only a single stratigraphical core is available, which shows some 2.5 m of basal *Phragmites* peat containing seeds of some aquatic species. This was covered by a rather amorphous peat with remains of *Eriophorum* and ericoid plants. Upwards, above about 6 m bgl, remains of *Sphagnum* are much more obvious, though still with *Eriophorum* and ericoid material.

Coom Rigg Moss has also developed in places from shallow water or swamp and, in this location, “shows a sequence of fen peat, brushwood peat and *Sphagnum–Eriophorum* peat and may be called a ‘raised bog’ profile”, some 6 m deep (Chapman, 1964a). Juxtaposed with this, mostly over higher ground (ridges), is a shallower peat developed by paludification. This peat consists of up to 3 m of *Sphagnum–Eriophorum* peat lying directly upon glacial drift. This peat increases in humification down the profile and the basal peat is dry, stiff and highly humified, and was referred to as a ‘blanket bog’ profile. There is no doubt that peat profiles from these two areas are strikingly different in their depth and some of their characteristics. However, their stratigraphical differences relate essentially to the lower parts of the profile. Near the top both have, as assessed from Chapman’s data, very similar peat and, in their coalesced form, supported essentially the same type of vegetation (a type of M18). There is therefore no reason to suppose that the present surfaces and ecohydrological properties differ materially, based on their different ontogeneses. As most of the area is covered by an over-arching dome of ombrogenous peat, in places spread over ridges, in others independent of them, the deposit has acquired a certain unity of character.

Not all ‘basin peat’ sites in the Roman Wall Country have developed from an initial aquatic phase – in some instances peat initiation seems to have occurred in waterlogged hollows. Thus a profile from Fell End Moss (Davies & Turner, 1979), immediately south of the Roman Wall, shows some 4 m of a basal fen or fen–woodland peat covered by about 1 m of transition-mire peat (with some remains of *Paludella squarrosa*), which gives way upwards into a banded ombrogenous peat with *Sphagnum* and *Eriophorum vaginatum* (and to some extent also ericoid remains) showing some abundance shifts with depth in the profile. In places the surface of the deposits more-or-less follows the sub-peat topography; in others it seems independent of this. Steng Moss (Davies & Turner, 1979) is stratigraphically rather similar to Fell End Moss, and peat both fills apparent basins and stretches across ridges. A profile in a basin was 7.3 m deep and the lower half consisted of fen or swamp peat, primarily *Phragmites* peat with some wood remains. Above this was a *Sphagnum–Eriophorum* peat, with variable amounts of ericoid remains. Profiles in a dome across a ridge were generally slightly shallower, but showed the same essential stratigraphy.

Walton Moss (*c.* 100 m aOD) has up to about 10 m depth of peat within the main basin and a somewhat complex developmental history of fen peat which appears to have formed earlier in the basin than on the gentle slopes outside of it, though these all became accommodated eventually beneath an over-arching dome of ombrogenous peat. Hughes *et al.* (2000) have suggested that “The stratigraphy of Walton Moss may be simplified into three basic units: (1) fen/fen carr deposits; (2) highly humified *Eriophorum/Calluna* peat; (3) fresher *Sphagnum*-dominated peat with localized *E. vaginatum* tussocks.” Within the upper peat, some banding of macrofossils is evident which has been interpreted in terms of phases of different wetness. These correspond partly, but not completely, to similar wetness phases reported from the nearby Bolton Fell. The overall pattern of fen <> highly humified ombrotrophic peat <> less humified *Sphagnum* or *Sphagnum–Eriophorum* peat has been shown by the North West Wetland Survey to be widespread in lowland ombrogenous mires throughout north-west England, though it is not clear to what extent the often striking transition from highly humified to less humified peat is contemporaneous amongst the sites.

2.4.2.2.4 Southern Pennines

Deposits of ‘basin peat’ do not seem to be widespread, or at least are not well-known, in the southern Pennines, though this doubtless depends in part upon the range of topographical variation encompassed by the notion of ‘basin peat’.

In the East Moor area, Lucas Moss has some 4.2 m depth of peat at its deepest and occupies a discrete basin (Sharp, 1997). There is no obvious evidence for basal muds or fen, though there are a few basal woody remains. Peat accumulation is reported to have started before 4190 BP. The recorded cores consist mainly of *Sphagnum* peat, banded or mixed with Cyperaceae peat (Long, 1994). Many of the cores are less humified, and apparently more 'sloppy' in the upper parts of the profiles, especially towards the centre of the deposit, but there is no clear indication of a distinct 'Lower Peat' and 'Upper Peat'

Elsewhere in the East Moors, deposits of deeper peat occupy hollows formed by some shallow valleyheads, and could be considered to form 'basin peat' – the deposits are certainly deeper and different to the peat surfaces on some of the flanking moorlands and Hicks (1971) referred to areas of "deep topogenous bog", in contradistinction to "blanket bog and shallow peats of less than 20 cm depth". She examined "four major topogenous deposits on the East Moor (Ringinglow Bog, Totley Moss, Leash Fen and Hipper Sick" and noted that "one feature common to all the deep peats is that they have formed, at least in part, over areas formerly covered with alder/birch woodland. Her detailed section from Leash Fen showed that this was covered by a humified *Eriophorum* peat and then by a top layer of fresher *Sphagnum–Eriophorum* peat.

Ringinglow Bog near Sheffield was the subject of some early and detailed stratigraphical investigation by Conway (1947). She indicated that fen woodland started to develop and deposited peat along one or more of the main drainage axes of the valley (draining southwards into Burbage Brook) at about the Boreal-Atlantic transition. This peat was minerotrophic in character and was probably irrigated both by groundwater outflows and surface run-off. At about the same time a very slow-growing monocot peat (which Conway referred to as a 'grassy flush') started to form lateral to the woodland, possibly partly because the accumulating fen woodland peat impeded drainage from its flanking slopes. Ericaceous and Cyperaceous peat with small amount of *Sphagnum* gradually accumulated on the flanks of the woodland and then over the fen woodland itself, either because telluric water no longer flooded the woodland (perhaps on account of the development of a deeper drainage system, or because it was modified by passage over or through the adjoining acidic peats. At about the start of the Sub-Atlantic period, there was stimulation of formation of *Sphagnum* peat, especially on the flanking slope (the former fen woodland area may still have been better drained), and this seems to have continued until fairly recent times, leading to the formation of deep peat, especially near the south-eastern corner of the eastern slope where it was up to 6 m deep – probably partly on account of water inflows from the adjoining upland. The highest point, more an extensive 'flat' than an obvious 'dome', forms a water-shedding area, feeding partly into the eastward-draining headwaters of the Porter Brook and Limb Brook valleys as well as south-westwards into the Burbage Brook. The peat shows some evidence for a lower, more humified, peat covered by a less humified peat rich in *Sphagnum imbricatum*. Remains of *Eriophorum vaginatum* occur more-or-less throughout the profile, but become more prominent towards the top and ultimately give way to a modern, *E. vaginatum*-dominated surface. The rate of peat accumulation in the deepest of the Ringinglow profiles is about twice as great, or more, than that of some sites from the Pennines 'proper' (Conway, 1954). Modern drainage streams appear broadly to follow the location of the Atlantic fen woodland, and may still roughly follow their pre-peat courses, and divide the peatland into the eastern 'Ringinglow Bog' and the western 'White Path Moss'. Groundwater outflows are known to occur in some places at the margins of the main peatland area, and support weakly-minerotrophic seepages. It is likely also that outflows occur into the drainage system from the partly-buried Friar's Ridge to the north, and help sustain a minerotrophic soakway system that helps to separate the two main areas of ombrogenous peat.

The 'hill peat' adjoining Ringinglow Bog was of quite different character to that within the main compass of the valleyhead basin. Immediately to the south of the eastern end of the site, a short distance above the road, Conway's site 'H' consisted essentially of *Calluna* peat, lacking *Sphagnum*, though with a reported more-or-less basal layer of peat with "*Calluna and Eriophorum vaginatum* dominant, *Sphagnum* rare", which was considered to have started to form at the start of the Sub-Atlantic period. The peat core reported was 1.2 m deep. A core made in 2023, in what must have been close to the same location, was only 0.35 m deep, almost certainly on account of wildfires and destruction of much of the peat.

2.4.2.2.5 Wales

Stratigraphical data are available from Elan Valley Bog (Moore & Chater, 1969) and Gors Lwyd (Slater, 1976) which seen to refer to the same site though perhaps, as Slater (1976) suggested to two different basin-like troughs with it, draining in different directions. Whether one or two, the site seems to have developed by terrestrialisation of a late-Devensian lake, followed by the accumulation of some 4 m depth of *Sphagnum–Eriophorum* peat on top of minerotrophic deposits (*Phragmites* and brushwood peats). In both studies, but particularly in that of the area examined by Moore & Chater, there is evidence of marginal spread of *Molinia* peat over a former *Sphagnum*-rich surface. "The spread of Molinia at the surface is probably explicable in terms of the erosion which occurred as a result of the cutting back of streams draining into the Ystwyth to the west, together with the possibility of some flushing from the surrounding hills at the margins of the bog" (Moore & Chater, 1969). Fojt (1985) has also reported on another mire basin (Gors Goch) in the Welsh uplands, but this was primarily a vegetation investigation, and stratigraphical data are not presented. In South Wales another late-Devensian basin site has been heavily eroded, but was the subject of detailed stratigraphical investigations (Smith & Cloutman, 1988), already reported in some detail by Wheeler *et al.* (2020) (Annexe 1).

2.4.2.3 Synthesis

The general pattern of peat stratigraphy in 'blanket peats' reported by Conway (1954) from the southern Pennines seems fairly generally applicable, in the deeper examples at least.

It is possible to recognise a generally minerotrophic basal peat of varying thickness and character, sometimes with quite thick layers of monocot / *Phragmites* and/or wood-rich peat. This may be absent, or at least reduced to a very thin layer of deposit, in thin or strongly sloping examples.

Above this is usually a well-humified peat with much *Eriophorum vaginatum* and *Calluna* and in which any *Sphagnum* can normally only be found microscopically. In some sloping situations with thin peat, this may be the main, perhaps only, layer represented.

On deeper peats at least, this humified peat layer is typically topped by a much fresher peat, rich in macroscopic remains of *Sphagnum*, still usually with some *Eriophorum*, but this may vary both horizontally and vertically. Banding of peat with *Eriophorum* remains often occurs in this layer, the fresher *Sphagnum*-rich bands generally attributed to wetter accumulation conditions which, in some instances at least, seem to be related to climate variation.

'Basin peats' are generally more variable than 'blanket peats', but much of their variation relates to the early (minerotrophic) phases of their development. The ombrogenous sequence above this is often similar to that found in blanket peats, with a lower layer of a well-humified sticky peat with much *Eriophorum* covered by an upper-layer of fresher *Sphagnum* peat, though often banded with *Eriophorum*-rich layers. A similar bipartite stratigraphy in the ombrogenous peat occurs in many examples of ombrogenous peats in the lowlands. It is not clear how well this subdivision correlates across ombrogenous peats in the uplands and lowlands.

In some sites the upper layer of peat contains little *Eriophorum*, at least locally, and presents as a rather pure *Sphagnum* peat. This appears particularly to be a feature of some domes of ombrogenous peat and its cause is not really known, though there have been various speculations.

2.4.3 Peat surface patterning and erosion

2.4.3.1 Surface patterning

A distinctive and important feature of some (but by no means all) ombrogenous peatlands is the occurrence of various types of surface patterning, expressed most characteristically as some form of micro-topographical mosaic. Two main broad types have been recognised: 'hummock–hollow' and 'ridge–pool' surfaces. Lindsay *et al.* (1988) and Lindsay (1995) have examined the distribution of surface patterning across ombrogenous mires in Britain and have proposed a system of bog microtopes for categorising the various components of surface pattern. In England and Wales surface patterning, when present, is mostly represented by a hummock–hollow micro-topography and in general, this is best developed in areas that are relatively flat and wet (central areas of raised bogs and on flatter parts of blanket bogs).

Steeper slopes of ombrogenous peat typically support a more uniform vegetation, usually lacking a conspicuous hummock–hollow surface relief, and are generally located over thinner peat deposits. Such bog vegetation is structurally and floristically rather uniform and in some situations it can constitute a degraded form of a more structurally-varied bog surface (Thom *et al.,* 2019), though the former existence of hummock–hollow surfaces on steeper ombrogenous peat slopes remains to be clarified. In many upland areas (*e.g.* southern Scotland, the Berwyns of eastern Wales, and in the Pennines) such slopes tend to support extensive tracts of vegetation dominated by heather and cotton-grass, and in these relatively high altitude, southern and eastern locations, more structurally-varied hummock–hollow complexes are generally associated with fairly flat areas, on the tops of hills or at the bottom of slopes, or on deep peat deposits that have developed over hollows and depressions (Tallis, 1969). Patterned surfaces are sometimes considered to be particularly desirable features of ombrogenous mires, but the reason for their localisation is often not apparent. For example, many of the mires of the Roman Wall Country which, until afforestation initiatives in the 20th century, were probably amongst the least damaged examples of ombrogenous 'basin' peatlands anywhere in England, are notable for their very limited surface patterning (*e.g.* Clymo, 1980; Hughes *et al.*, 2000), despite their surfaces in some instances being very wet (*e.g.* Butterburn Flow, Barber, 1981). Whilst there is some evidence of the loss of pools following afforestation of adjacent land (Chapman & Rose, 1991), as these workers noted there is no clear evidence that this is also responsible for changes observed on un-afforested central parts of these mires, an issue which remains unresolved.

In some locations, particularly in parts of the southern and central Pennines, 'fossil' evidence of a former patterned surface is apparent. At Ringinglow Bog this is suggested by a particular irregularity of the peat surface on the crown of the mire, which coincides with the few remaining plants of *Andromeda polifolia* on the site. Further north, on a 'rounded plateau' area of Marsden Moor (Greater Bobus), Meade (2020) and his co-workers identified patterned surfaces as "a series of shallow pans in the peat, each surrounded by a matrix of taller and denser vegetation, which is often much sparser in the pan itself, where there is a strong cover of *Eriophorum angustifolium* Common cotton-sedge." There were three such areas, all located on relatively deep peat (mostly between about 1.5–2.5 m depth) and two were on 'flat' or fairly gentle (< 5 °) slopes on the plateau. The third had a steeper surface, up to about 10°, but was associated with a small gully at the plateau margin, in what appears to be a 'water collecting' area.

The origin and persistence of surface patterning has been a matter of some debate. There seems to be a general view that, once established, hollows and hummocks seem to be persistent in the long term, though Baird *et al.* (2015) found evidence of apparent long-term persistence of microforms and of their alternation in different places at Cors Fochno in Wales. There is some evidence that the localisation of patterning may reflect sub-peat topographies. At the Silver Flowe in south-west Scotland, Boatman (1983) found some evidence that hummock–hollow complexes were associated with sub-peat ledges and pool systems with sub-peat hollows. At Forsinard in northern Scotland, a pool complex was situated over a hollow in the underlying mineral substratum (Belyea & Lancaster, 2002). Some surface pattering appears to have been established for some five millennia (Moore, 1977), other examples are more recent, the initiation of that on the Silver Flowe dating from around 900 BP (Boatman, 1983.

Tallis & Livett (1994) and Tallis (1994) examined the development of surface patterning along two very short sections in a shallow col on Alport Moor at 515 m aOD, draining east into Nether Roedale Clough and west into North Grain. They showed that the patterning had developed since around 2200 BP upon a featureless and relatively level surface and was primarily a consequence of low peat accumulation rates in the places that became hollows. The cause of initial retarded peat growth in the hollows is not really clear, and the topographical context of the location, with water flow paths, and the presence of a nearby erosion complex, mean that it may be tricky to disentangle autogenic from allogenic processes in the development of the hollows. However, it may well be a response to a climatically-induced increase in surface wetness and constraints upon drainage, and the capacity of *Sphagnum* hummocks in such conditions to grow faster than peat accumulates in the hollows.

2.4.3.2 Erosion and surface patterning

Erosion of upland ombrogenous peatlands is widespread in some parts of Britain, especially in the southern Pennines, and there has been considerable debate about likely causes. Erosion has a long timeline, dating from at least the Middle Ages, and has been attributed variously to natural ontogenesis of the mire, climate (frost, wind, drought and flood), climate change (usually toward wetter conditions), burning, grazing and drainage. In general, because of the long timeline, industrial pollution is not usually advanced as a direct cause of erosion, but it may well have prevented or constrained the natural 'healing' of eroded surfaces because it may have contributed to the loss of

Sphagnum from many moorlands, and because it may have helped to acidify the residual peatland surfaces to a point at which even acidophilic wetland plants find conditions uncongenial for growth.

It is not the purpose of this report to review the numerous issues involved with the erosion of upland ombrogenous peats, but some comment is appropriate about the relationship between erosion and surface patterning, particularly with regard to the anastomosing and sometimes intricate 'Type 1' erosion associated with relatively flat upland areas. Tallis (1985a & b) considered that "there is fairly general agreement that Type 1 dissection systems represent eroded pool-and-hummock complexes, where excess water has been drawn off by a general lowering of the water table." Such surfaces may have developed from pool systems, where contiguous pools have coalesced to form runnels, a process observed to occur in parts of the Silver Flowe (Boatman, 1983). If correct, this proposition carries with it the implication that, for example, much of the heavily-eroded Kinder plateau was formerly covered, in whole or part, by a patterned bog surface – possibly with an M18-type of vegetation. Subsequently Tallis recognised other views that summit erosion may have occurred within "a topographically rather uniform surface" (Mackay & Tallis, 1996) and concluded that "Concrete evidence either way is lacking." Whilst this may well be the case, early on both Conway (1954) and Tallis (1964b, c) had recognised that bands of fresh *Sphagnum* peat, formed it was thought in response to increased wetness of climate, might have limited cohesive properties and be particularly unstable and vulnerable to erosion, and it would seem reasonable to infer that the sort of patterned surface examined by Tallis & Livett (1994) could be predisposed to erosion. It certainly seems to be the case that it is the wetter, perhaps once more patterned, surfaces of some upland bogs that are more susceptible to erosion, as at Waun Fignen Felen (Smith & Cloutman, 1988) and Cors Goch (Ciloerwynt) (Ratcliffe, 1977; Fojt, 1985). Perhaps more contentious might be the suggestion that *in some particular situations* the formation of a patterned system itself may represent an early stage of the erosion process.

3 METHODOLOGY

The methodology used in the present investigation was designed to provide backward-compatibility with the existing data set used for the original Wetland Framework project (Wheeler *et al.*, 2009). Thus field sampling was based on the recognition of representative examples (stands) of distinctive vegetation types and at each sampling point broadly the same variables and rankings were recorded as before. Data analyses also used the same methodologies as before.

3.1 Fieldwork planning

Available national, regional, and local datasets have been acquired (where available) from Natural England, Natural Resources Wales, Environment Agency, Forestry England and conservation organisations such as Northumberland Wildlife Trust (see below). The data provided have predominantly been used to plan which sites to visit and to devise appropriate sampling regimes at each site. Some datasets have fed into the data analysis stage of this project.

- British Geological Survey superficial (peat) GIS layer. British Geological Survey data (2008)
- England Peat Layer GIS files (Natural England).
- Peatlands of Wales GIS files (Natural Resources Wales).
- National LiDAR data GIS files (Environment Agency, Natural Resources Wales). LiDAR DTM 50cm–1m (2019–2021).
- Peat depth data GIS files (Natural England, Natural Resources Wales, Forestry England, Northumberland Wildlife Trust, Northumberland National Park Authority).
- Vegetation survey data GIS files (Natural England, Natural Resources Wales, United Utilities).
- PhD thesis of Angus Lunn (1958), who studied the blanket bog landscape of Northumberland.
- Published accounts of selected sites in the Wales, South Pennines, North Pennines, and mires from the Roman Wall Country of Cumbria and Northumberland (including some Border Mires sites).
- Locations of hydrological installations (Moors for the Future, Natural Resources Wales, Forestry England). However, most of these are either only very recently installed (in 2022), or

are planned to be installed during 2023 or 2024; consequently water level data are not yet available.

- Old hydrological monitoring installations were identified at several Border Mires sites, but the data from these have not yet been located.

A combination of LIDAR data, vegetation maps, peat depths, and aerial images were used to plan the most efficient and effective routes to access each site, with the aim of obtaining sample data from the maximum range of peat depths, topographic situations, and vegetation types at each site. Sites were selected partly based on the availability of existing vegetation maps (*NVC* surveys) and, where possible, other, particularly stratigraphical, information. Otherwise by constraints of access and accessibility.

3.2 Field data acquisition

At each site, samples were recorded from the main ombrotrophic vegetation types, along with some minerotrophic samples. These latter were mostly peripheral or otherwise marginal to the main ombrotrophic peat deposits and included some examples apparently irrigated with groundwater. Where possible, sample locations were aligned along a rough transect, to facilitate the generation of sections of peat and sub-peat topographies. In a few instances this was not readily possible, because samples were taken to be close to existing hydrometric installations, which were not necessarily arranged in a straight line. The time available for the field work precluded any systematic recording of peat stratigraphy, desirable as this would have been, though informal observations were made on the character of the near-surface peat and of the material at or near the base of the peat profile.

Key data collected for representative stands are summarised below, and detailed descriptions of the data categories and the scoring system used in the field are provided in Annexe 1. Single samples were gathered from different vegetation types and, where present, different topographic or surface condition types within the same vegetation unit.

- vegetation type (*i.e.*, *NVC* type): where not already mapped, species and cover values were recorded
- peat depth, using a peat probe (where not already available)
- basic peat stratigraphy (using either gouge or Dutch auger) of the top layer (acrotelm), the lower layer (catotelm), and the basal layer beneath the peat (where this could be ascertained)
- approximate slope of the peat surface
- pH & EC measurements, particularly in minerotrophic areas (using handheld Hanna HI98127 and HI98312 meters)
- presence of pools, water flow tracks, other channels, etc
- surface ‘wetness’
- Presence of peat pipes where evident, or likely to be present
- topographical context of the sample (including notes on apparent water flow paths etc, external to the sample)
- Degree of surface patterning (pool, hummock and tussock microtopography)
- Presence, size and extent of erosion features
- Additional information regarding presence and abundance of *Sphagnum* mosses, and heather height categories.

The ranked data recorded at each sampling point were broadly the same as those recorded by Wheeler *et al*. (2009, Appendix 2, Section 3), but a small number of additional data were introduced to reflect conditions and circumstances that had not been present at most of the lowland sites previously examined.

Peat Surface Configuration (water shedding to water collecting) – introduced partly because at some sites the peat surface topography is not coincident with that of the site as a whole.

Surface Patterning – including an index of pool–hollow–hummock diversity and of tussock diversity (based mainly on *Molinia, Eriophorum vaginatum* and *Trichophorum cespitosum*).

Erosion – based on amplitude and the proximity and disposition of gullies.

Furrowing (associated with afforestation).

Upslope extent of stand and of **marginal slopes** – to accommodate the approximate position of the stand within a long sloping topography.

In contrast, some groundwater-related terms were not estimated. No attempt was made to estimate Aquifer Type or the Piezometric Head category, but some general notes were made on the proximity of potentially water-bearing strata. In those small number of instances where it applied, Groundwater outflow type, Proximity to groundwater outflow and Level of surface relative to groundwater outflow were all estimated in the field.

As the sampling necessarily took place during the winter months, water-related variables all relate to winter conditions. Thus, no estimate could be made of summer water level.

3.2.1 Survey areas

Because of the short timescale of this phase of the project only relatively few geographic regions could be sampled. These comprised the Roman Wall Country of Northumberland and Cumbria (including a number of Border Mires); sites in the Bowland Fells, in north Lancashire, and the North Pennines in North Yorkshire; sites in the South Pennines; and sites in northern and central Wales (see Figure 1). Whilst it would have been desirable to have had greater regional representation, this dataset does have the strength of incorporating sites from a range of northern, central, and western locations throughout England and Wales. Time constraints meant that neither Scotland nor Northern Ireland could be included in the present phase of this project; this should be rectified in future phases.

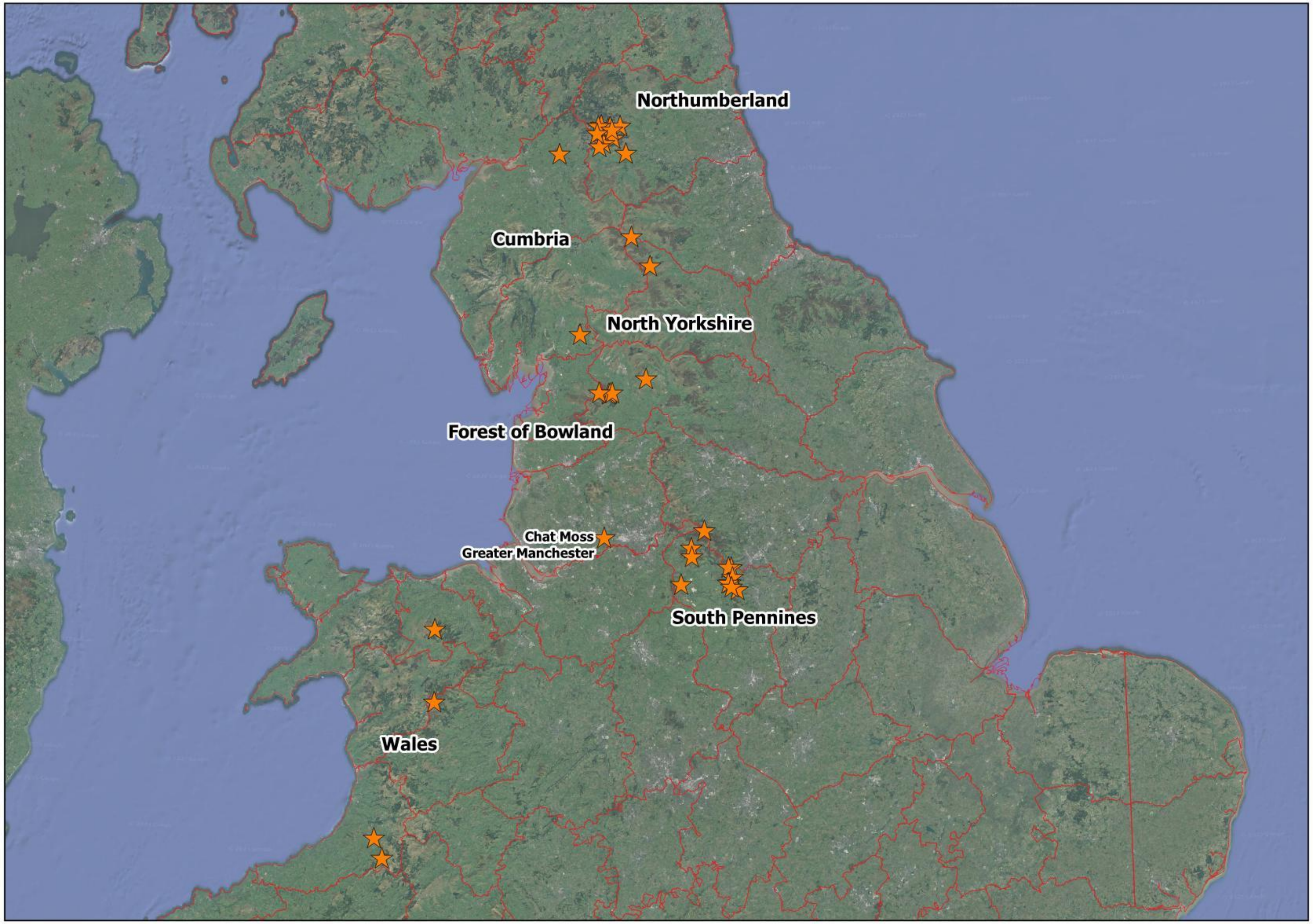
In total 29 sites were visited, comprising three sites in Wales, ten in the Roman Wall Country, ten in the South Pennines, four sites in the Bowland Fells, one in the North Pennines, and one in northern Lancashire (see Figures 2 to 6). In total 236 individual samples were recorded. Sites and samples are listed in Table 2.

Data were extracted from published accounts and Natural England survey data for several additional bog sites (O'Reilly, 2014): Muckle Moss, in the Roman Wall Country (southern Border Mires area); Walton Moss in Cumbria, south of Carlisle; Foolmire and Red Sike Moss in the North Pennines; Malham Tarn Moss in the Yorkshire Dales; Kinder Scout, in the South Pennines; and Cors Caron (Tregaron Bog) in mid-Wales. These were not included in the data analyses but were used to construct informative section profiles of each site for comparative purposes (see Annexe 2 (Section 11.2)), or solely to calculate slope gradients (Malham Tarn Moss).

Table 2. Field site locations, distribution by region and number of samples per site.

Region	Site Name	No of samples	Easting	Northing
South Pennines	Combs Moss	10	404600	375900
South Pennines	Featherbed Moss & Within Clough	10	409110	392085
South Pennines	Langsett Moors	12	414900	399770
South Pennines	Leash Fen	4	429620	373600
South Pennines	Lucas Moss	3	426360	376700
South Pennines	Ringinglow Bog	10	426850	383364
South Pennines	Sandyford Brook	1	426360	376700
South Pennines	Stoke Flats	3	426360	376700
South Pennines	Totley Moss	3	427100	379000
South Pennines	White Path Moss	8	425620	383525
Bowland Fells	Cross of Greet	6	368232	460871
Bowland Fells	Crutchember Fell	6	373032	460532
Bowland Fells	Halstead Fell	6	373280	460955
Bowland Fells	Hasgill Fell	6	372452	460268

Region	Site Name	No of samples	Easting	Northing
North Lancashire	Stone Park (Old Scotch Road)	11	359688	486733
North Pennines	Shaklesbrough, Cotherstone Moor SSSI	3	390800	517100
Border Mires	Butterburn Flow	10	367300	575800
Border Mires	Coom Rigg Moss	11	369150	579480
Border Mires	Felecia Moss	8	372126	577660
Border Mires	Gowany Knowe	8	373050	578750
Border Mires	Grain Heads Moss	11	374550	573700
Border Mires	Hummel Knowe	10	370300	571400
Border Mires	Muckle Samuels	11	367850	579010
Border Mires	Pundershaw	11	377500	579150
Border Mires	The Lakes	11	373850	577350
Border Mires	The Wou	10	368000	570050
Wales	Figyn Blaen-brefi	12	271750	254600
Wales	Hafod Elwy	12	295300	356100
Wales	Moel Eunant	9	295000	323800



Site names and locations are given in Table 2

Figure 1. Survey regions and site locations across the UK.

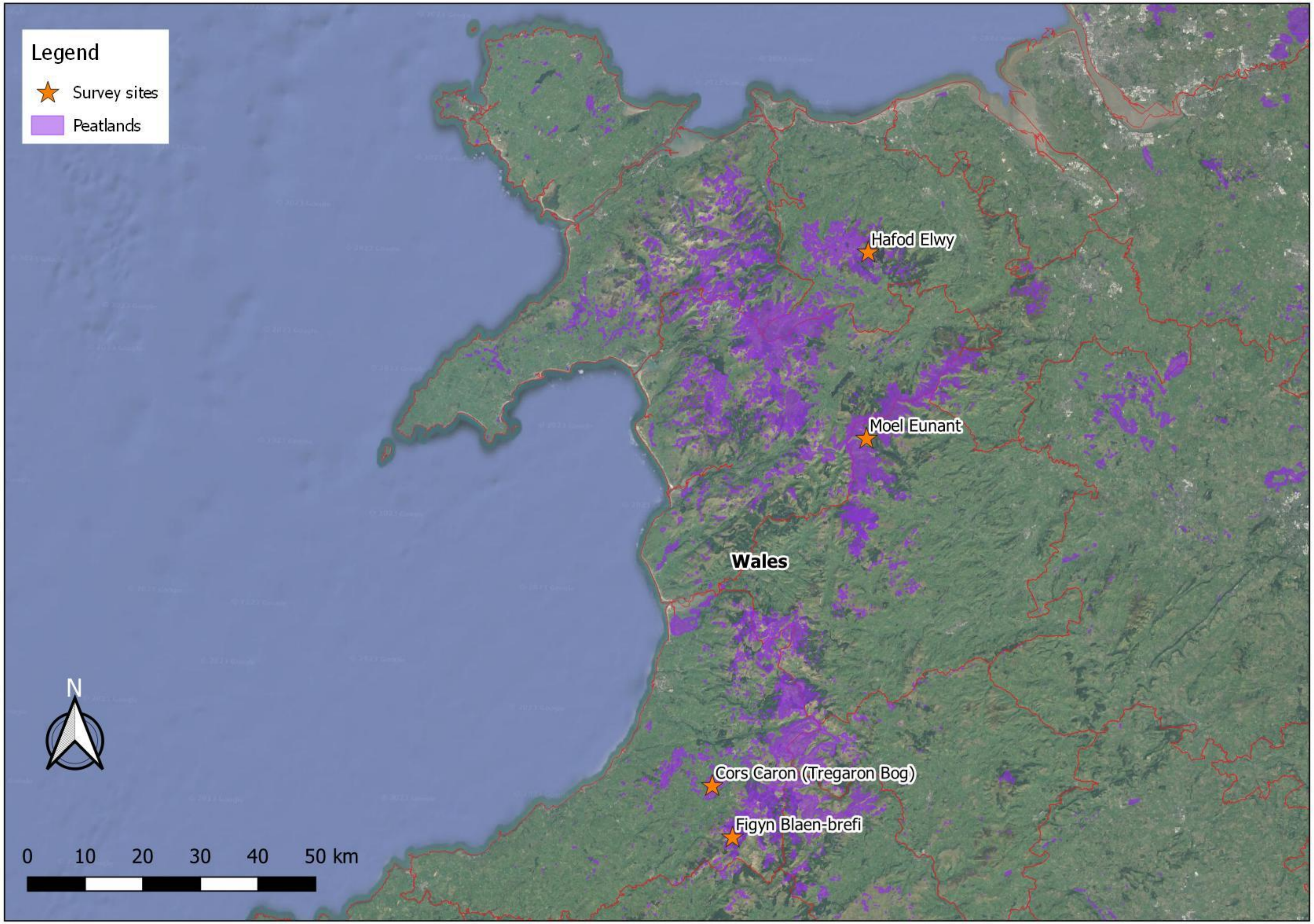


Figure 2. Wales: peat distribution and site locations.

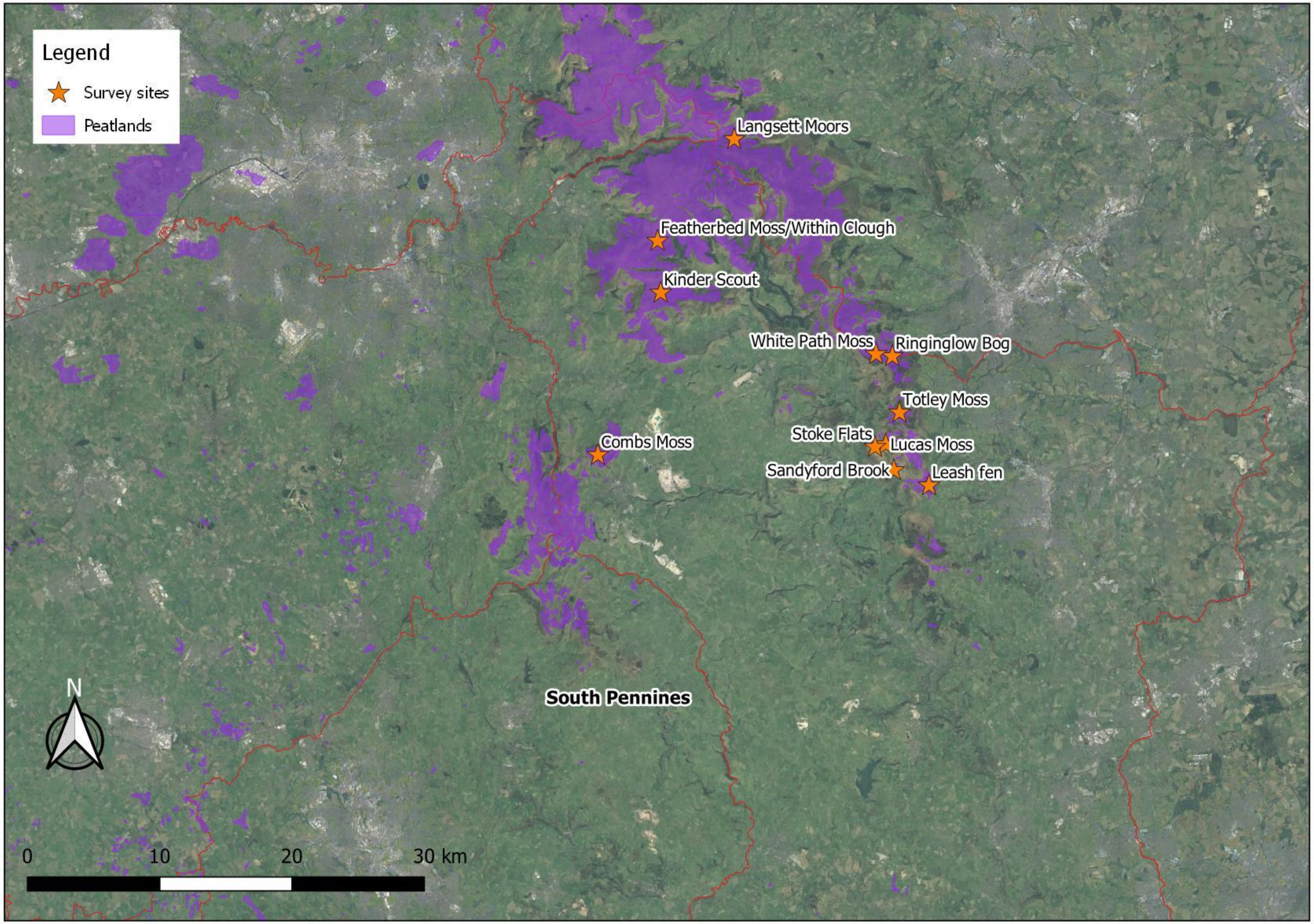


Figure 3. South Pennines peat distribution and site locations.

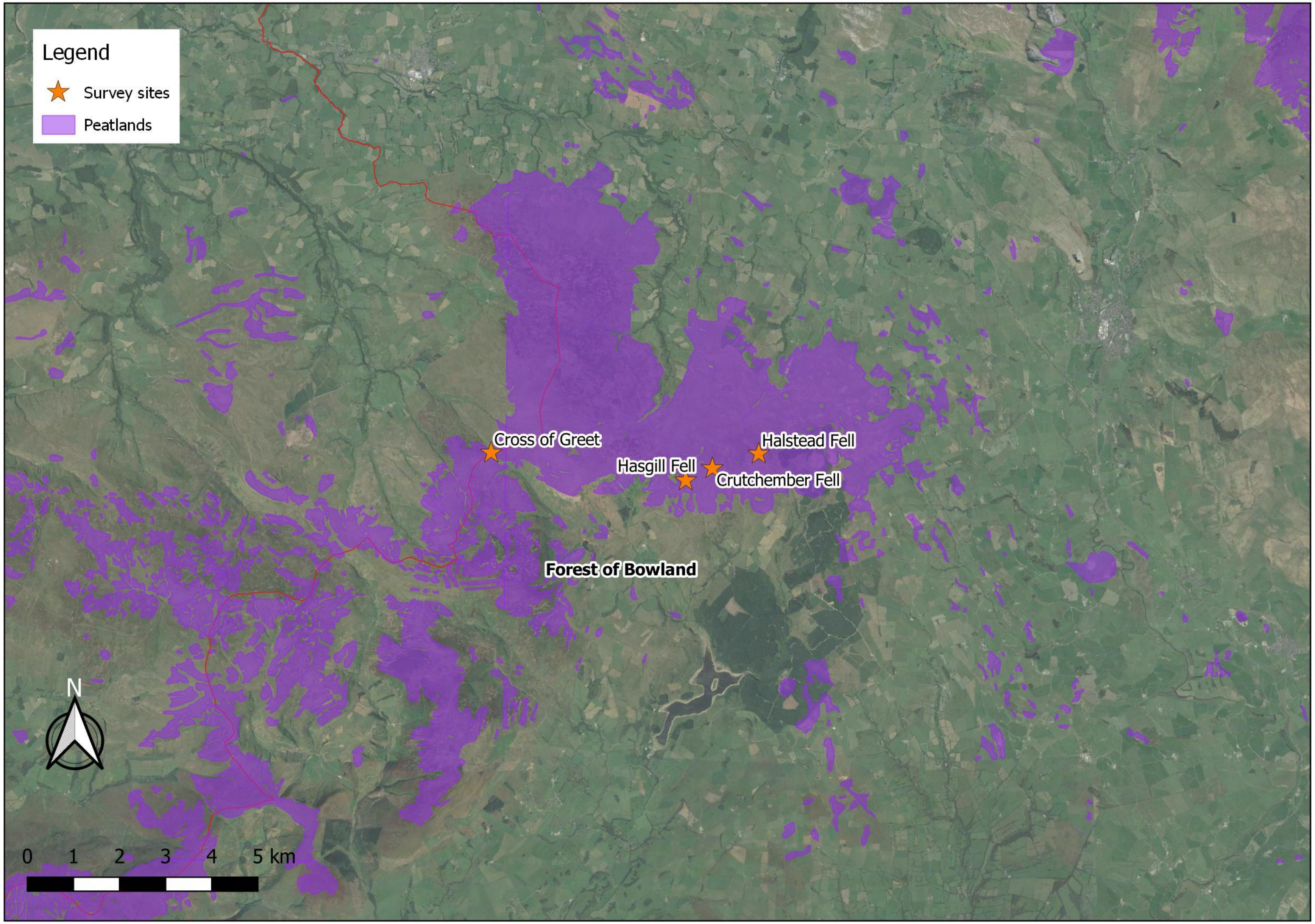


Figure 4. Forest of Bowland peat distribution and site locations.

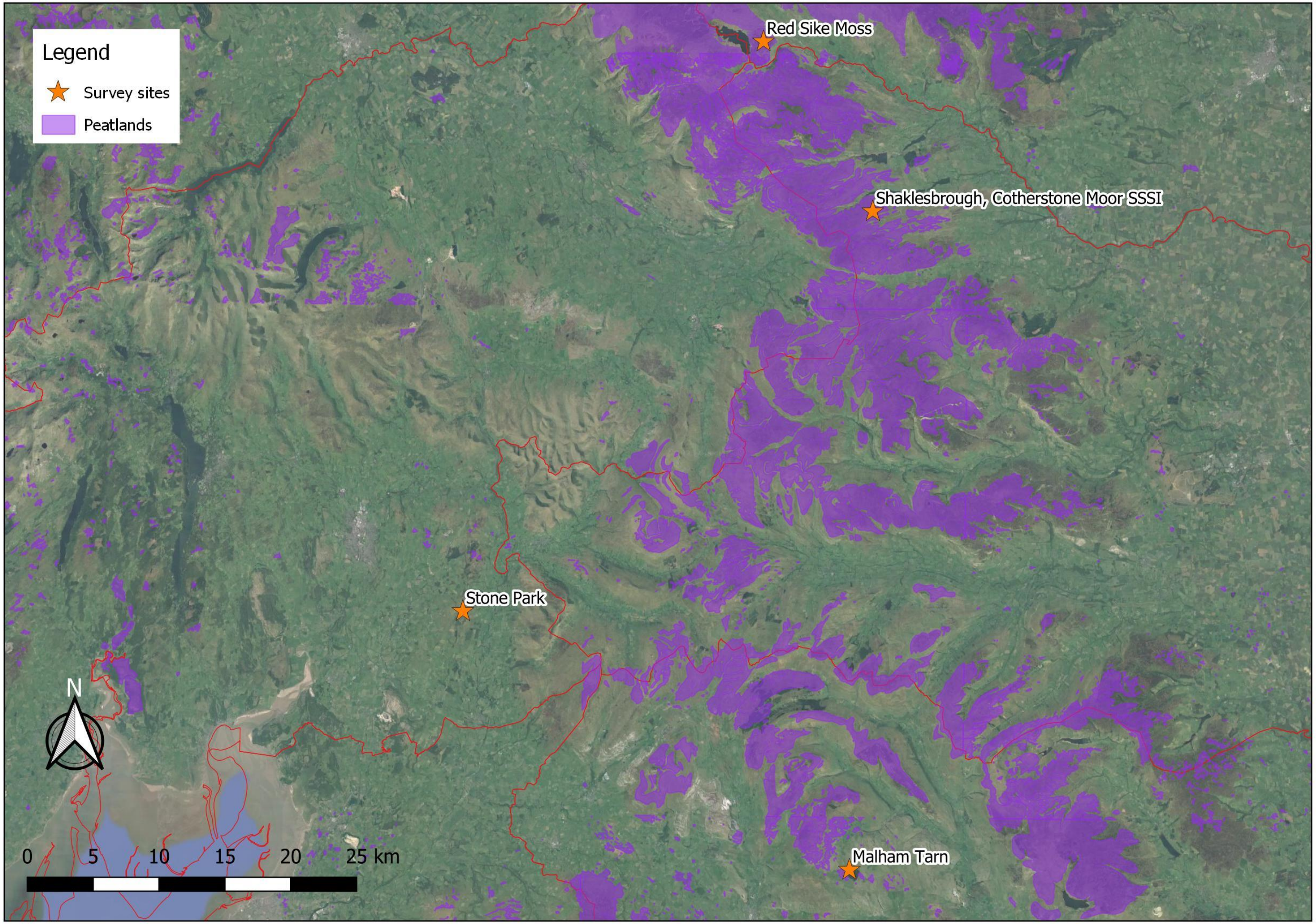


Figure 5. North Yorkshire, North Pennines & south Cumbria peat distribution and site locations.

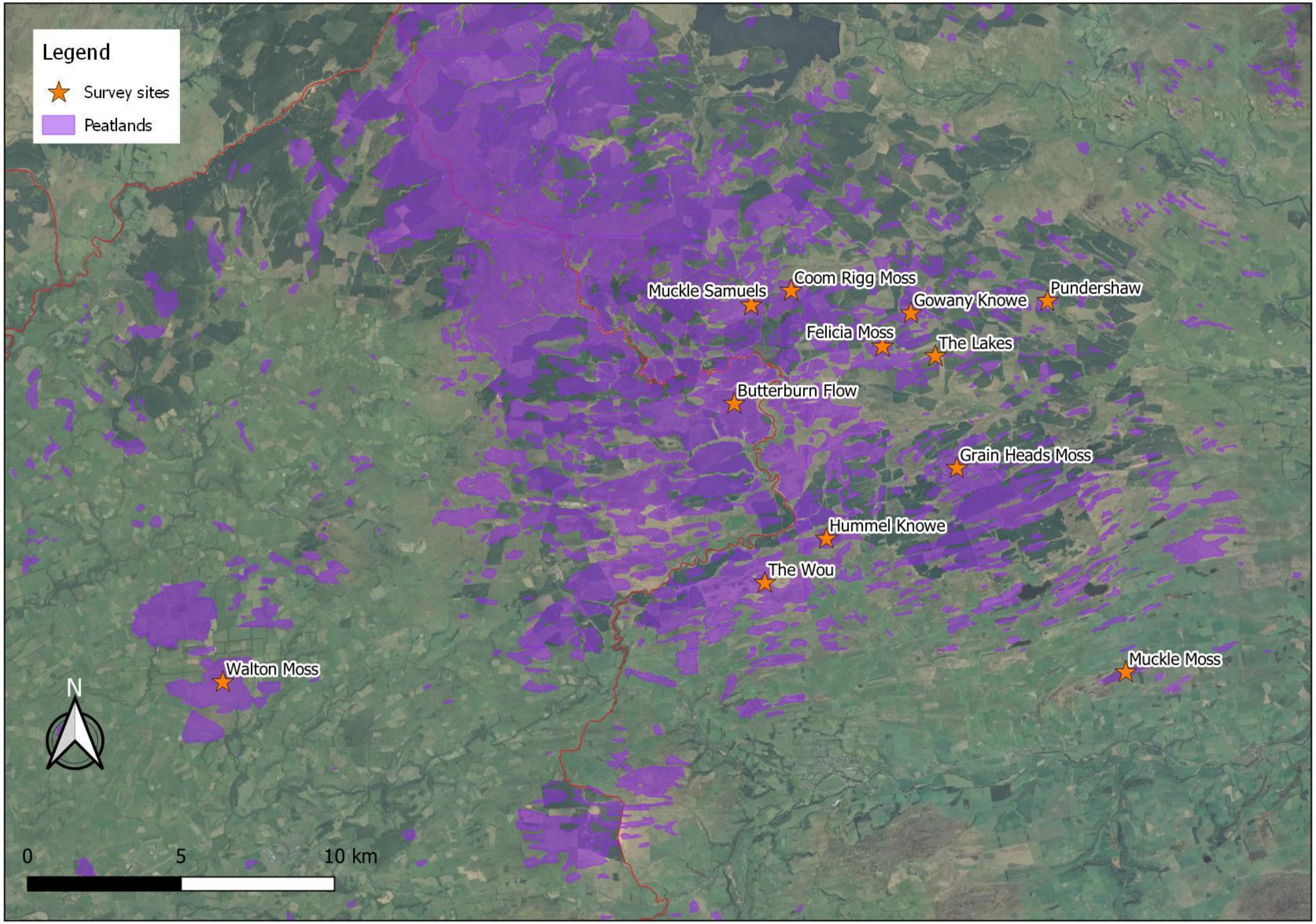


Figure 6. Roman Wall Country (including the Border Mires) peat distribution and site locations.

3.3 The landscape context of the sites examined

Estimates of altitude, mean annual precipitation and evapotranspiration for the sites examined are summarised in Table 3 together with similar information for some reference sites.

The Pennine sites considered were all on Carboniferous bedrock, but vary considerably in their topographical character, the identity and hydrogeological properties of the stratum at rockhead, and the degree of cover by Superficial deposits (Drift). Many of the higher-level examples have little evidence of Till, either because it was never deposited or because it was subsequently eroded. Periglacial solifluction deposits (Head) are widespread, though not always mapped, and can form aprons along the base of some slopes.

The Carboniferous rock sequence of most of the sites considered here is generally regarded as forming a multi-layered aquifer, with water-bearing layers (mostly sandstones and limestones) separated by aquitards (mostly mudstones, siltstones and shales). The extent to which any groundwater outflows occur (both now and, presumably, in the past) depends upon the properties of the rocks, including their propensity for fracture flow (which seems to be the main route for water movement within them), their dip and their potential for recharge (Jones *et al.*, 2000). Some outflows may also be largely prevented or obfuscated by superficial deposits. Head encompasses deposits of strikingly variable character. In some instances these may support groundwater flow from bedrock, so that the eventual discharge point of this at the surface is well down-slope of its stratum of origin.

3.3.1 Southern Pennines

The South Pennine peatlands occupy both a 'shelf and edge' topography along with some longer, less precipitous, slopes and spurs dropping into adjoining valley systems. They mostly occur over a Namurian ('Millstone Grit') bedrock and in some places the topography has a strongly tabular structure, with flattish peat-rich plateaux bordered by steep, often craggy, 'edges' from which peat is generally absent. However, even sites generally regarded as plateaux, such as the Kinder Scout massif, at around 630 m aOD (on Kinderscout Grit), is considerably dissected by valleyheads and has but limited areas that can be regarded as 'flat' (see Figure A10, Annexe 2). Featherbed Top, around 540 m aOD, is some 3.5 km north of the Kinder Scout plateau and is a much less tabular affair. These hills were not covered by Devensian ice and are not plastered with Till, though there are significant areas of Head in some locations, particularly below steep slopes. The Kinderscout Grits can form locally important aquifers (Jones *et al.*, 2000), but any outflows in the southern Pennines seem generally likely to occur lower downslope.

Combs Moss, 2km north-west of Buxton and with a maximum altitude of 507 m aOD, is another extensive plateau, though smaller than Kinder Scout, again edged by small cliffs and steep scarp slopes. The top of the plateau appears tilted, slopes broadly to the north-west, and supports deep peat across the entire surface that reaches approximately 3.5m depth in places.

The East Moors area of the Peak District also provides a good example of 'shelf and edge' topography, but at a lower altitude (between about 300–400 m aOD), with mires developed on flattish surfaces of Millstone Grit that dips eastwards beneath Lower Coal Measures. The deeper peats generally occupy shallow, but often extensive, depressions, in some places extending close to the western-boundary 'edge' and draining over it. One good, small but deep, basin is known from Lucas Moss (Sharp, 1997). In some places thin peats also occur on gentle slopes and ridges, though some of these examples seem more like over-developed peaty podsols or peaty gleys than true peat. In some of these sites the present-day shallow peat cover may be a consequence of past burning and subsequent erosion: "Houndkirk Moor, near Sheffield, was burned in 1958, and 4–5 ft [1.2–1.5 m] of peat has been stripped off subsequently, so that bedrock is now exposed over considerable areas. Much of this loss of peat occurred in the first summer after burning" (Tallis, 1964b).

Many of the sites examined are developed over or below Namurian deposits of Chatsworth Grit or Rough Rock, both identified as potentially important aquifer horizons by Jones *et al.* (2000), or associated with lower Westphalian sandstones (including Crayshaw Sandstone and Loxley Edge Rock) which are likely to be water bearing, and minerotrophic mires have developed on some slopes beneath these. The extent to which groundwater outflow may have had an occult impact upon the hydrodynamics of some of the ombrotrophic mires is an interesting, but largely unresolved, consideration.

3.3.2 Bowland Fells

The Bowland moors occupy the upper slopes and summits (up to 544 m aOD) of generally somewhat rounded hills but with steep marginal slopes and deep peripheral cloughs, and craggy in places ('knots'). The sites examined were generally on slopes towards the tops of the fells (*c.* 400 m aOD), and were upon early Namurian strata, near or across the mapped contact between Brennand Grit (sandstone) and Pendle Grit (interbedded sandstone and siltstone). It seems likely that the fells were once covered by Till but that this has been removed from the higher levels by periglacial processes; Till has been mapped in places up to around 420 m, and may underlie the sites examined, its distribution obscured by the mapping of peat. It is also likely that Head is present on the slopes beneath the peat, perhaps forming aprons towards their base. Pendle Grit was identified as a potentially important minor aquifer in some locations by Jones *et al.* (2000). Brennand Sandstone is also likely to be water-bearing, raising the possibility of some groundwater outflows on or beneath its lower slopes.

3.3.3 Lonsdale

One little known ombrogenous site was examined, for comparative purposes, at Stone Park (near Killington). This occupies the bowl-like headwaters of Burns Beck (which feeds into the River Lune). The site is located at around 190 m aOD in the northward-draining part of a col between two hills of Silurian sandstones (Kirkby Formation), and is itself upon this rock. In the vicinity of the site there is a cover of Till, in places with drumlins, and Till may underlie some of the fairly shallow peat (3.5.m was the deepest measured), but such basal substratum determinations as were possible on the field visit suggest that it was mainly underlain by sandstone or a derived deposit. A number of small streams originate in the valleyhead and appear to be spring fed. Fairly base-rich conditions and fen vegetation occurs over some of the area, but a wedge of slightly domed ombrogenous peat has accumulated between two of the main streams. The site is located in a high rainfall area, and rainfall and evapotranspiration measures are very similar to those from Widdybank Fell some 300 m higher in the north Pennines.

3.3.4 North Pennines (Moor House and Upper Teesdale)

Whilst bordered to the west by the great Pennine Escarpment, the eastern slopes of the Moor House area are relatively gentle, if somewhat irregular, and contribute to a broad valleyhead for the upper reaches of the River Tees (*viz.* the area west of Cauldron Snout). BGS mapping of the area (Sheet E&W 25, Alston) has omitted any peat, presumably on account of its ubiquity, which enables a clearer identification of earlier superficial deposits than is often the case. As mapped, Till occupies much of the valley-bottom alongside the Tees and the lower slopes of the valley sides, up to around 600 m aOD, but is absent from the higher slopes and summits. Much of the area of Till, and much of the higher slopes, appear to be covered by peat. However, there is little evidence of peat at the highest levels, where Johnson & Dunham (1963) suggested a former peat cover has been very largely removed by erosion. Much of the valleyhead is located over what were formerly regarded as 'Yoredale Series' cyclothemic rocks. Upper Alston Formation deposits (generally thin and rather impure bands of limestone banded with sandstones, mudstones and siltstones) occupy most of the valleyhead, with Stainmore Formation deposits forming much of the western summit ridge (at about 850–893 m aOD at Cross Fell), with sandstones, siltstones, mudstones and some thin limestones. Bands of harder rocks, particularly sandstones and limestones impart a 'ledge and edge' topography to the valleyhead slopes and in places springs emerge at their base (Johnson & Dunham, 1963). Towards the eastern end of the 'Upper Tees valley' dolerite intrusions (Great Whin Sill) are evident and in the area of Widdybank Fell have resulted in local metamorphosis of Melmerby Scar Limestone (Lower Alston Formation) into a deposit that, at and near the surface, has weathered into a friable, freely-draining 'sugar limestone'. In this area, at around 500 m aOD, the flattish Whin Sill surfaces are mostly peat covered but flanking sugar limestone deposits do not appear to be. In places, groundwater emerges from the limestone onto the Whin Sill aquiclude.

3.3.5 Cumbria and Northumberland

The Border Mires of the 'Roman Wall Country', straddling the boundary between Cumbria and Northumberland, are quite different in their character and topographical context to the others considered here, and could be said to provide English counterparts to the mires of the Flow Country of Caithness. The area is developed over a south-eastwards dipping sequence of Dinantian rocks, and its southern limit is more-or-less where these pass beneath Namurian (Stainmore Formation) deposits along the bottom of the Tyne valley. North of this the rocks, Alston Formation limestones, sandstones and siltstones along with an associated Whin Sill intrusion, form a series of often narrow ridges and troughs, within which some of the wetland basins are located. Further north of these, and over much of the area of the 'Border Mires', the bedrock is Tyne Limestone Formation, comprised of "cyclical beds of mudstone with either sandstone or limestone beds predominant" (Jones *et al*., 2000). Generally, the grain of the bedrock opens up northwards, and the wetland basins tend to become broader and less elongated east–west. It is thought that the troughs in which most of the basin wetlands occur represent softer rock strata (mudstones etc) that were preferentially scooped by more-or-less west-to-east movement of Devensian ice. Much of the area is covered by Till, deep in places (locally more than 55 m thickness, according to Frost & Holliday, 1980), and with drumlins. "As the ice melted back, lakes, some of which persist to the present day, formed in ice-eroded and drift-dammed basins. In post-glacial times the basins became sites of peat deposition, followed by more widespread development of blanket-peat in the higher parts of the district" (Frost & Holliday, 1980). The ground rises north-westwards towards the Larriston Fells and reaches some 500 m aOD. Hill-peats dominate the northern parts of the area, where they largely have been afforested. This area reaches north-westwards up to around 500 m aOD in the Larriston Fells, whereas the peat basins of the Roman Wall country are mostly at around 200–300 m aOD. The overall difference in the types of peat found across this area is expressed in the soil map, in that the peat areas north-west of (approximately) Paddaburn have been mapped as Winter Hill association soils, whereas those to the south and east of this have been mapped as Long Moss association soils. However, although these latter hollows provide clear examples of 'basin peats', many of them also have thinner peats, more akin to 'hill peats' on their surrounding slopes, and these sometimes straddle the ridges between adjoining basins. Conversely, further north, there are some peat basins embedded within a more general expanse of hill peat.

3.3.6 Wales

Figyn Blaen-brefi

Figyn Blaen-brefi is situated in a broad, shallow, curving valleyhead within the hills to the south-east of Tregaron, in mid-Wales. The mire lies at between 410 m and 430 m altitude in a south-east–north-west trending peat-filled trough bounded by low undulating mineral ridges to the south, north-east, and west that rise 10–40 m above the mire surface, before descending into adjacent valleys. The site is underlain by Silurian rocks, mostly Rhuddnant Grits Formation but with Glanyrafon Formation at the south-easternmost end. Both deposits consist of interbedded mudstone and sandstone, and the sandstones are likely to be water-bearing and may support significant fracture flow. Rhuddnant Grits outcrop along, and rise well above, the southern and western slopes of the trough, but are covered by Devensian Till along much of the north-eastern slope. Till may well underlie much of the peatland area, but this is not known from the BGS mapping. There is visible evidence of apparent groundwater outflow along both the southern and northern margins of the peatland.

Most of the mire of Figyn Blaen-brefi drains to the north-west and then northwards into the Afon Brefi, which then winds its way south-westwards for approximately 3km before joining the Afon Dulas. The far south-eastern end of the mire drains to the south-east into a small stream, the Nant Ganol. The surface of the mire is gently sloping in most parts, with the exception of the highest point near the south-eastern end, which forms a narrow saddle between the rising slopes to north and south. Erosion along the main axis of the valley has resulted in extensive areas of bare peat and a network of channels and upstanding peat haggs which have recently been recontoured and blocked with peat dams to form a series of pools and narrow lagoons. Some of the erosion is roughly dendritic and associated with headwater erosion by the two drainage streams (Davies, 1945). Low (2012) has suggested that some of the irregularities in the peat surface may be a consequence of slumping and slides in what is undoubtedly a very wet site.

Hafod Elwy

Hafod Elwy is located in the Mynydd Hiraethog (Denbigh Moors), a range of hills between Betws-y-Coed and Ruthin, in North Wales. The mire occupies a broad shallow valley that forms the headwaters of both the Nant Y Gors goch, which flows south-west into Alwen Reservoir, and the Nant Bryn-gors-goch, which flows south-east into Llyn Brenig. The mire lies at between 410 m and 420 m aOD, forming a broad saddle at 418 m aOD, between a mineral ridge to the north-west (Cerrig Caws, 459 m aOD), and a slight rise to the south-east (Bryn y Gors-goch, 422 m aOD). Nantglyn Flags Formation rocks (mudstones and siltstone) outcrop on Cerrig Caws, and Denbigh Grits Formation rocks (mudstones, siltstones and sandstones) on Bryn y Gors-goch. Till is mapped to the north-east and, to some extent, south-west of the peatland area, but it is not known to what extent it occurs beneath the peat.

The majority of the mire drains to the south-west, with only a small part draining to the east.

Much of the mire surface has been afforested and recently cleared, and is surrounded by mature conifer forest. The north-western edge of afforestation is a deep axial channel that also marks the county boundary, and beyond this the unforested mire forms part of Hafod Elwy Moor NNR, comprising three 'lobes' of deep peat separated by apparently natural water flow tracks. For the most part the axial channel also appears to be natural, apart from its northern-most limb, which may have been partially ditched as it forms a fairly straight boundary with the formerly afforested area. At one point the water flows south through a large peat pipe, which also appears to be a natural feature.

The southern and eastern parts of the mire were formerly afforested, and most of this area is gently sloping to the southwest, but in the saddle region it is virtually flat, before beginning to slope gently down to the eastern outflow. The afforested part is drained by a dense network of ridge-and-furrow that drain into larger ditches, which enter arterial ditches that flow into the headwaters of either stream. These have recently been dammed as part of a restoration project.

Moel Eunant

Moel Eunant is situated in mid-Wales 20 km north-east of Dolgellau, close to the north-western end of Llyn Efyrnwy, on the broad rounded summit ridge of Y Berwyn, which runs north-west from the reservoir and attains a maximum elevation of 568 m aOD at Moel Eunant. Where sampled the ridge has fairly steep slopes on the southern flank, cut by several rush-filled gullies that drop into the broad valley of Eunant Fawr approximately 100m below the ridge top. In contrast, the northern flank, though also incised by rushy gullies, has more gentle gradients dropping down to the northern valley, at around 450 m aOD at the confluence of Nant Eiddew Fach with Nant Eiddew Fawr. The summit of the ridge is generally broad and gently undulating and supports peat depths of around 2–3m, whereas the northern slopes have peat depths of between 0.5 and 2.5m, and the southern slopes support patchy thinner peat or peaty podsols of about 0.1 to 0.5m. The summit ridge has suffered extensive erosion damage and recent work has dammed the erosion channels and rushy gullies in an attempt to reduce water flow and peat loss.

The bedrock of the area is all Silurian. The section itself occupies a strip of Dolgau Mudstones Formation, flanked on either side across the ridge by sandstone-containing rocks (Pen-y-Gelli Formation and Llanymawddwy Formation to the west, Penstrowed Grits Formation, forming the Moel Eunant ridge, to the east). There is no reason to suspect that the samples examined were influenced by outflows from these rocks.

Table 3. Mean average rainfall and evapotranspiration estimates (mm) for the investigated upland ombrogenous sites for the period 1961–2022, with some data for selected lowland sites and others for comparative purposes.

PET: Potential evapotranspiration*; PETI: Potential evapotranspiration with a correction for canopy interception.

Data provided by the Environment Agency (v1.0 of the EA_PET and EA_PETI dataset), the Met Office (Met Office HadUK Rainfall dataset), and the Centre for Ecology and Hydrology (CEH–GEAR dataset) under Open Government Licence v3.0 [Met Office: Hollis *et al.*, 2018; CEH: Tanguy *et al.*, 2019].

Ombrogenous Bog Sites	Altitude (m aOD) **	Rainfall	PETI	PET	Rainfall – PETI	Rainfall – PET
South Pennines						
Combs Moss	450	1443.2	549.8	500.0	893.4	943.2
Featherbed Moss/Within Clough	550	1565.7	528.9	477.2	1036.8	1088.5
Langsett Moors	450	1549.3	542.9	490.3	1006.4	1059.0
Leash fen	275	960.0	586.6	546.6	373.4	413.4
Lucas Moss	345	1051.1	574.3	531.8	476.8	519.3
Ringinglow Bog	415	1068.8	562.3	519.4	506.5	549.5
Sandyford Brook	280	1051.1	574.3	531.8	476.8	519.3
Stoke Flats	290	1051.1	574.3	531.8	476.8	519.3
Totley Moss	360	1005.4	573.8	531.5	431.5	473.9
White Path Moss	415	1135.5	558.9	514.9	576.6	620.6
Bowland and Lonsdale						
Cross of Greet	430	1935.5	523.3	470.8	1412.2	1464.7
Crutchember Fell	400	1715.9	532.9	482.0	1183.1	1234.0
Halstead Fell	380	1715.9	532.9	482.0	1183.1	1234.0
Hasgill Fell A & B	400	1832.1	528.5	476.8	1303.5	1355.3
Stone Park (Old Scotch Road)	190	1489.9	556.4	511.4	933.5	978.5
North Pennines						
Moor House	600	1929.1	451.3	399.7	1477.8	1529.4
Shaklesbrough, Cotherstone Moor	420	1173.6	533.3	483.6	640.3	690.0
Widdybank Fell	500	1466.4	512.5	458.1	954.0	1008.3
Roman Wall Country						
Butterburn Flow	280	1186.0	536.7	488.5	649.3	697.5
Coom Rigg Moss	320	1300.7	523.3	475.0	777.4	825.7
Felecia Moss	315	1225.0	528.7	480.7	696.3	744.4
Gowany Knowe	285	1165.2	534.9	488.1	630.3	677.1
Grain Heads Moss	280	1102.0	545.5	497.1	556.5	604.8
Hummel Knowe	245	1122.8	556.1	506.9	566.7	615.9
Muckle Moss	225	820.1	599.4	556.4	220.7	263.7
Muckle Samuel's Moss	300	1289.4	524.7	476.6	764.8	812.9
Pundershaw	240	1059.3	542.3	498.5	517.1	560.8
The Lakes	300	1167.4	532.0	484.7	635.4	682.7
The Wou	225	1104.1	558.4	509.9	545.8	594.2
Walton Moss	100	917.3	582.1	543.0	335.2	374.3
Wales						
Figyn Blaen-brefi	425	1695.8	526.6	477.1	1169.3	1218.8
Hafod Elwy	400	1429.6	546.2	491.5	883.4	938.2
Llyn Vyrnwy	500	2213.7	529.3	469.7	1684.4	1744.0
Reference Sites						
Lowland England						

Ombrogenous Bog Sites	Altitude (m aOD) **	Rainfall	PETI	PET	Rainfall – PETI	Rainfall – PET
Danes Moss	160	944.2	611.9	571.2	332.4	373.0
Fenns & Whixall Mosses	90	722.9	614.6	577.4	108.3	145.5
Gordano	5	831.2	709.3	668.5	121.9	162.7
Holme Fen	0	564.1	652.1	623.5	–88.1	–59.5
Shapwick Heath	5	694.9	656.5	625.7	38.3	69.2
Thorne Moors	3	592.7	664.9	633.4	–72.2	–40.8
Wedholme Flow	15	899.9	605.9	567.4	294.0	332.4
Winmarleigh Moss	5	914.8	617.9	580.6	296.9	334.2
Wales						
Cors Caron	165	1268.1	584.6	543.4	683.4	724.6
Cors Goch (Ciloerwynt)	460	1811.7	531.4	484.3	1280.3	1327.4
Gors Lwyd	385	2014.8	520.9	468.4	1493.9	1546.4
Scotland						
Claish Moss	10	2200.2				
Cross Lochs	160	1159.6				
Moss of Cree	10	1266.1	572.2	532.5	693.9	733.6
Munsary Dubh Lochs	100	986.2				
Silver Flowe	250	2357.0	508.2	464.9	1848.7	1892.1

* PET estimates relate to a hypothetical well-watered short grass reference crop.

** Some of the sites span a considerable altitude range. The value provided is indicative only

4 DATA ANALYSES

The examination, analysis, and interpretation of the field data has been made using quasi-objective multivariate clustering and ordination procedures in conjunction with a collaborative assessment by ecologists and a peatland hydrologist. The outputs from these analyses have been used alongside schematic sections that have been produced for each site visited, and selected sites from the published literature, to feed into the development of a conceptual understanding of the range of blanket bog and allied minerotrophic mire types encountered during this project.

All of the schematic sections are reproduced in Annexe 2 (Section 11.2), and maps showing the locations and orientations of each transect are provided in Annexe 3 (Section 11.3).

Representative photographs illustrating particular features at a range of sites are provided as a separate resource; photo ID and descriptions are given in Annexe 4 (Section 11.4).

4.1 Detrended Correspondence Analyses

Detrended Correspondence Analysis (DCA) is a multivariate statistical technique used to find the main factors or gradients in large data matrices. DCA was used here to explore the relationships amongst the samples based on the recorded variables; between the variables, based on the samples to which they applied; and separately, the relationships of both samples and variables to the recorded vegetation types (for descriptions of the main vegetation types encountered, see Section 6).

The analyses were based on ranked scores of water and water-related variables, *i.e.* variables relating to: water level and flow; rainfall and potential evaporation; height and disposition of the surface in relation to any known groundwater and surface water sources, and its distance from these; topographical context of the stand (slopes etc); distances and disposition with regard to potential water sinks (mostly drains, furrows and gullies); characteristics of the upper and lower layers of wetland infill within the stands (and between the stands and any known water sources or sinks); and characteristics of the uppermost layer of mineral material below the wetland infill of the stand (referred to as the basal substratum).

An ordination of all of the samples based on their recorded variables shows two discrete clusters of points (Figure 7). The largest of these forms a fairly broad, fuzzy grouping. The smaller contains samples with higher loadings along Axis 1 and these all correspond to samples from locations where significant groundwater outflow is thought to occur. As these form an outlier from the main cluster of samples, and as they can mostly be assigned to existing WETMECs, these samples were omitted from all further analyses, which thereby focussed on samples from the main ombrotrophic areas.

The ordination of the samples excluding the apparently groundwater-fed examples (Figure 8) shows a generally loose cluster of points, of somewhat different configuration to the cloud of ombrotrophic samples when ordinated with groundwater samples (Figure 7). Whilst largely showing a continuum of variation, there are some apparent discontinuities and these are emphasised graphically in Figure 9 (the size of the grey ‘dots’ reflects the number of samples contained within them). The Peat Surface Configuration rankings (Table 4) have been superimposed on the ordination in Figure 9 and Figure 10 – these sub-divide the cluster into diagonal zones partly, but not completely, in accord with the visual discontinuities. Thus, Peat Surface Configuration rank 1 (water shedding) samples occupy low loadings on both axes 1 and 2, whilst rank 6 (water collecting) samples occupy high loadings on both axes.

Table 4. Peat surface configurations and their rankings.

Rank	Description	Examples
1	Water shedding	Dome, ridge, top of slope
2	Water shedding & receiving	Slopes
3	Water collecting on a slope	Small flattish area on a slope
4	Flat unconfined	Plateau or other more-or-less level ground
5	Axial trough	Channel or narrow valley bottom
6	Water collecting	Hollow or shallow basin

The DCA plot of the recorded variables, based on the samples in which they occurred (Figure 10) also shows some similar diagonal trends. The two variables separated furthest along Axis 1, and also well separated along axis 2, are the two measures of surface patterning used – hummock–hollow–pool diversity and tussock diversity – which indicates that these two patterning types occupy contrasting sets of samples. The two variables separated furthest along Axis 2 are Peat Surface Configuration (high loadings) and Erosion Features (low loadings). Proximity to Gullies is quite closely associated with the Erosion variable on the ordination. This may suggest that Axis 2 broadly relates to a water retention gradient, but the Winter Wet variable plots almost in the centre of the diagram, which suggests that it was not closely related to either Peat Surface Configuration, or to its opposite in the form of Erosion. This may be because, as these measurements were made in winter, the water level rankings were rather similar across most samples. Top-layer permeability estimates also plotted close to the centre of the ordination and were closely related to the winter wetness rankings. This was also the case in the plot of Axis 1 and 2 for the slope of adjoining ground and the level of the sample area in relation to the level of the base of any adjoining slope. However, the ‘marginal inflow’ variables all had high loadings on Axis 3 of the ordination (not shown) and formed a discrete group within this, and one related to the occurrence of stands of M6 vegetation.

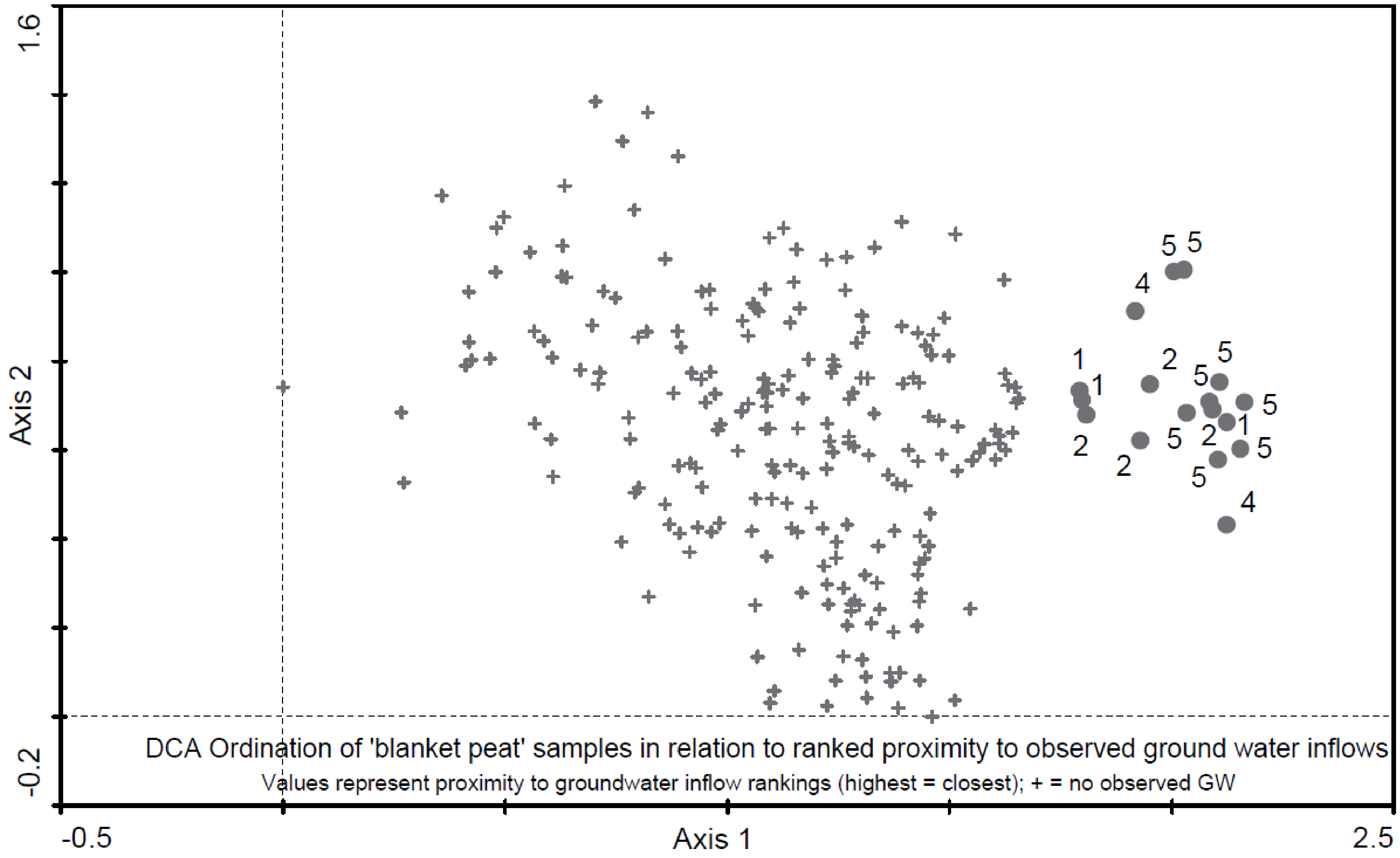


Figure 7. DCA ordination of 'blanket peat' samples in relation to ranked proximity to observed ground water inflows.

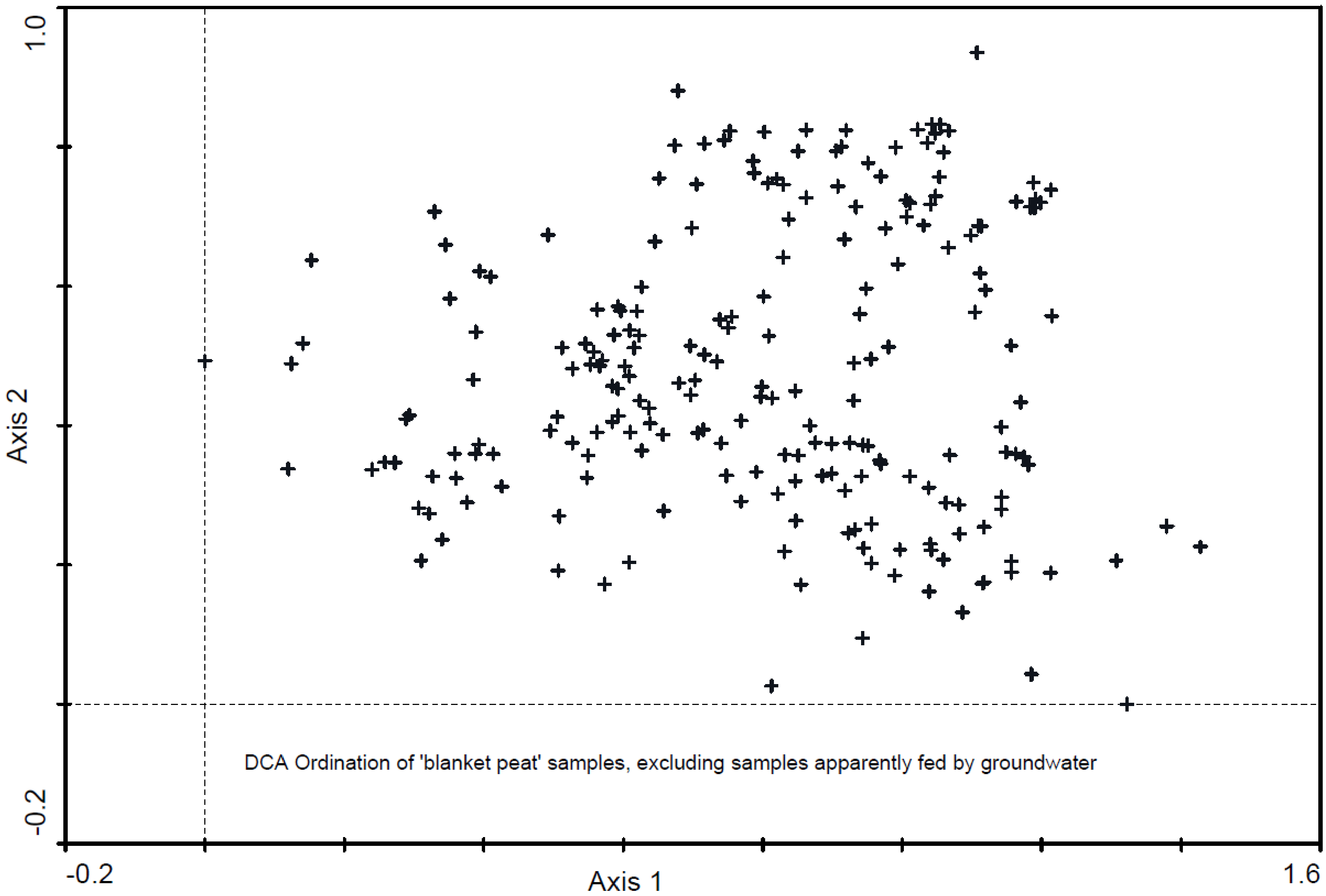


Figure 8. DCA ordination of 'blanket peat' samples, excluding samples apparently fed by groundwater.

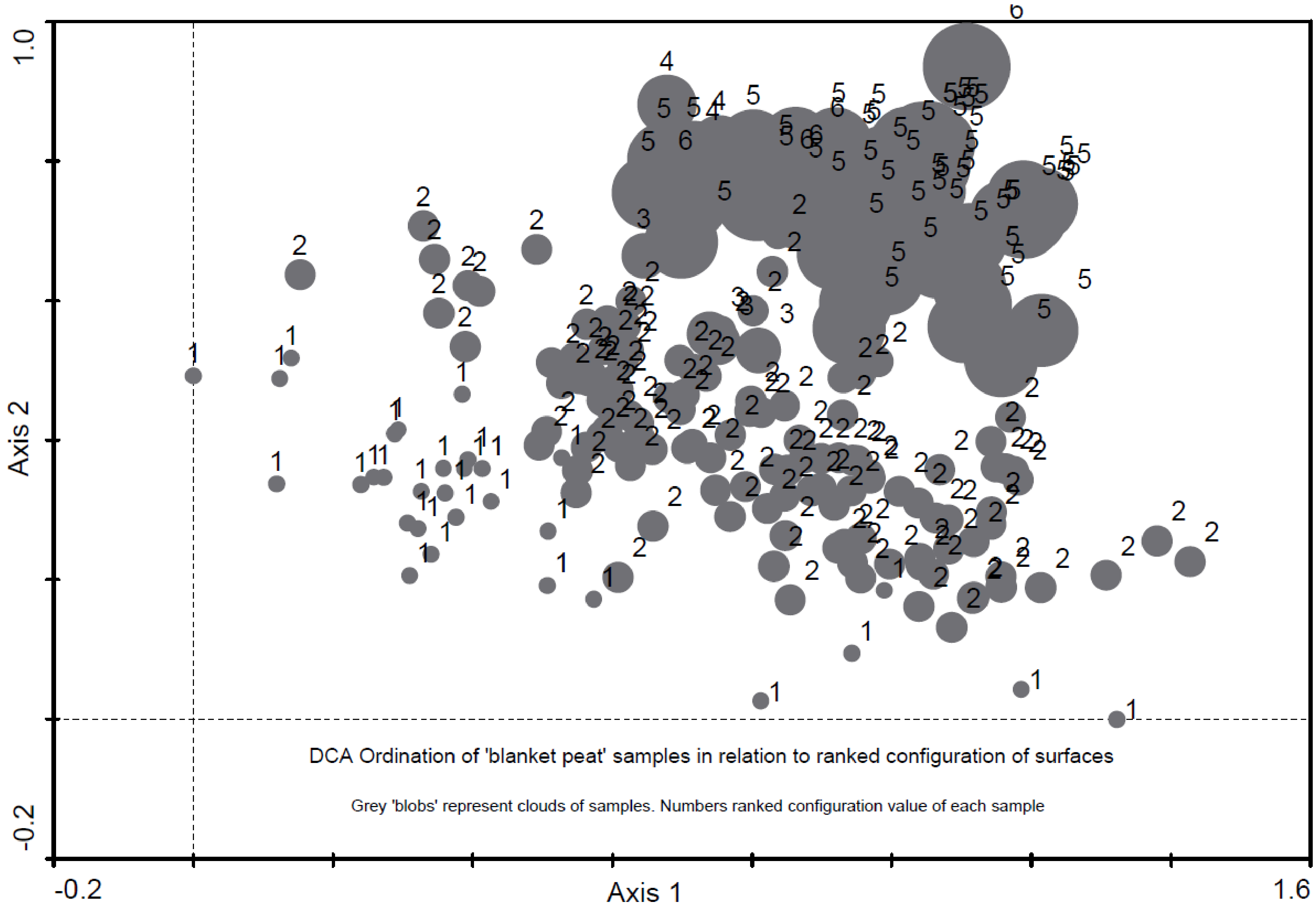


Figure 9. DCA ordination of 'blanket peat' samples in relation to ranked configuration of surfaces.

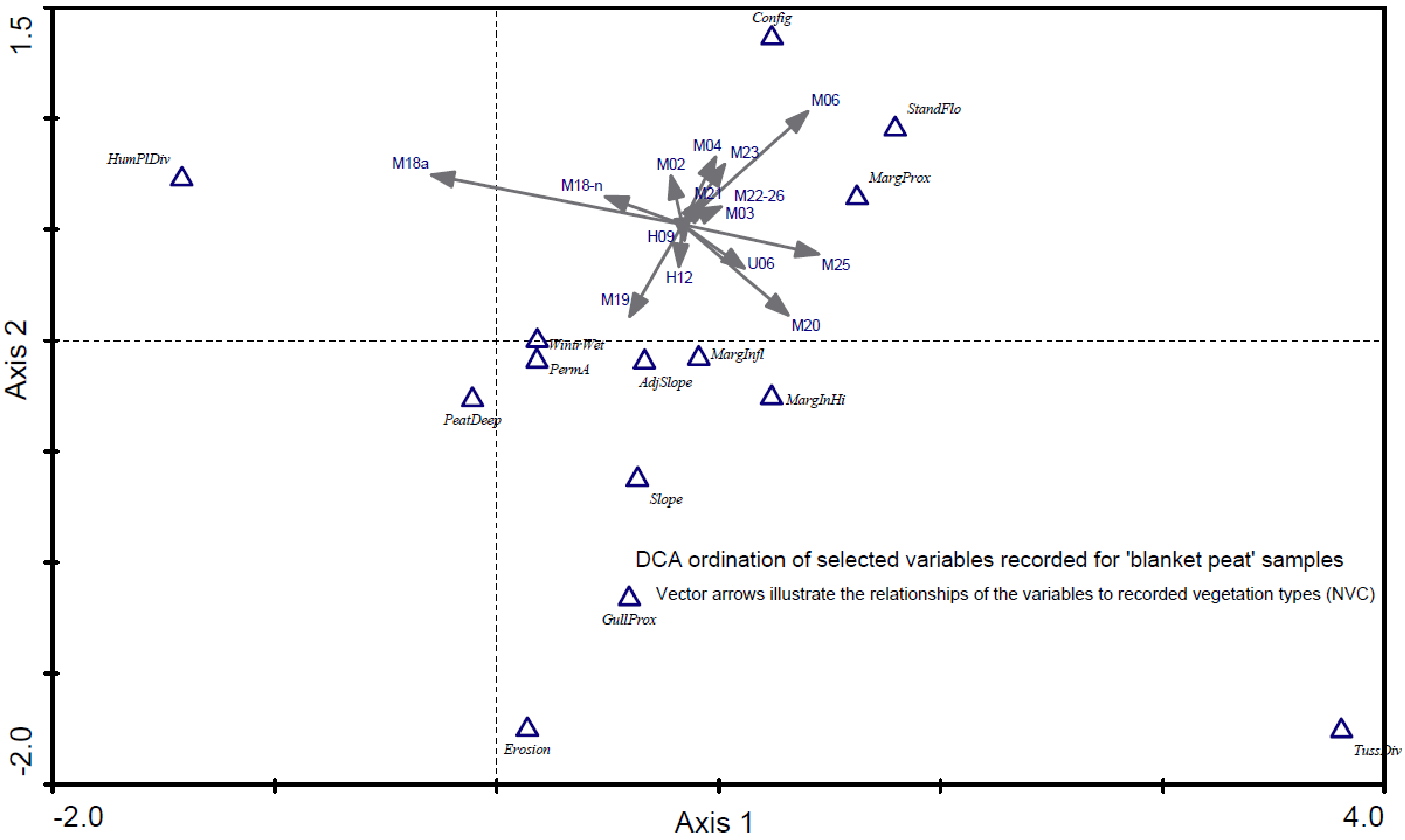


Figure 10. DCA ordination of selected variables recorded for 'blanket peat' samples, in relation to NVC vegetation types.

4.2 Cluster Analyses ('Wards Method')

The clustering method used to examine the data was based on a sequential hierarchical agglomerative fusion of samples in which each successive cluster is formed by whichever next dichotomous fusion of sample pairs minimises the increase in the error sum of squares of the dataset (Wards Method). This procedure allows for the inclusion of missing values. Variables were not differentially weighted but the range of all variables was standardised before the analysis. The 6-cluster stage was selected for examination based on a Moving Average Best Cut Significance Test (t-Statistic) when all samples were analysed, and the 5-cluster stage when the groundwater-fed samples were excluded from the analysis. The 5-cluster model was refined by reallocation of some samples using a k-Means Analysis, based on Euclidean Sum of Squares. 7% of the samples were re-allocated from their original clusters. This procedure helps to correct misclassification of samples which can occur, particularly to samples added at an early stage of the fusion process, as cluster compositions change with the addition of new members. It also helps permit the identification of outliers and exemplars for each cluster.

The results from the 5-cluster model are displayed in Figure 11.

4.2.1.1 Cluster A (59 samples)

This contains some mostly very wet surfaces in a range of trough-like configurations. Many, but not all examples are in topographical troughs. The cluster contains both apparently-ombrotrophic and minerotrophic samples and it is probably its inclusion of the latter that account for this cluster forming the primary split in the dendrogram. The minerotrophic areas generally make a very minor contribution to the surface of the mires, whilst some ombrotrophic examples form quite extensive, trough-bottom surfaces, typically sloping down-trough, but flatter across-trough. Some of them are dominated by a very wet version of M18, as in The Lakes. Muckle Moss, not field-sampled or analysed here but for which information was obtained from Pearson (1954, 1960), almost certainly also comes into this category. Some eroded valleyhead troughs with axial flow were also clustered here, with M18 examples from Felecia Moss and Figyn Blaen-brefi, and with M19 at some other sites. However, most of the samples in Cluster A were from smaller, narrower troughs, apparently flow paths (soakways or watertracks). Many of these formed a discrete marginal zone separating ombrogenous deposits from adjoining slopes of mineral ground, but some appeared to be endotelmic. Marginal examples appear to receive drainage water both from the ombrogenous deposits and from the mineral slopes, and this is often reflected in their vegetation, but not always in pH and electrical conductivity (EC) values measured in their waters. M6 is the dominant plant community in such situations, but others include M4, M23, M25 and M20. Axial flow-paths nearer the centre of the troughs appear to be uncommon and have sometimes been ditched. Examples have been recorded from Crutchember Fell, Pundershaw Moss, Felecia Moss, Muckle Moss and Hafod Elwy. When embedded within a wider surface of M18, such flows were recorded as supporting a wetter version of that community, or of M4 or M21. Some blocked, and very wet, ditches at Hafod Elwy also clustered into this unit, with M2 and M19 vegetation, as also did a large, very wet, peat cutting area at Hasgill Fell, located in what may once have been a water-shedding situation.

4.2.1.2 Cluster B (31 samples)

All samples in this cluster had water-shedding surfaces, mostly fairly flat, but with 3 on very gentle slopes. These occupy a wide range of topographical contexts, sometimes being draped across domes or ridges of mineral ground, in other cases forming autogenic mounds of varying configuration, within basins or flatter surfaces. Autonomous mounding most typically occurs in appropriate situations on the slopes, or at the foot of slopes, but examples located across topographical watersheds are also sometimes additionally mounded to some extent across the underlying mineral ridges. Examples lower down the slopes were often, but not always, separated from the slope above (which may be of mineral ground or have a peat cover) by a form of soakway, which presumably collects some of the slope drainage. Mounding in such situations is variable, with some examples of strong and steep mounding, well above the likely ingress of any slope drainage, but others are shallower and less obviously isolated from this (except by any soakways). Nonetheless, there is generally no evidence, either in the vegetation or in measurements of pH and EC, of discernible mineral enrichment of mounded surfaces below the topographical watershed. Although they have been designated as 'water shedding', based on their surface peat configuration, they are not at all well drained, presumably on account of their 'flatness', and there is little visual evidence of water flow. Two thirds of the samples supported M18a vegetation. Most of the rest had M19a but two are M19-poor, one supported H12 dry heath, and four M20. Two thirds were on deep peat >3m, but a few were on shallow peat (two are c. 50 cm). Estimated Top-layer permeability was mostly moderate to high.

4.2.1.3 Cluster C (7 samples)

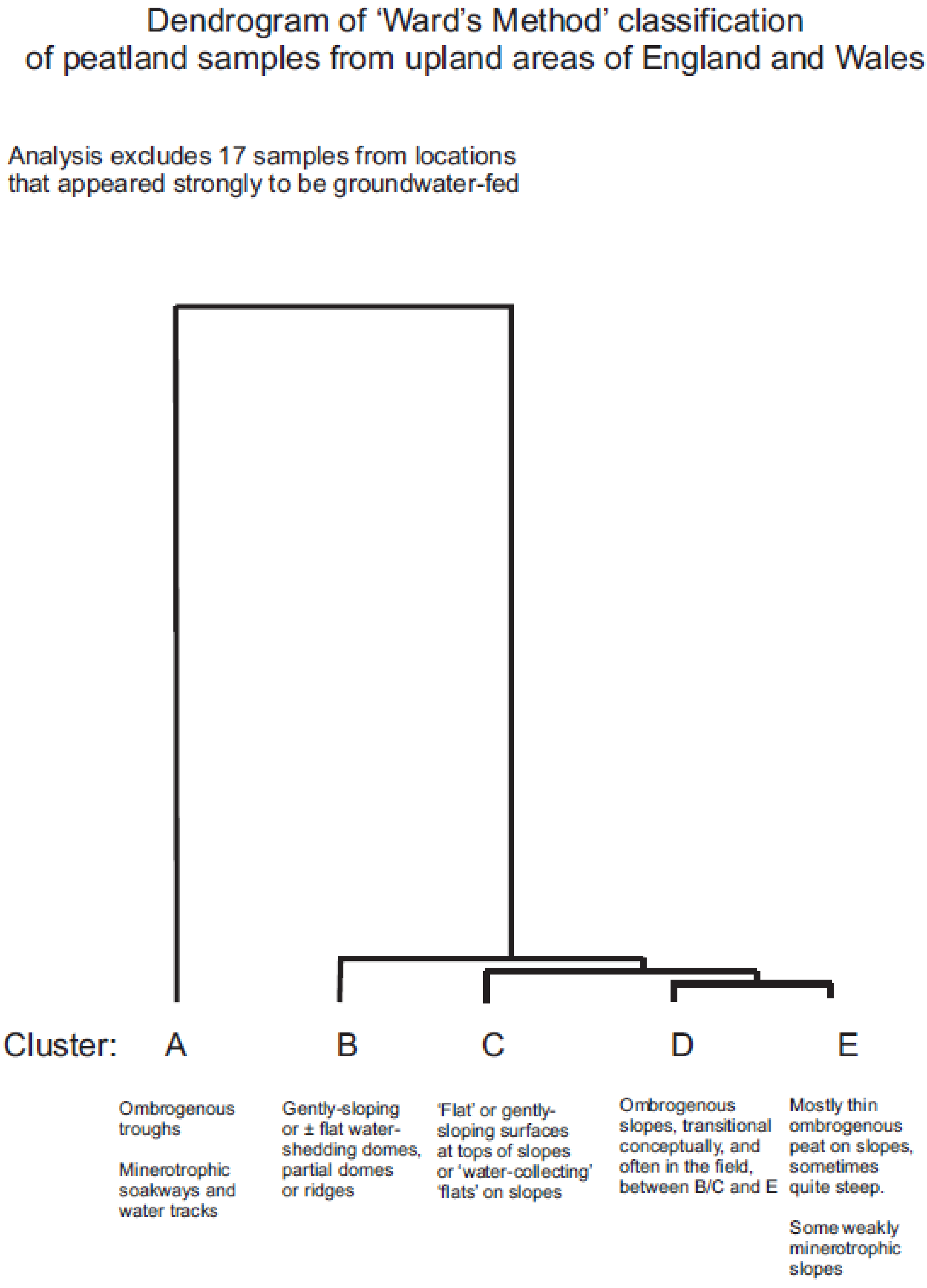
This small cluster is closely related to Cluster B. It essentially constitutes more-or-less flat peat surfaces situated on plateaux at the top of slopes or on 'flat', water-collecting areas on the slope. The small number of samples available appears to under-represent what appears to be a widespread, though not necessarily extensive, category of peatland. Peat depth is variable, typically consistently shallower than that of the deeper deposits found in Cluster B samples, but well within the range of the shallower Cluster B deposits, especially those that support M19 and M20 vegetation. The Cluster B deposits all supported either M18a or M19 vegetation. Unlike examples of Cluster B deposits that occur on lower slopes or footslopes (*e.g.* Grains Head Moss), examples of Cluster C surfaces on lower slopes are not separated from the more strongly sloping peat above them by ditches or soakways and are more likely to receive inflows of upslope peat water.

4.2.1.4 Cluster D (60 samples)

This cluster essentially represents ombrogenous samples on slopes, typically on quite deep peat. In many ways it is intermediate between Clusters B and E, and in some sites this is reflected in field zonations. Cluster D surfaces sometimes occur marginal to (and below) those of Cluster B and can represent a down-slope continuation of these. The surface topography of examples lower down the slope suggests that they are potentially in a position to receive water flow from the slope above. Their vegetation is dominantly either M19 or M18, and they show some surface patterning, but their hummock–hollow diversity, which in some instances is comparable with that of Cluster B surfaces, is comprised primarily of variation in the types of hummocks, and there is often little by way of representation of pools. Tussocks are also poorly developed. The top-layer peat was mostly either amorphous or mixed *Eriophorum–Sphagnum* peat, with 'pure' *Sphagnum* or *Eriophorum* peats occurring in smaller, but equal, proportions within the samples referred to this cluster. Some examples of 'pure' *Sphagnum* peat occurred, mostly from the steep margins of large water-shedding deposits of ombrogenous peat in situations which in other contexts might be considered to constitute a 'rand'.

4.2.1.5 Cluster E (62 samples)

This is a variable cluster of slopes and probably corresponds most closely to the general perception of the character of 'hill peat'. In general, the peat is somewhat shallower, drier at the surface and more steeply sloping than is the case with Cluster D samples, and often occurs in samples that are closer to gullies or furrowed surfaces. Also allocated to this cluster were some samples on quite deep peat that had previously been afforested and partly drained or furrowed. Most samples support vegetation with abundant *Eriophorum vaginatum* or *Molinia* (M20, M25, M19-m, M20-m, some M19a, rarely M18a with *Molinia*), and the surfaces are often dominated by tussocks, with very little by way of other surface patterning. In examples in which *Molinia* or *Eriophorum vaginatum* is not abundant, the vegetation is often rush dominated (M6c/d) or dry heath (H9, H12). The most frequent types of peat in the Top Layer were either amorphous or mixed *Eriophorum–Sphagnum peat.*



See text for details of analysis

Figure 11. Dendrogram of 'Ward's Method' classification of peatland samples from upland areas of England and Wales.

4.3 Relationships amongst individual variables and with vegetation types

4.3.1 Spearman Rank Correlations

The univariate relationships between pairs of ranked variables were examined by Spearman Rank correlation, based on all the samples in the dataset (Table 5). Variables were those shown by DCA ordination to be the most important.

Table 5. Spearman Rank Correlation matrix between selected variables.

Variables (see Annexe 1): PeatDeep: peat depth; PermA: top layer permeability; Slope: surface gradient; HumPlDiv: hummock–pool diversity; TussDiv: tussock diversity; StandFlo: stand flow; GullProx: gully proximity; Sphagnum: *Sphagnum* abundance; Heather: heather height.

Spearman rho:	*PeatDeep*	*PermA*	*Slope*	*HumPlDiv*	*TussDiv*	*StandFlo*	*GullProx*	*Sphagnum*	*Heather*
PeatDeep	1								
PermA	0.233154	1							
Slope	–0.34011	–0.34796	1						
HumPlDiv	**0.518771**	*0.141092*	–0.30855	1					
TussDiv	*–0.17801*	*–0.08463*	*0.136125*	**–0.45664**	1				
StandFlo	*–0.10101*	*0.187043*	*0.04618*	–0.21812	*0.053491*	1			
GullProx	*–0.03642*	–0.24494	0.286399	*–0.12876*	*0.002306*	*0.058066*	1		
Sphagnum	**0.412923**	**0.442615**	–0.35777	**0.468688**	–0.26166	*0.105037*	–0.26464	1	
Heather	0.35739	–0.21073	*0.047417*	0.360653	*–0.16514*	–0.34511	*0.127851*	*–0.00604*	1

Less than 0.235	p < 0.005 (not significant)	*0 to 0.2*	No correlation
0.235 or above	p >/= 0.05 (significant)	0.2 to 0.4	Weak correlation
0.329 or above	p >/= 0.01 (highly significant)	**0.4 to 0.6**	Moderate correlation
0.43 or above	p >/= 0.001 (very highly significant)	**0.6 to 0.8**	Strong correlation

The main relationships that emerge from this correlation matrix can be summarised:

Slope

- ***Sphagnum* abundance: weak –ve correlation, highly significant**
- **Peat depth: weak –ve correlation, highly significant**
- **Top layer permeability: weak –ve correlation, highly significant**
- Hummock–Pool diversity: weak –ve correlation, significant
- Gully proximity: weak +ve correlation, significant

Hummock–Pool Diversity

- **Peat depth: moderate +ve correlation, v.highly significant**
- **Tussock diversity: moderate –ve correlation, v.highly significant**
- ***Sphagnum* abundance: moderate +ve correlation, v.highly significant**
- **Heather height weak +ve correlation, highly significant**

Top Layer Permeability

- ***Sphagnum* abundance: moderate +ve correlation, v.highly significant**
- Gully proximity: weak –ve correlation, significant

Sphagnum abundance

- **Peat depth: moderate +ve correlation, highly significant**
- Tussock diversity: weak –ve correlation, significant
- Gully proximity weak: –ve correlation, significant

Heather height

- **Peat depth: weak +ve correlation, highly significant**

- **Stand flow: weak –ve correlation, highly significant**

4.3.2 *Relationship between the abundance of* Sphagnum *and selected surface conditions*

The Spearman Rank correlations (Table 5) indicate significant positive relationships between the ranked estimates of *Sphagnum* abundance in samples with estimates of surface patterning, top-layer permeability and peat depth, and a significant negative relationship with surface slope.

R Meade has kindly provided data collected by himself and colleagues (Meade, 2020) from Greater Bobus[9] (Marsden Moor, SE0309), a far-from pristine rounded plateau area of ombrogenous peat. The area sampled included the plateau top, from about 390–420 m aOD with a slope of mostly less than about 5°, and its steeper margins, from about 300–420 m aOD and with slopes typically reaching to around 30° and, in a few instances, steeper. Data were collected from points on a regular 100 m grid.

Table 6. Peat surface wetness, slope and depth of samples from Greater Bobus (Marsden Moor, South Pennines) in relation to the occurrence of *Sphagnum* in the vegetation and in the top 50 cm of peat.

Based on data supplied by R. Meade and reported by Meade (2020). Surface wetness, peat depth and the presence of *Sphagnum* was estimated or measured in the field. Slope was determined from Lidar contours.

***Sphagnum* presence**		**Surface wetness of samples (number of samples)**			**Slope (mean)**	**Peat depth (cm) (mean)**
	n	**Dry**	**Moist**	**Wet**		
***Sphagnum* present in vegetation**	40	4 (35%)	22 (55%)	14 (35%)	5.9°	154.5
***Sphagnum* absent from vegetation**	402	111 (28%)	230 (57%)	61 (15%)	8.8°`	85.1
***Sphagnum* present in top 50 cm of peat**	88	4 (5%)	54 (61%)	30 (34%)	6.63°	165.0 cm
***Sphagnum* not in top 50 cm of peat**	353	111 (31%)	197 (56%)	45 (13%)	8.75°	78.6 cm

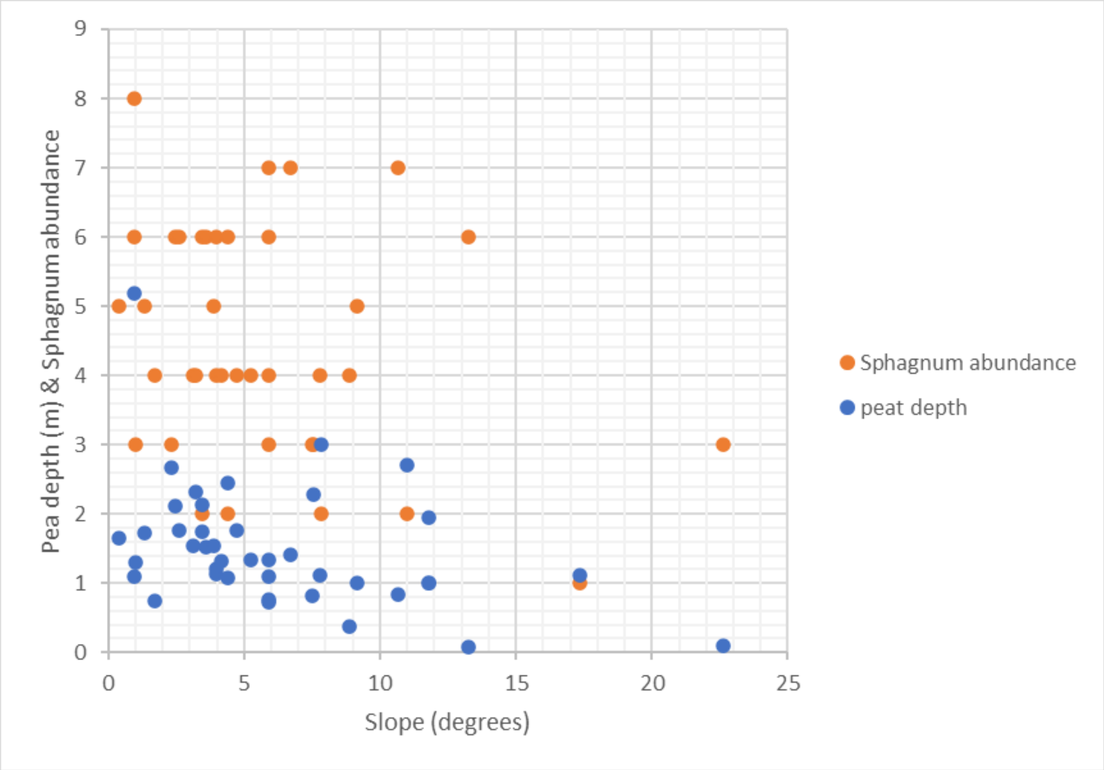
Fewer than 10% of the sample points had *Sphagnum* in the current vegetation (Table 6), and they generally occupied shallow slopes, deeper peats and wetter surfaces than samples without current *Sphagnum. Sphagnum* was recognised in the top 50 cm of peat at about twice as many sample points as those at which was now present, and this may well be an underestimate of its former occurrence because of the difficulties of detecting *Sphagnum* macroscopically in humified peat samples, especially ones that have dried out. As, overall, the more steeply-sloping areas tend to be drier than shallower slopes, *Sphagnum* remains may be particularly difficult to detect on these. Hence it is difficult to assess from these data whether the evidence of fewer *Sphagnum* remains on more steeply-sloping, shallower peats is because they never occurred there or because they have become difficult to recognise.

The maximum slope recorded from the samples was 40° (with only 7 cm of peat). Almost all of the samples with current *Sphagnum* were on slopes less than 10°, but a very small number occurred on slopes up to 23 °. It is suspected that these may have been in locally-flushed conditions rather than on the open peatland surface, but this is not known.

Meade and his co-workers also estimated the prominence of *Sphagnum* in their samples on a ranked scale. A scatter diagram (Figure 12) shows the relationship between the prominence of *Sphagnum* at Bubus and peat depth and slope; it is clear that both the deeper peats and locations with most *Sphagnum* occupy the shallower slopes. Most *Sphagnum* occurred in sites with less than a 10° slope, but below this neither the slope or peat depth influenced the prominence of *Sphagnum.* They also reported the prominence of *Sphagnum* in the top 50 cm of peat (Figure 13). This showed a broadly

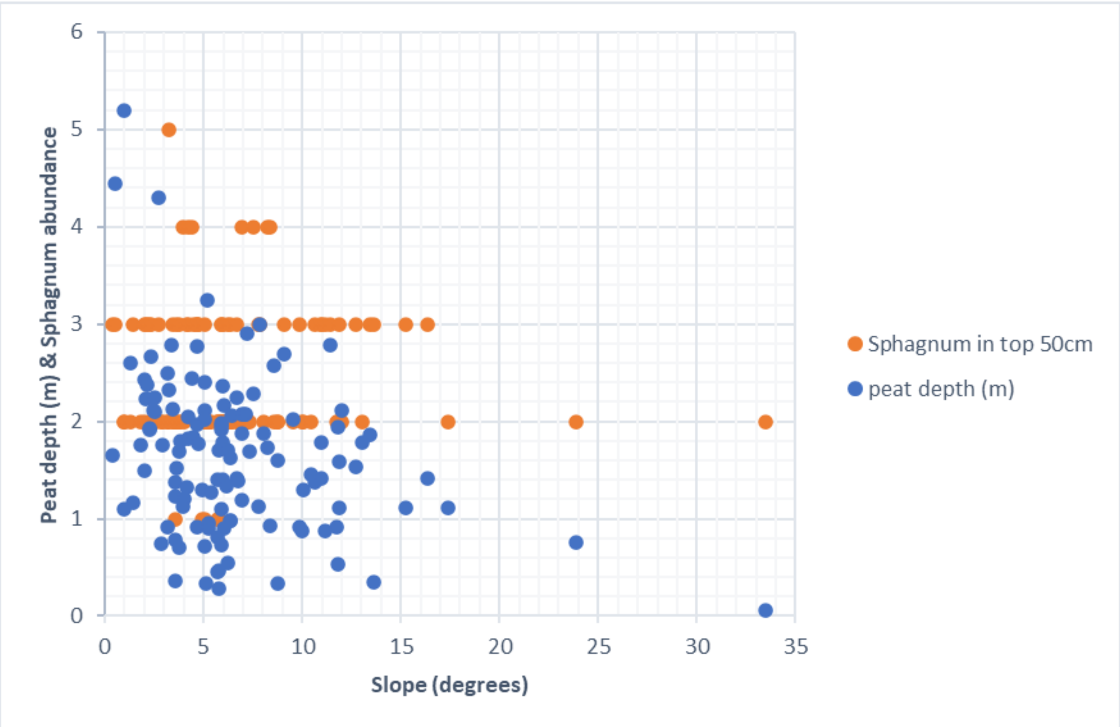
[9] Though to derive from OE *busc* (a bush or shrub) (Smith, 1961)

similar relationship with slope as did the prominence of *Sphagnum* on the surface, but with a suggestion that slightly steeper slopes supported more *Sphagnum* in the past than is the case now.



Data were provided by R Meade (Meade, 2020).

Figure 12. Prominence of *Sphagnum* in vegetation samples at Greater Bobus (Marsden Moor, South Pennines) in relation to peat depth and slope.



Data were provided by R Meade (Meade, 2020).

Figure 13. Prominence of *Sphagnum* in the top 50 cm depth of peat in samples from Greater Bobus (Marsden Moor, South Pennines) in relation to peat depth and slope.

4.4 Peat types and vegetation in relation to conditions on ombrogenous surfaces

4.4.1 *Relationship between ombrogenous vegetation-types and selected surface features*

An examination was made of the relationship between the type of peat and vegetation reported from individual samples and various features of surface conditions at locations that were presumed to be ombrogenous because of the occurrence of one of the three main 'ombrotrophic' vegetation-types, *viz.* M18, M19 or M20.

The relationship between these communities and other features is examined in more detail in the Community Accounts, but Table 7 provides a summary of some salient conditions associated with them. In essence, the mean cover of *Sphagnum* (based on ranked values – see Annexe 1 (section 11.1)) in the samples declined in the sequence M18 > M19 > M20, whilst the cover of heather was similar in M18 and M19, but much less in M20. Differences in mean values of pH and EC are small and their significance is uncertain, but mean pH declines slightly from M18 to M20 whilst EC shows the reciprocal trend. Peat depth decreases from M18 to M20, which is partly a consequence of the absence of M18 from shallower, more strongly sloping, surfaces. Mean surface quakiness and estimated top- (A) and mid-layer (C)[10] permeabilities show a similar trend, but the ranked winter wetness was higher in M20 than in M19. M20 samples were also associated with possibly more permeable basal substratum (S) condition than the others. Examples of M18 were, on average, associated with fewer erosional features than either M19 or M20.

Table 7. Relationships between the occurrence of the three main ombrotrophic vegetation types of the mires examined and selected surface features.

Values are community means based on field measurements (pH, EC, peat depth) and ranked values (the others).

ComType	n	Sphag	Heather	pH	EC	Peat Depth	Wintr Wet	Wint Quake	Perm A	Perm C	Perm S	Erosion	Slope
M18	44	3.75	2.89	4.17	67.14	5.27	4.77	3.11	4.45	3.93	2.80	0.16	1.59
M19	90	2.28	2.80	4.08	72.38	2.81	4.07	2.34	3.90	3.43	2.92	0.68	2.31
M20	24	1.42	1.00	3.99	77.06	1.99	4.21	2.00	3.88	3.42	3.40	0.54	2.17

Table 8. Relationships between the occurrence of the three main ombrotrophic vegetation types of the mires examined and the number of samples in which *Sphagnum* occurred at different levels of ranked abundance.

Higher rank scores equate to greater cover of *Sphagnum*. Values are proportion of occurrences.

		Proportion of samples in each rank of *Sphagnum* abundance in each vegetation type				
	n	**0**	**1**	**2**	**3**	**4**
M18	*44*	0%	2%	5%	9%	84%
M19	*90*	18%	10%	22%	27%	23%
M20	*24*	25%	29%	33%	4%	8%

A high *Sphagnum* cover is a particular feature of M18 (Table 8). The three communities also show some differences in their relationships to the main peat types on which they occur (Table 9). Both M18 and M19 samples occurred widely upon top-layers of both *Sphagnum* and *Sphagnum–Eriophorum*

[10] The transition between the Top layer and Mid layer were defined in the field by the presence of a marked change in peat stratigraphy (e.g. from loose fresh *Sphagnum* peat to firm, dark well-humified peat. Where no visible change was observed an arbitrary transition depth was recorded (c. 50cm).

peat, but the greatest number of M18 samples was on *Sphagnum* peat and of M19 on *Sphagnum–Eriophorum* peat. Many M19 samples also occupied an amorphous (*i.e.* highly humified) peat top-layer, whilst this was fewer in the case of M18. Broadly similar trends were found in the mid-layer peat, but there the proportion of samples upon amorphous peat was greater for both M18 and M19 samples. No examples of M20 occupied a *Sphagnum* peat top-layer, and were spread across *Sphagnum–Eriophorum, Eriophorum* and amorphous peat types, though one example was upon a mid-layer of *Sphagnum* peat. Some examples of both M19 and M20 did not have a 'mid-layer', on account of the thin-ness of the peat.

Table 9. Relationships between the occurrence of the three main ombrotrophic vegetation types and the main types of top-layer and mid-layer peats beneath presumed ombrogenous peat surfaces.

Peat categories recorded from a single sample have been excluded. Values are proportion of occurrences.

A – amorphous; E – *Eriophorum* peat; M – monocot peat; N – none; S – *Sphagnum* peat; SE – *Sphagnum–Eriophorum* peat; U – unknown.

		Top Layer						Mid Layer					
NVC Type	***n***	**A**	**E**	**M**	**S**	**SE**	**U**	**A**	**E**	**N**	**S**	**SE**	**U**
M18	44	16%	9%	2%	41%	30%	2%	25%	9%	0%	36%	27%	2%
M19	90	30%	8%	1%	21%	31%	7%	49%	4%	6%	9%	26%	6%
M20	24	33%	8%	0%	0%	38%	17%	42%	8%	13%	4%	17%	17%

4.4.2 Relationship of ombrotrophic peat types to surface conditions

The relationships between ranked categories of winter surface wetness (see Annexe 1 (section 11.1)) and the main macroscopic components of the top-layer and mid-layer peats beneath presumed ombrogenous peat surfaces is indicated in Table 10. The majority of top-layer *Sphagnum* peats were recorded from samples assigned to wetness class 5. This was also the case for top-layer *Sphagnum–Eriophorum* peats, but these were spread somewhat more widely amongst the other wetness classes. This relation was also the case broadly in the mid-layer peats, but these had fewer examples of *Sphagnum* peat in total. Amorphous peats were recorded from most wetness classes, but especially in categories 3 to 5, in both the top layer and mid-layer peats (but more examples were encountered in the latter). The small number of examples of *Eriophorum* peat were also spread mostly across wetness classes 3–5, in both the top- and mid-layers. Although any conclusions from this must be tentative, they suggest that accumulations of *Sphagnum*-rich peat are particularly associated with 'near-surface' winter wetness conditions, but generally not with conditions much wetter than that.

Table 10. Relationships between ranked categories of winter surface wetness and the main macroscopic components of the top-layer and mid-layer peats beneath presumed ombrogenous peat surfaces.

Peat categories recorded from a single sample have been excluded. Higher rank scores equate to increased winter surface wetness. Values are proportion of occurrences. A – amorphous; E – *Eriophorum* peat; M – monocot peat; N – none; S – *Sphagnum* peat; SE – *Sphagnum–Eriophorum* peat; U – unknown.

		Top Layer						Mid Layer					
Winter Wet	***n***	**A**	**E**	**M**	**S**	**SE**	**U**	**A**	**E**	**N**	**S**	**SE**	**U**
2	*5*	60%	0%	0%	0%	40%	0%	40%	20%	20%	0%	20%	0%
3	*38*	50%	8%	0%	11%	26%	3%	68%	5%	5%	5%	16%	0%
4	*30*	20%	17%	3%	20%	33%	3%	53%	7%	7%	10%	20%	3%
5	*78*	17%	6%	1%	31%	35%	9%	26%	5%	4%	22%	33%	9%
6	*6*	17%	0%	0%	33%	17%	33%	0%	17%	0%	50%	0%	33%
7	*1*	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%

Relationships between ranked categories of surface slope (see Annexe 1 (section 11.1)) and the main macroscopic components of the top-layer and mid-layer peats beneath presumed ombrogenous peat surfaces have also been examined (Table 11). These showed that the majority of examples of

Sphagnum and *Sphagnum–Eriophorum* peat were found on ± flat or very gentle slopes, but that there was some tendency for *Sphagnum–Eriophorum* peat to be found also on somewhat steeper slopes than was the case for *Sphagnum* peat. Examples of amorphous and *Eriophorum* peat were found on all categories of slope which had peat, but most were from categories 2 and 3 (very gentle or slight). Amorphous peat was better represented in the mid-layer than in the top-layer and *Sphagnum*-rich peat was less well represented in this.

Table 11. Relationships between ranked categories of surface slope and the main macroscopic components of the top-layer and mid-layer peats beneath presumed ombrogenous peat surfaces.

Peat categories recorded from a single sample have been excluded. Higher rank scores equate to increased slopes. Values are proportion of occurrences. Ranked categories are given in Annexe 1.

A – amorphous; E – *Eriophorum* peat; M – monocot peat; N – none; S – *Sphagnum* peat; SE – *Sphagnum–Eriophorum* peat; U – unknown.

		Top Layer						Mid Layer						
Slope	***n***	**A**	**E**	**M**	**S**	**SE**	**U**	**A**	**E**	**M**	**N**	**S**	**SE**	**U**
1	50	18%	2%	4%	34%	32%	10%	32%	8%	2%	4%	22%	24%	8%
2	55	27%	7%	0%	25%	35%	4%	38%	7%	0%	2%	20%	27%	5%
3	42	29%	17%	0%	12%	31%	10%	50%	5%	0%	7%	5%	26%	7%
4	11	55%	9%	0%	9%	18%	0%	64%	0%	0%	18%	9%	9%	0%
5	0													

4.4.3 Relationships between types of mid-layer and top-layer peat beneath ombrogenous surfaces

A matrix has been compiled to show the vertical relationships observed for the main peat types associated with presumed ombrogenous surfaces (Table 12).

Table 12. Matrix showing the transition between peat types upwards from Mid-Layer to Top-Layer peat, beneath presumed ombrogenous peat surfaces.

*Figures denote number of occurrences; none signifies that there was no mid-layer, i.e. peat was very shallow.

	Top Layer					
Mid Layer	**Amorphous**	***Eriophorum* peat**	**Monocot peat**	***Sphagnum* peat**	***Sphagnum–Eriophorum* peat**	**Unknown**
Amorphous	29	2	1	13	18	
***Eriophorum* peat**	1	3		1	5	
Monocot peat			1			
None	5					3
***Sphagnum* peat**	4	2		15	4	
***Sphagnum–Eriophorum* peat**	3	5		7	23	
Unknown		1		1		8

With regard to the three main peat types encountered (*Sphagnum, Sphagnum–Eriophorum* and amorphous peat) the greatest number of transitions observed in each case, was one of self-replacement (i.e. no change in type between the mid- and upper-layers). However, a large number of examples of top-layer *Sphagnum* and *Sphagnum–Eriophorum peat* had also developed on top of an amorphous peat mid-layer whilst in a small number of instances a top amorphous peat layer was situated upon a mid layer of *Sphagnum* or *Sphagnum–Eriophorum* peat. There was also a small number of transitions from mid-layer *Sphagnum* peat to top-layer *Sphagnum–Eriophorum* peat, and *vice versa.*

The *Sphagnum* or *Sphagnum–Eriophorum* to amorphous top-layer transitions were almost entirely associated with examples of M19 or M20 vegetation, and occurred at such sites as Combs Moss, Leash Fen and White Path Moss, but a single example was also recorded from M18 vegetation on the slope of Coom Rigg Moss. Almost all of the *Sphagnum* peat self-replacements were reported from the Border Mires, many from examples of M18 vegetation, some from M19, but a further example was recorded from beneath M18 vegetation at Hafod Elwy. A few of the transitions from mid-layer amorphous peat to top-layer *Sphagnum* or *Sphagnum–Eriophorum* peat were also from some sites in the Border Mires, but most were from sites elsewhere and a majority were associated with M19 vegetation. The two transitions from a mid-layer *Sphagnum* peat to a top-layer *Eriophorum* peat were both in the Border Mires.

4.5 Surface patterning on ombrogenous upland peats

Surface patterning is a widespread if variable feature of upland ombrogenous peatlands. Table 13 is based largely on the microtopographical elements suggested by Lindsay (1995; 2010) slightly modified and increased to include 'tussocks' as separate elements (see Annexe 1, section 11.1).

In general, the 'aquatic' (pools *etc.*) elements were not well represented on the sites examined. Wet hollows and shallow pools (A1 and A2) were most widespread, and were prevalent in M18 vegetation, decreasing in a sequence of M18 > M19 > M20. A very small number of deeper pools was recorded, all of them in M19.

The 'terrestrial' elements of the patterning (hummocks, T1 to T4) were more widely evident and, with the exception of T1 ('slight undulations') also showed a sequence of decreasing prevalence from M18 to M20. In the case of T1 it seems as if the 'slight undulations' of the surface recorded in M19 and M20 were largely subsumed into more prominent hummocky features in M18.

Tussocks of all sizes (U1 to U4) showed an inverse relationship to the communities to that of the hummocks and pools; they were most prevalent in M20 and least in M18.

Table 13. Occurrence of microtopographical elements* in samples of ombrogenous peatland surfaces examined, categorised by *NVC* community.

*Based largely on the microtopographical elements suggested by Lindsay (1995; 2010) slightly modified and increased to include 'tussocks' as separate elements (see Annexe 1, section 11.1). Values are means for each community based on a field ranking of abundance (1–5 scale) for each element.

	A1	A2	A3	A4	A5	T1	T2	T3	T4	U2	U3	U4
M18	0.73	0.30	0.00	0.00	0.00	0.16	3.11	2.50	0.41	0.07	0.07	0.00
M19	0.38	0.18	0.06	0.03	0.00	0.62	1.09	1.24	0.21	0.80	0.53	0.04
M20	0.25	0.00	0.00	0.00	0.00	0.67	0.21	0.67	0.08	1.83	1.38	0.21

Very similar trends were found in the mean maximum pool depth and the estimates of diversity (Table 14). The maximum mean height of hummocks was slightly greater in M20 than in M19, but there were fewer hummocks in M20 than in M19 (Table 13).

Table 14. Microtopographical features of ombrogenous peat surfaces examined, categorised by *NVC* community.

Values are means for each community, based on field measurements (pool depth and hummock height) or on a summation of the range of microtopographical elements recorded (diversity indices).

	Max pool Depth (cm)	Max hummock Height (cm)	Pool Diversity	Hummock Diversity	Hummock + Pool Diversity	Tussock Diversity
M18	4.55	36.82	1.02	6.18	7.20	0.14
M19	3.22	27.20	0.64	3.12	3.77	1.38
M20	1.79	29.88	0.25	1.63	1.88	3.42

The greatest hummock diversity was associated with a *Sphagnum*-based top layer, especially when this is a 'self-replacement' from a *Sphagnum*-based mid layer (Table 15). In general, *Sphagnum*–*Eriophorum* peat top layers did not support so much patterning – which was, in fact, curiously similar in prevalence to that associated with *Eriophorum* peat. Mean pool diversity was consistently low across all peat types, and very similar between *Sphagnum* and *Sphagnum–Eriophorum* top layers (and absent from the *Eriophorum* top-layer samples). Most of the *Eriophorum* top-layer sites were outwith the Border Mires, and most were associated with M19 vegetation (only two with M18).

Table 15. Relationships between the Top Layer and Mid Layer main macroscopic peat components and patterning diversity of presumed ombrogenous peat surfaces.

Peat categories recorded from a single sample have been excluded. Values are mean diversity for each pattern category. Peat types have been sorted in order of decreasing hummock + pool diversity.

Main Peat Components	Pool Diversity	Hummock Diversity	Hummock + Pool Diversity	Tussock Diversity	*n*
Top Layer					
Sphagnum peat	0.9	5.2	6.2	0.5	37
Eriophorum peat	0	4.3	4.3	0.7	13
Sphagnum–Eriophorum peat	0.8	3.4	4.2	1.4	50
Unknown	0.5	3.6	4.1	1	11
Monocot peat	1	3	4	1.5	2
Amorphous	0.5	2.9	3.4	2.1	42
Mid Layer					
Sphagnum peat	1.4	5.5	6.9	1	25
Sphagnum–Eriophorum peat	0.3	4.1	4.4	1.2	39
Unknown	0.5	3.9	4.4	0.7	10
Monocot peat	0	4	4	0	1
Amorphous	0.7	3.1	3.8	1.4	65
Eriophorum peat	0.5	3.3	3.8	1.3	10
No mid layer	0.1	1.7	1.8	2.8	8

4.6 Relationships between peat surface topography and sub-peat topography and with vegetation types

The inter-relationships amongst individual recorded variables, as examined above, indicate some general trends, but not their applicability in specific instances. Moreover, although these records report circumstances at individual sample points, they do not necessarily capture the wider relationships between them, and their relationship to the topography and sub-peat topography of the sites as a whole. For these reasons, where possible the samples were oriented so that they could be used as a basis for topographical sections (see Annexe 2, Section 11.2). Here we report some relationships and insights that arise from an informal comparison of the sections. For additional clarity examples of some sections are also reproduced below.

It is worth noting that the recorded vegetation in some (many?) situations may be the product of both natural prevailing environmental conditions and the effects of human impacts. For example, in parts of the South Pennines extensive drainage, rotational burning and, possibly the atmospheric pollution of hill bog has led to the development of dry heath vegetation (mainly H9) on deep peat, where presumably bog vegetation would once have been prevalent (*e.g.* M19 or perhaps even M18). Similarly, widespread burning and heavy grazing of hill bog areas is thought to have led to the dominance of *Molinia caerulea* in the southern Pennines and parts of Wales. Elsewhere, drainage of very deep and formerly very wet peat for forestry (*e.g.* in the Border Mires) may have resulted in the conversion of M18 to M19 vegetation, though it is also possible that much of this work was focussed on naturally better-drained surfaces (mire slopes) that already supported M19. The top layer peat, which will in large measure have pre-dated any forestry operations, of the slopes of the mires examined was mostly Amorphous or *Sphagnum–Eriophorum* peat (both 28% of the samples) whilst both *Sphagnum* peat and *Eriophorum* peat were found in 16% of samples (see Section 4.4.1). This suggests that, not surprisingly, the slopes were better drained naturally than the crowns of the mires in question, in at least some instances.

Ditching of lagg areas during afforestation and the subsequent downwash of eroded material may have modified the vegetation present at the base of slopes to produce M6, M20 or M25 vegetation, where once there may have been other, more diverse, minerotrophic vegetation types present. Although there are some exceptions, the state of these areas prior to afforestation or other major initiatives, does not seem generally to be documented and it is not possible to be certain what vegetation was formerly present. It is likewise difficult to predict accurately the effects of the removal of pressures such as drainage or forest cover, except in very broad terms.

4.6.1 Hill Slopes (‘Hill Bogs’)

The most distinctive feature of ombrogenous ‘blanket peats’ is that they can occur on slopes which in drier, lowland, climates would be occupied – if they were occupied by peat deposits at all – only by mires irrigated mostly by telluric water sources (*i.e.* groundwater outflows). Such sources may also be present in upland locations, but there climatic conditions favour the development of ombrotrophic peats on sloping ground without topographical constraints upon drainage.

The estimates of peat slopes collected here relate to the surface slope of the deposit. If consideration is restricted to the more conspicuously-sloping ombrogenous surfaces (*i.e.* excluding those that are ‘flat’ or nearly flat), it is clear that these can occur in two rather different circumstances. One is where they represent roughly the slope of the underlying sub-peat terrain; the other is where they form an often-marginal part of a rather different deposit, such as the edge of a deeper peat unit (often an ombrogenous dome, partial dome or bulge). Most examples of the first of these categories were grouped by cluster analysis into Cluster E, whilst many of the second were placed within Cluster D, though this partitioning was by no means exact.

In this section of ‘Hill Slopes’, consideration is given only to those ombrogenous surfaces which roughly follow that of the underlying terrain. These seem to correspond to what are often designated as ‘hill peats’, an inexact label but one which refers to much of the ombrogenous peat deposit that covers huge expanses of upland Britain.

‘Hill peat’ was encountered in all of the regions considered here, except for the lowland site of Stone Park. In some locations it was essentially peripheral to other types of (usually topogenous) ombrotrophic deposits, or occurred on steeper slopes that linked them together. Elsewhere, it was the dominant or only form of ombrogenous peatland in the landscape and this circumstance was encountered in Wales (Moel Eunant), South Pennines (Combs Moss, Featherbed Moss, Langsett Moors), Bowland (Cross of Greet) and North Pennines (Moor House). This type of peatland is doubtless important also as an extensive landscape feature in the Border Mires, but examples there seem generally to have been afforested and were not examined (though examples of thin sloping peats associated with other types of ombrogenous mire in the Roman Wall Country were considered). An illustrative section for Featherbed Moss is provided in Figure 14.

The slopes occupied by this type of deposit vary greatly: gradients of up to 1 in 5 have been determined. In general, the steeper gradients have the thinner and more amorphous peats, a low winter water table and an absence of *Sphagnum* and of any surface patterning. In some instances their vegetation is a form of heathland (H12) rather than the M19 or M20 of other slopes. However, the thickness of the deposit is determined by geographical location as well as by gradient. For example, in the Eastern Moors of the Peak District, which are at the south-eastern limit of 'blanket peat' formation in Britain, 'hill peat' is generally absent from the steeper slopes and, where it occurs on shallower slopes it is usually thin and often transitional to stagnopodzol or stagnohumic gley soils (though the thinness of some of these deposits may sometimes be an unnatural consequence of past wildfires).

Flow of water down-slope in hill peats must increase with distance from watersheds, but no evidence was found to suggest that it leads to a significant change in the character of the ombrogenous peat surfaces or composition of their vegetation with distance downslope. It appears that sloping ombrogenous peats often drain into small endotelmic flow tracks and thence into erosional gullies or hillside streams. In some sites patches of minerotrophic mire (mostly M6) occur on the slopes, but these seem mostly, if not exclusively, associated with gullies and streams and may occur at or below locations where these have cut down to the underlying mineral material, or sometimes perhaps, as Johnson & Dunham (1963) suggested, where peat pipes at or near the peat–mineral interface come to the surface. There was no evidence in the locations examined that the development of minerotrophic patches was related to increased rates of flow of endotelmic water, nor from groundwater outflows, though some such outflows might well be expected from some of the Pennine sandstones.

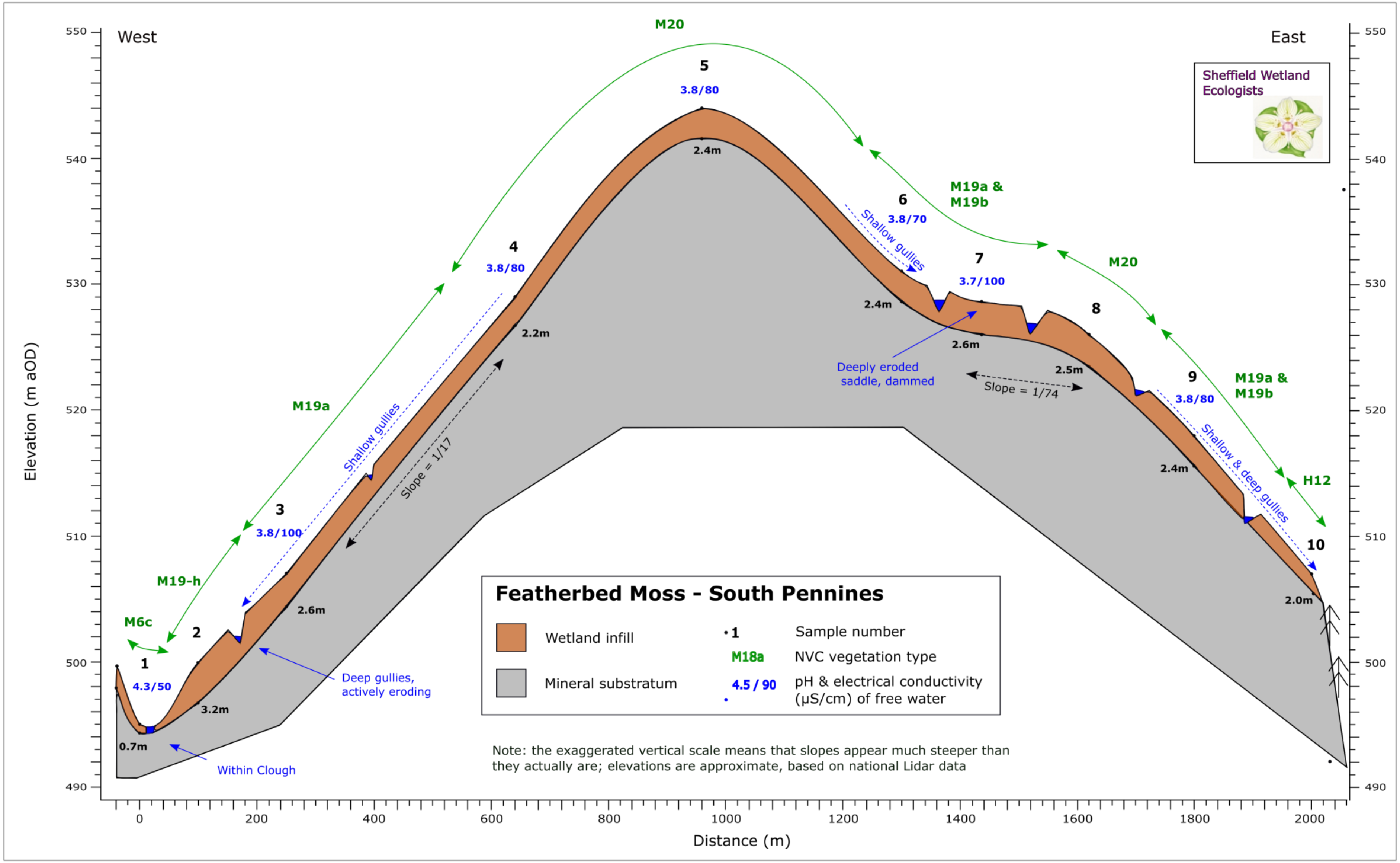


Figure 14. Featherbed Moss, South Pennines, west to east section.

The greatest influence on the character of the ombrogenous peat surfaces and their vegetation on the hill peat slopes appears to relate primarily to their gradient. Slackening of the slope, such as is associated with small benches on the hillside can be associated both with an increased depth of peat and, often, considerable anastomosing erosion. An example on the east side of Featherbed Moss is associated with a deeper and more eroded peat and with a change to M19 vegetation from the M20 vegetation of the slopes above and below the bench. Such 'flattenings' – and heavy erosion – is perhaps more typically a feature of the flatter parts of the summit ridge or saddle, as was observed at Langsett Moor (Figure A11, Annexe 2) and Moel Eunant (Figure A5, Annexe 2). By contrast, on the Featherbed Moss section (Figure A9, Annexe 2) there is little evidence for either deeper or eroded peat across the summit ridge, at least at the point of the section, and the summit peat seemed little different from that of the slopes, and is considered to be a form of 'hill peat'. However, elsewhere in this same area, flatter summits supported deeper peat, more erosion and, in some places, evidence of surface patterning, including shallow pools with some *Sphagnum cuspidatum* and *S. fallax.* This was found also, for example, in places on the plateau of the nearby Alport Moor, and in some small water-collecting locations of the slopes, though the vegetation of much or all of that peatland area, patterned or not, appeared to be assignable to M20.

4.6.2 Ombrogenous mounds on flat(-ish) surfaces

Some of the most extensive examples of ombrogenous peat in the lowlands are, or once were, located on the 'flat' surfaces of lake sediments, river floodplains and coastal alluvia. Many have been much modified, some largely or completely destroyed, and in remaining 'intact' examples the margins have often been much modified. Cors Caron, on lake deposits, forms one of the 'best' remaining examples (see Figure 15) and has had the benefit of some stratigraphical investigation (Godwin & Mitchell, 1938; Godwin & Conway, 1939; Hughes & Barber, 2003) (see Figure A6, Annexe 2).

In the uplands, Malham Tarn Moss probably provides the best example comparable with Cors Caron, again developed on former lake deposits, albeit punctured by mounds of glacial material which have not completely been covered by the eventual substantial dome of ombrogenous peat. This is bordered around much of its periphery by a stream which separates it from rising upland slopes, and to the east by Malham Tarn. The ombrogenous peat is unconformable with the Tarn, probably largely on account of an increase of 1m+ in the Tarn water level following the damming of the outflow in the late 18th century, so the natural hydroseral relationship is not evident.

In Upper Teesdale, Red Sike Moss forms a more subdued mound of ombrogenous peat, somewhat irregular on account of erosion in places (Turner, *et al.* 1973), in a shallow basin on a broadly 'flat' bench of Whin Sill (Figures A25 to A28, Annexe 2). It is separated from the rising slopes of 'sugar limestone' to the east by a stream, but on the other sides is unconfined, and a layer of thin 'hill peat' slopes steeply down to the Tees – or at least did, before the area was flooded by Cow Green reservoir. Formation of this hill peat was initiated later than the main Red Sike Moss mound, and its ontogenic relationship to this, if any, is uncertain.

Slightly upstream of Red Sike Moss, and now completely inundated by the reservoir, Foolmire Moss once presented a quite deep dome of peat on flattish ground alongside the Tees (Figure A 24, Annexe 2). This impression is created partly because Foolmire Sike cuts across the valley-bottom peat deposit a short distance from the adjoining hill slopes, and although Turner *et al.* considered this to be a watercourse of long standing, it remains the case that the conformation of this valley-bottom deposit to the adjoining slopes elsewhere along its length has not been reported. It may also be noted that although the peat surface is mounded independently of the underlying Till, this mounding seems to have been created, at least along the length of the section, by a mounded bottom layer of *Phragmites*–wood peat, across which there is a fairly similar thickness of *Sphagnum* or *Sphagnum–Eriophorum* peat. Unfortunately, due to its destruction it is no longer possible to check these features.

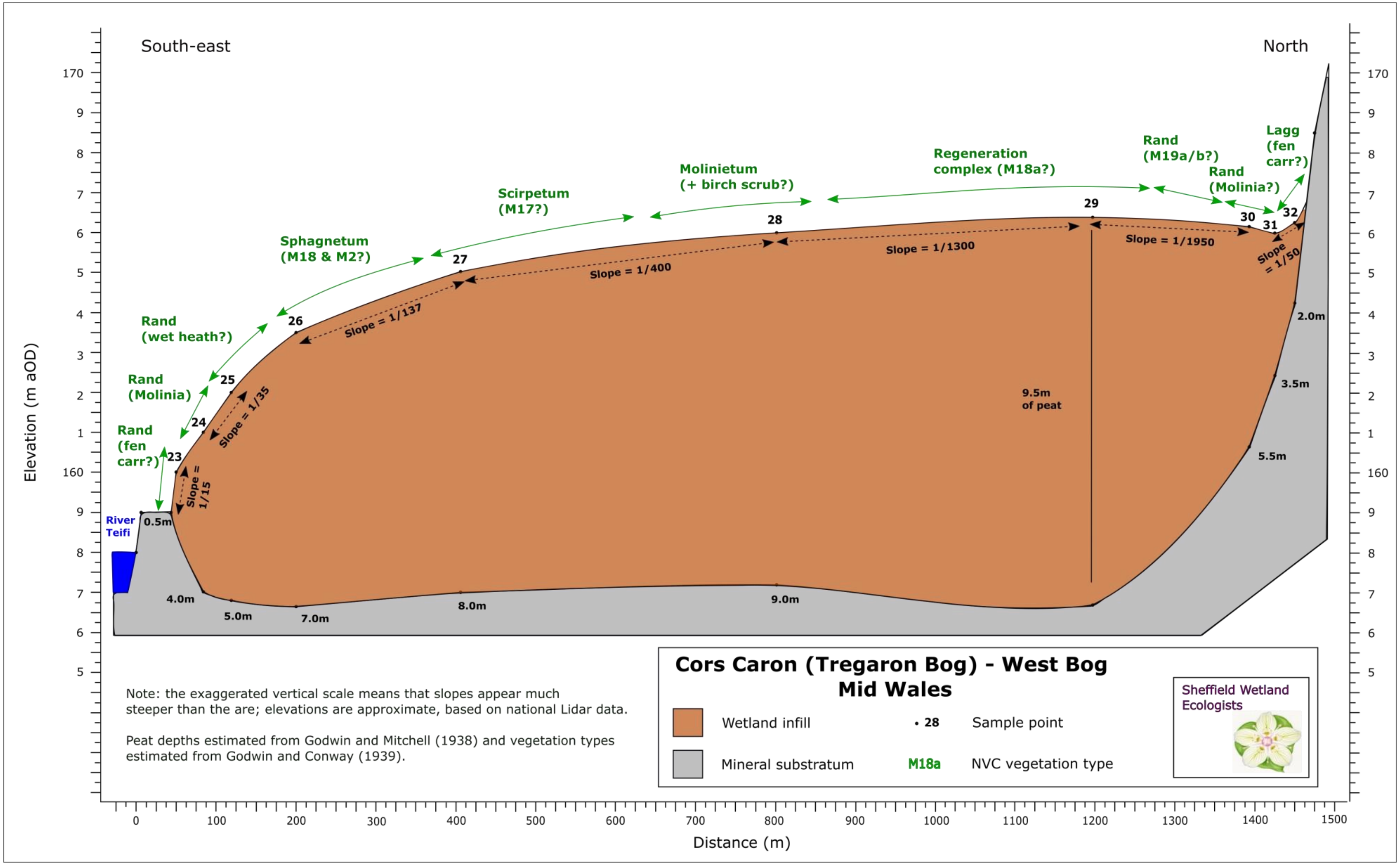


Figure 15. Cors Caron West Bog, Mid Wales, south-east to north section.

4.6.3 Ombrogenous mounds on gentle slopes

This distinct, but small, category, is based largely on four of the mires in the Eastern Moors region of the Peak District. These all occupy broad, shallow, gently sloping valleyheads within the 'shelf' element of the 'shelf-and-edge' topography of this area, and the underlying sub-peat topography is gently sloping but essentially planar (or at least 'smooth'). Ombrogenous peat deposits within this category are variable, but can be regarded perhaps as somewhat tilted examples of 'ombrogenous mounds on flat(-ish) surfaces.

Ringinglow Bog is by far the most investigated of the sites within this category. It occupies a pan-like valleyhead on the east side of the main drainage axis of Burbage Brook. White Path Moss, also with ombrogenous peat, is located on the west side of this drainage axis. Ombrogenous peat accumulated at Ringinglow Bog lateral to, above, and later than, the fen woodland that occupied the main drainage axis. Thus at one time the site consisted of a fen woodland axis flanked upslope by developing bog. Eventually, the fen woodland also largely developed an ombrogenous cover, but the drainage axis – which is partly groundwater fed – has persisted, separating the two gently sloping bogs on either side. The topographical crown of the peat surface of Ringinglow Bog is at the highest location, most distant from the drainage axis, and is more of a flat peat surface than an obvious 'dome'. It is close to the watershed of the sub-peat topography, and a small area of peat has also developed on the side of this that drains east to the Don. Although it varies north–south, peat is deepest in this part of the mire, reaching to some 6 m depth in places (see Figure A14, Annexe 2). There are the microtopographical remains of a patterned surface in some of this area, and some residual plants of *Andromeda polifolia*, and there can be little doubt that it once supported M18 vegetation, since mostly converted into M19, probably in response to atmospheric pollution from nearby Sheffield. Conway commented that "one has only to go to any spot in the central region of the bog, pull up a tuft of cotton-grass, and scrape away 5 cm. of solid surface, to obtain a handful of the freshest and most typical bog-building *Sphagnum* peat, showing large well-preserved *Sphagnum* shoots."

The section provided here for Ringinglow Bog runs north–south along the crown at the top end of the bog. Other sections have been provided by Conway (1947) and one, running west–east, is reproduced here (Figure 16). Although the deepest peat of the bog does occurs at the crown, the configuration of the peat deposit nonetheless differs from that which can be found on a 'flat-bottomed' deposit, such as the western bog of Cors Caron (see Figure A 6, Annexe 2). At that site, impaired drainage associated with increasing distance from the drainage point (Afon Teifu) has resulted in the mounding of a deepening peat deposit against the rising slopes of the adjoining hillside. At Ringinglow Bog, and in similar sites developed on a sub-peat slope, the effect of impaired drainage seems to have been to stimulate peat formation ever further upslope. Thus the surface profile of the peat deposit is broadly similar to that at Cors Caron, but it does not increase in depth in the same way. The upslope accumulation of peat at Ringinglow was halted once it reached the watershed with the eastward-draining Porter valley. Conway (1947) referred to this as "a very small and ill-defined overflow in the north-east corner", but is very likely that this overflow to the east helps to account for the 'flat' surface of the crown of peat.

The slope of the peat surface increases towards the main drainage stream and is in places sufficiently steep to form what Conway considered to be a rand structure. These steeper slopes also have some small drainage streams, which Conway considered to be features of peat drainage (in contrast to the main drainage stream which she recognised pre-dated the extensive formation of peat and which is flanked by M6 vegetation). There is also an apparent endotelmic soakway, which is marked by a swathe of a *Molinia*-rich version of M19 vegetation.

The stream that separates Ringinglow Bog from the similarly-sloping White Path Moss appears to be sourced by groundwater outflows from one or more of the potential aquifers that underlie the peatland, including the half-buried Friar's Ridge.

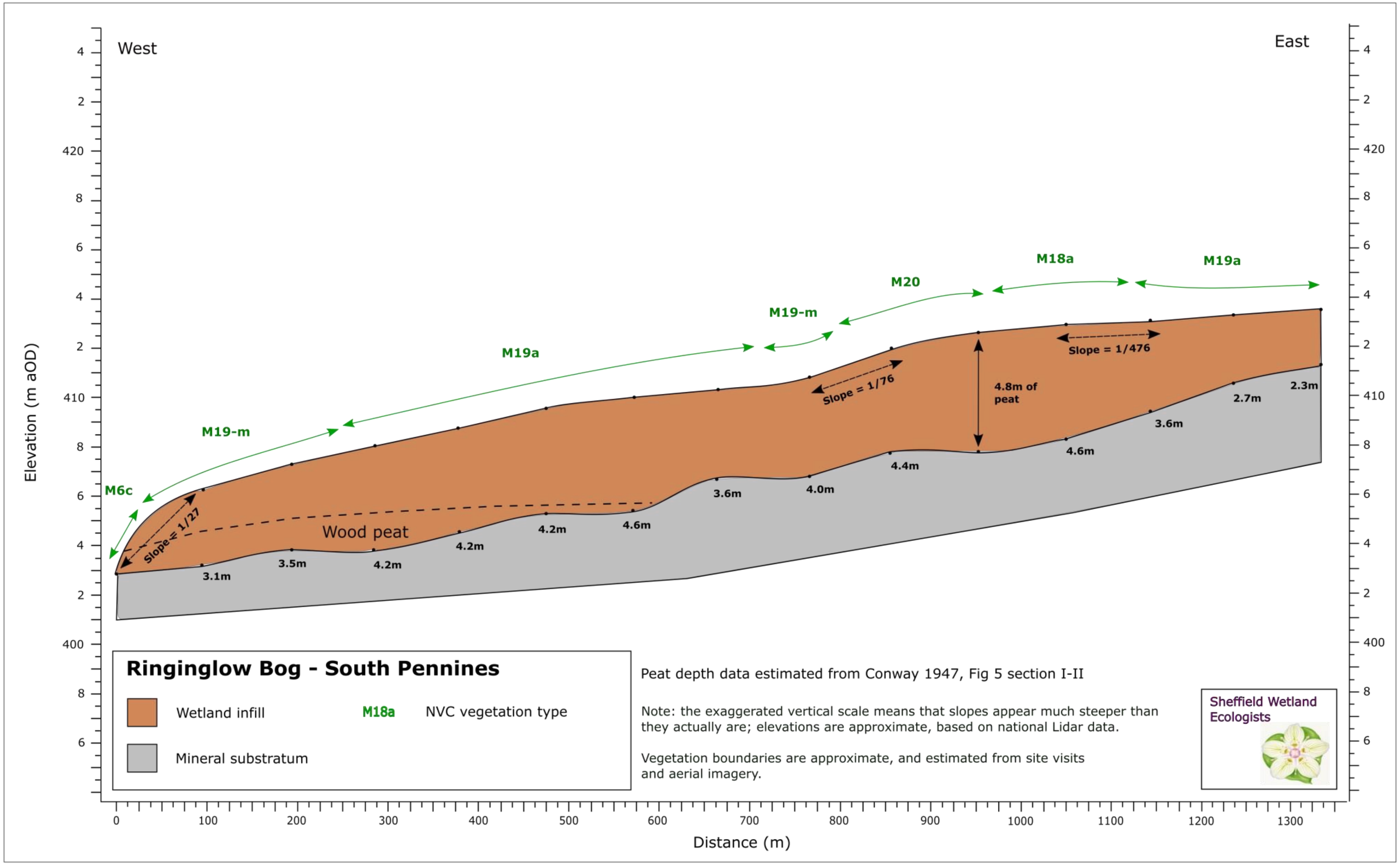


Figure 16. Ringinglow Bog, South Pennines, west to east section.

White Path Moss has been much less well examined than Ringinglow Bog and, in the section examined (Figure A 18, Annexe 2), consists of rather deep peat, partly domed between two (probably ancient) streams. This has affinities with the sections from Stone Park (Figures A29 and A30), also in a valleyhead bowl (though formed upon more strongly undulating mineral ground) in which ombrogenous peat is subdivided by spring-fed streams and where minerotrophic conditions, probably sourced from groundwater outflows, occur lateral to the ombrogenous peat and support fen vegetation. It is not known for either site the extent to which the streams have determined the disposition of the ombrogenous deposits, perhaps partly artificially, or whether their courses have been determined partly by the development of these. The ombrogenous surfaces at Stone Park are generally more obviously domed that at White Path Moss, though the degree of 'doming' is subdued at both sites. They also support M18 rather than the M19 at White Path Moss.

Hicks's (1971) section across part of Leash Fen indicates a generally lesser sub-peat slope than Conway had recorded from Ringinglow; across the peat surface Leash Fen slopes as a gentle half-dome (Figure A 12, Annexe 2), from the north-east margin where it is confined by rising hill slopes and where, along the line of Hicks' section, the peat is some 6.5 m deep, to the drainage outlet near the north-west corner, where it is not topographically confined. In the absence of a north–south section across the deposit, its overall conformation is not known, but it seems that it is very shallowly-domed towards the southern end, where it drains to the south-east.

4.6.4 Basins and Partial Basins

Very few examples of ombrogenous surfaces were encountered that were in reasonably symmetrical basins. Perhaps the best example is provided by the rather small Lucas Moss close to the top of a steep Gritstone Edge in the East Moors (Figure A 13, Annexe 2). This contains up to around 4 m depth of peat and has a shallow dome and a narrow lagg around most sides except for the north-west, where it merges into shallow hill peat. The apparently ombrogenous surface has developed over fairly loose peats, probably weakly minerotrophic in character, and is clearly independent of the sub-peat topography.

More widely encountered than the above type of deposit is that associated with asymmetric, 'partial' basins which have a lower lip at a markedly lower level than the upper one – which is often, but not always, more-or-less on the opposite side of the basin. One of the clearest examples of this, partly because it represents a fairly self-contained unit, is provided by Walton Moss in the Roman Wall Country in Cumbria. This is said to be a kettle hole, and Hughes (1997) and Hughes *et al.* (2000) have provided a useful stratigraphical section (reproduced in Figure 17). This essentially shows the peat infill to be a partial autonomous dome, banked up against the taller wall of the basin and draining southwards over its lower lip. Along the line of the section, the crown of the dome occupies a large, almost level surface at around 101.5 m aOD, and sinks northwards by only about 1 m to a shallow 'lagg' which separates it from the rising slope of Till to the north. South of the crown, the somewhat convex peat surface curves steeply downwards over the lower lip of the basin to a gradient of about 1 in 25 and thins to a mire margin at around 86 m aOD. This margin is unconfined, and below it is a further steepening of slope. Similar partial domes occur in a number of other locations elsewhere, especially in the Roman Wall Country Border Mires sites, and are described further below.

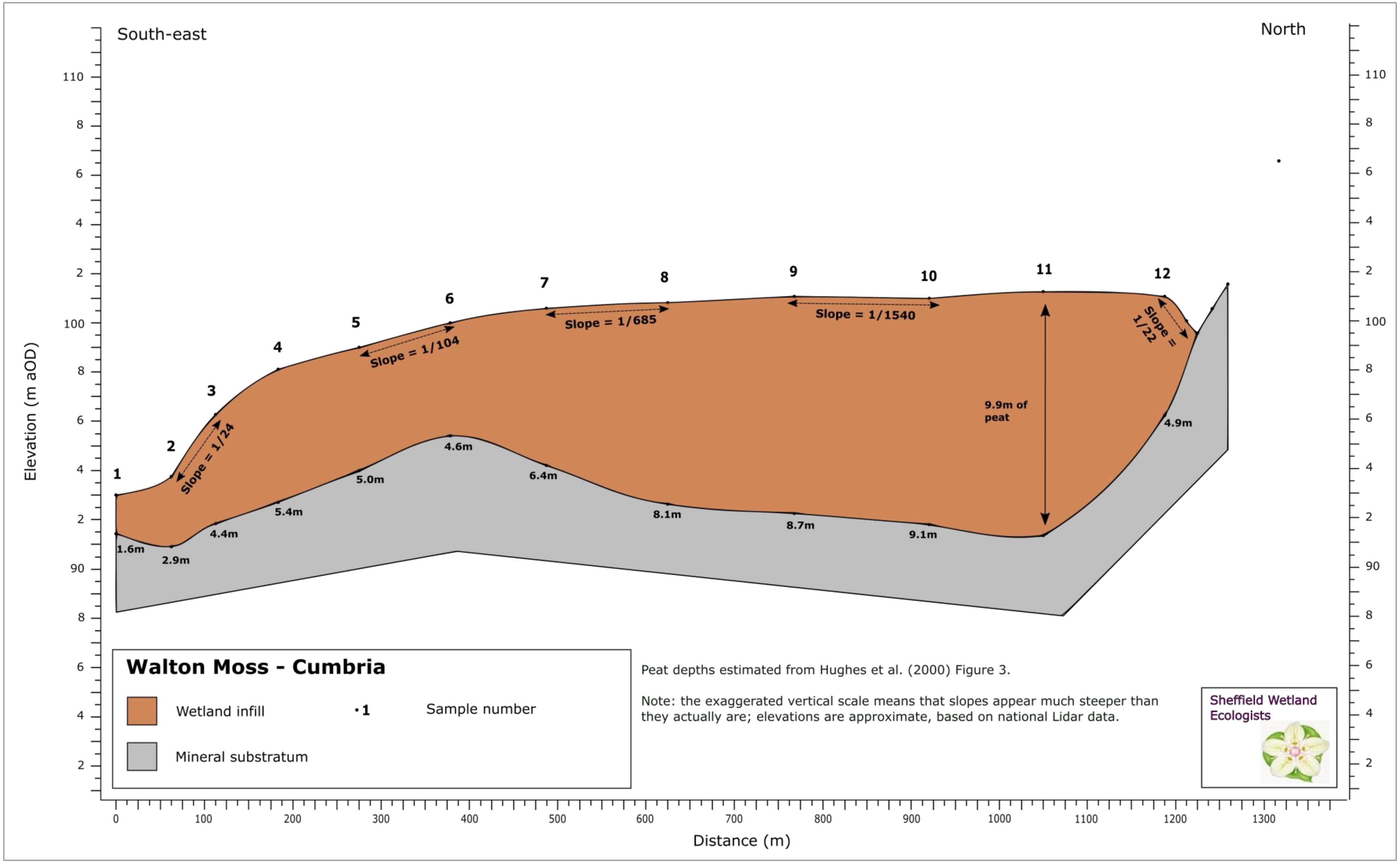


Figure 17. Walton Moss, Cumbria, south-east to north section.

4.6.5 Troughs

This very distinctive type of ombrogenous mire occurs in the Roman Wall Country in Northumberland, where its clearest development is known from two sites.

The Lakes is a long, narrow trough that forms an eastward-draining valleyhead between low hills that rise to around 310 m aOD on either side. The significance of its name is not known, but much of the site is very wet and, in places treacherous. A longitudinal profile, made in the western part of the mire shows the peat surface to slope eastwards at a gradient of around 1 in 130 over an irregular sub-peat surface of low ridges and shallow hollows, steepening to about 1 in 30 at the easternmost end, and clearly largely independent of the underlying ground (Figure 18). A lateral profile shows a fairly flat surface sloping gently from north to south beneath a substantial forested slope on the north side, but contained southwards by a lesser mineral ridge (Figure 19). Surface conditions are particularly unconsolidated near the southern margin, with water flow tracks, perhaps partly because the cross-valley profile results in enhanced flow to this area. There is a ditched ‘lagg zone towards the northern margin, which probably intercepts surface flow from the slopes above, but there is no evidence for any doming across the section. This may be because the hydrodynamics of the peatland are dominated by longitudinal drainage down the peat slope, and it can be conjectured that the steeper slope at the eastern end is similar to the rand feature of some other ombrogenous sites.

Muckle Moss has been described in detail by Pearson (1954, 1960) and his sections have been used here (see Annexe 2, Figures A43 and A44). The site has many similarities with The Lakes and occupies the head of a long trough mostly flanked by mineral ridges, though lower than at The Lakes and absent in one location where there is a small lateral outflow to the north. The western part of the site is clearly developed over a shallow basin that once contained a late-glacial lake. However, the mineral trough rises quite steeply to the west of the basin – the peat deposit is banked against this and the surface forms a mostly fairly even and very gentle slope down to the east, with a gradient of about 1 in 550. It is quite possible that at an early stage of the development of the mire ombrogenous peat may have formed a mound domed across the lake infill and that this has become ‘submerged’ by up-trough peat accumulation, in the location furthest from the drainage points. This is not evidenced obviously in Pearson’s stratigraphical data, though there is a rather curious break of slope and a disruption of the otherwise generally longitudinal vegetation pattern into something more circular at the point where a former ‘dome’ might perhaps be expected to have been located. One transverse section (E–F, Figure A 43, Annex 2), towards the western end of the mire, shows the peat surface clearly contained by the flanking ridges, and with a slightly concave surface. There is clear evidence of down-slope flow lines which, unlike The Lakes, seem to be particularly along the central axis of the trough, though it seems possible that this may be a legacy of a former drainage initiative. At one point along the trough (section P–Q) the mineral ridge along its north side is broken where there seems to have been a natural drainage outlet to the north, and here the peat surface on the northern side of the trough falls northwards, with a convex profile, to an unconfined margin. From this point eastwards, the peat infill in the trough thins, much as at The Lakes, to what is assumed to be a main and particularly wet drainage outlet. Drains have been cut in various places along the base of slopes and along the centre of the mire.

Both The Lakes and Muckle Moss support M18 vegetation, flanked for the most part by M19 (M20 in places) yet their topographical context is one which, in southern England, would be expected more likely to be occupied by M21 vegetation. This has been mapped on the *NVC* map of Muckle Moss, but only along the axial flow line, and also along part of the margin of The Lakes. Both sites would appear to be vulnerable to some ingress of telluric surface drainage, but there is no obvious floristic evidence to suggest that the M18 surfaces are anything but ombrotrophic.

The Lakes and Muckle Moss are both particularly wet sites. Lunn (1958) considered Muckle Moss to be perhaps the most dangerous mire of the Roman Wall Country. Evidence from down-trough movement of some fence posts across part of the mire suggests that there has been some down-trough movement of peat, particularly along the central flow axis, and this may also account for the occurrence of some quite deep, possibly tensional, pools.

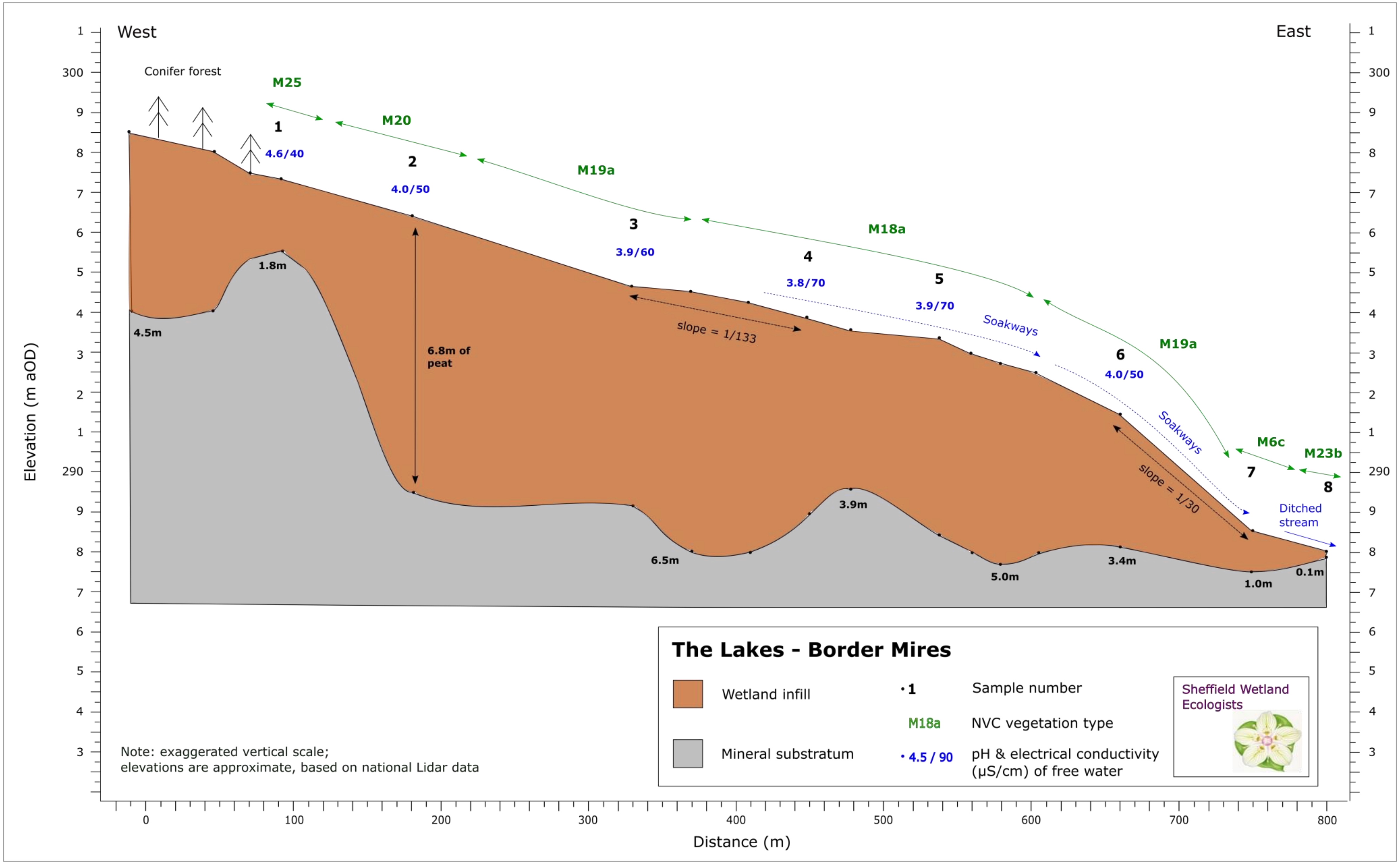


Figure 18. The Lakes, Border Mires, west to east section.

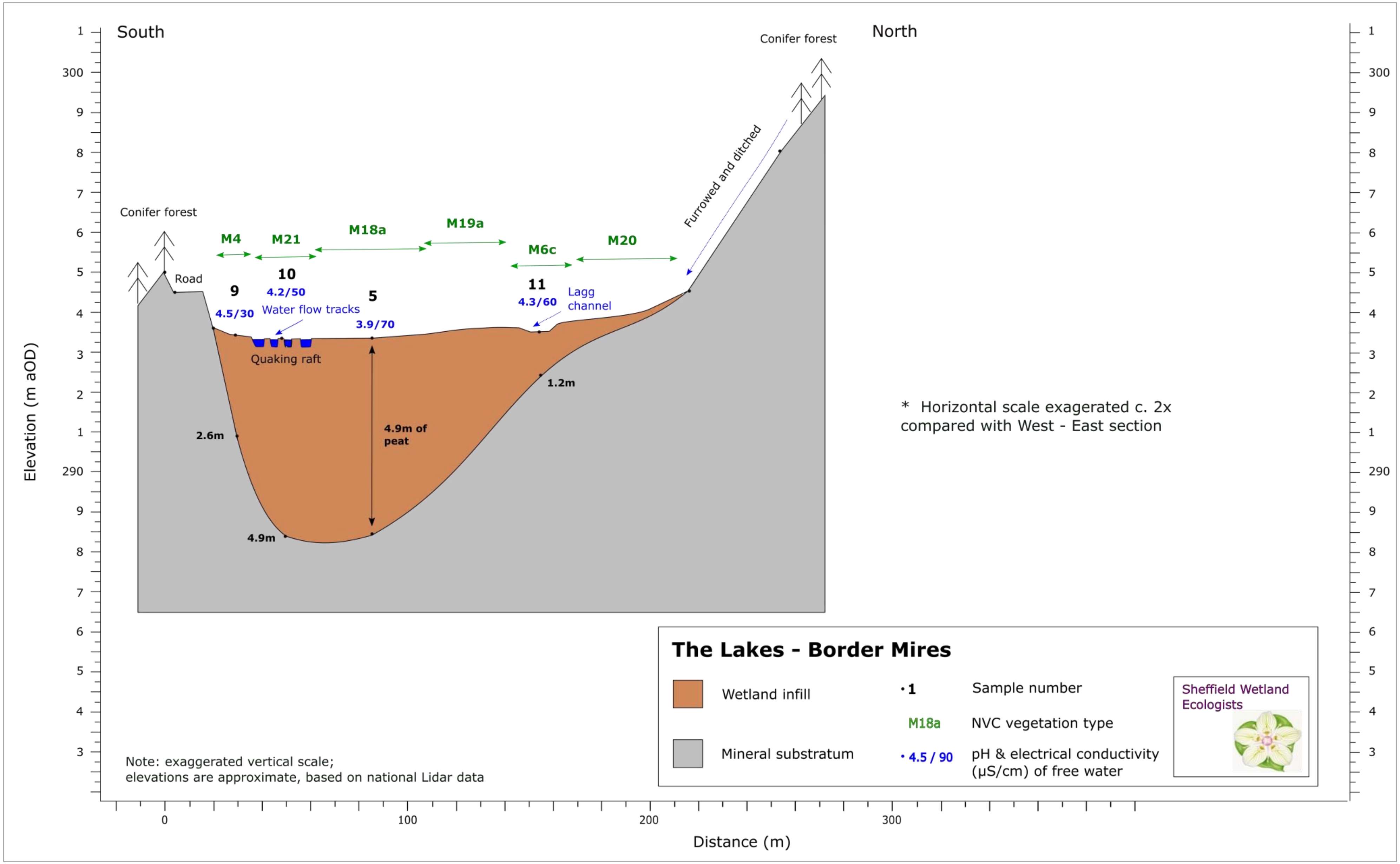


Figure 19. The Lakes, Border Mires, south to north section.

Elsewhere in the Border Mires, the trough along the axis of The Wou seems to provide another example of this type of mire, at least at the more ombrotrophic upper (eastern) end (Annexe 2, Figure A 52). In Wales it is possible that the south-west trending trough at Hafod Elwy may also represent a rather drier version of this type (Figure A3, Annexe 2), though it has been much disturbed by drainage and afforestation. It seems rather likely, based on the stratigraphical data provided by Moore & Chater (1969) and particularly by Slater (1976), that Gors Lwyd, called a 'raised bog' by Rudeforth *et al.* (1968), may also fit here, but we have not examined this site and it has been subject to some erosion. Elsewhere in England, the southward-flowing upper slope of Fen Bogs provides an example of this type of ombrotrophic habitat.

4.6.6 Ombrogenous ridges and crests

In many of the Roman Wall Country mires, including many of the Border Mires, peat has accumulated over minor ridges and yet its surface conformation may bear no evidence this. In others, such as Butterburn Flow and Coom Rigg Moss, peat has accumulated over ridges or other eminences and this is reflected to greater or lesser degree in its surface conformation (Figure 20).

The relationship of peat surface and sub-surface topography to sub-peat ridges depends partly on their magnitude and conformation. At Featherbed Moss, along the line of the section (Figure A9, Annexe 2), the peat across the top of the ridge is very similar in depth and character to that on the hill slopes below, and it can be regarded as a topographical variant of 'hill peat'. However, in some other locations, including at some other points across Featherbed Moss and nearby locations, the ridge is broader and flatter than that in the section, and can support a deeper peat. This is particularly the case in some cols or small valleyheads, where differences from the hill-peat slopes may be marked by some degree of surface patterning. However, the higher-level examples of this examined here have mostly been heavily eroded, and it is difficult to assess their salient characteristics. This is, for example, the case with sample 8 on Langsett Moors (Figure A11, Annexe 2). However, a relatively un-eroded surface was sampled on a flattish 'saddle' at Combs Moss (Figure A7, Annexe 2) in which there was some 3.3 depth of peat, clearly mounded slightly above the mineral ground. In places this had considerable surface patterning, with high hummock and pool diversity indices, and some surfaces were referable to M18.

The mire at Hafod Elwy has been considerably modified by forestry operations and associated drainage. It occupies a fairly shallow col and drains both to the south-west and north-east, though principally to the south-west. The south-east–north-west section (Figure A3, Annexe 2) presents a gently concave surface with some 6 m depth of peat over a broad depression, probably the valley head, whilst the south-west–north-east section (Figure A4, Annexe 2) seems to cut across this obliquely. It does, however, demonstrate a mounded surface across the hollow, with some 7 m depth of peat, and some of this supports M18 vegetation. In addition to numerous drains, a soakway associated with M21 and similar vegetation crosses a lower part of the peat mound towards its western end. This may represent natural drainage obliquely from the slopes of Hafod Elwy Moor NNR into the axis of the mire valley.

The ridge at Moel Eunant is fairly flat-topped (Figure A5, Annexe 2), but is also partly affected by severe erosion, and also influenced by restoration activities. One of the samples (4) is on intact peat. This is slightly deeper than the hill peat on the slopes but, although highly humified, it is rich in *Sphagnum* remains, and *S. papillosum* is also locally abundant on the surface and contributes to the moderate hummock diversity recorded in that area.

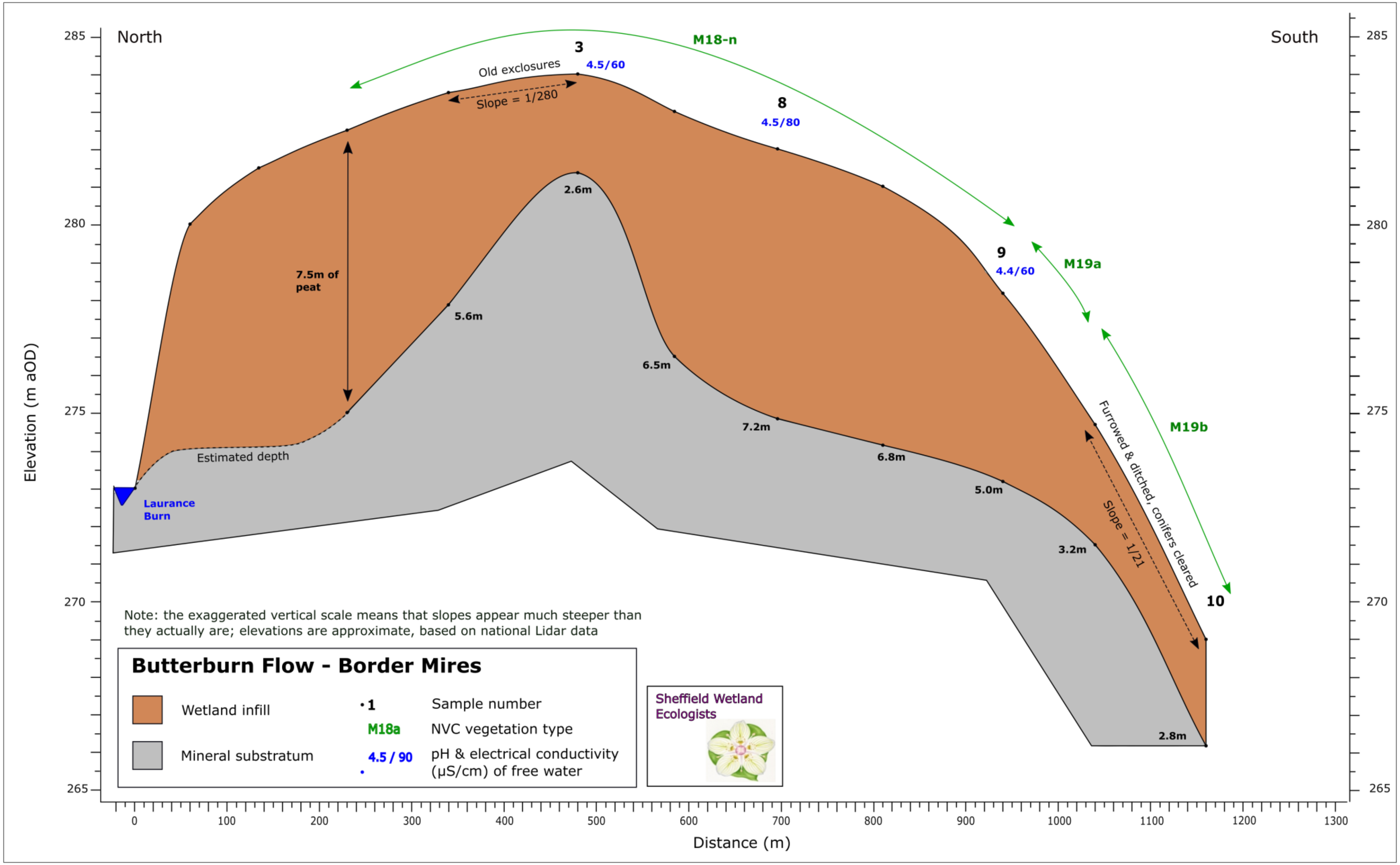


Figure 20. Butterburn Flow, Border Mires, north to south section.

4.6.7 Ombrogenous deposits over irregular terrain

The 'basin peat' sites examined in the Roman Wall Country provide a particularly rich and diverse assemblage of topographical and sub-topographical variation, and some detail of this is provided here for specific sites. Some of the sites considered here have been described by Wheeler *et al.* (2020; Annexe 1).

4.6.7.1.1 Gowany Knowe

Gowany Knowe, like several of the more northerly examples of 'basin peatland' in the Roman Wall Country, is fairly isodiametric and supports a (very) roughly concentric arrangement of *NVC* type. The main 'topogenous' area occupies a shallow hollow, elongated east–west (Figure A 38, Annexe 2). Along this axis ombrogenous peat forms a very distinct, more-or-less symmetric, autonomous dome with topographically unconfined margins – at both ends peat slopes down to small streams. The surface of a north–south section across the crown of the dome (Figure A 37, Annexe 2) is also independent of the sub-peat topography, but shows much less of a dome, more a gently-sloping surface that curves downwards northward to a point where the slope steepens so that it is replaced by hill peat. Southwards the dome is banked against a steeply-rising hill-slope, also covered by hill peat and (formerly) conifers, and forms topographically a shallow spur of deep peat extending northwards from the hillside. However, it is partly separated from this by a shallow, lagg-like trough, marked by a band of M25 and M6 vegetation. M18 vegetation is largely associated with the crown of the dome. It is surrounded almost everywhere by an irregular zone of M19 vegetation, mostly on the slopes falling from the crown but also along the southern side where any fall of slope is either eastwards or westwards but where the surface is more-or-less flat to the margin of the mire. The M18 / M19 mire is surrounded by M20 and M25 vegetation, partly associated with the lowest slopes of the ombrogenous dome, mostly with hill peat on the rising or falling hill slopes on either side of it. On and near the western margin of the mire, and particularly on what seem to be soligenous slopes towards the north-western outflow there is some relatively rich minerotrophic mire (O'Reilly, 2022) which supports stunted *Phragmites*, one of the very few locations in Northumberland for *Carex lasiocarpa* (Swan, 1993) and, formerly at least, *Carex limosa* and various basiphilous bryophytes (see also Section 5.9.5.3). It is possible that the apparent loss of species from this area is a consequence of forestry operations.

4.6.7.1.2 Hummel Knowe

Hummel Knowe occupies a more elongate location than Gowany Knowe but it shares with it a substantial mound of autonomous ombrogenous peat along the east–west axis (Figure A 42, Annexe 2), with a total peat depth of more than 10 m beneath the crown of the dome. Both east and west ends of the deposit are unconfined – at the west end a drainage channel divides it from a separate ombrogenous deposit, at the east end a slope drains down to Pudgment Sike. However, at its eastern end the 'dome' is situated over a mound of mineral ground, and the marginal peat slope there thins into a stand of flushed M20 hill peat, whilst most of the dome is covered by M18 vegetation. The junction between the two is marked by a number of narrow ditched channels, which have been allocated variously to M17, M20 and M25. Elsewhere the M18 of the dome is surrounded almost everywhere by a narrow band of M19 vegetation. It is possible that at the eastern end the mound (or ridge?) of mineral material may act as a sort of vertical 'chicane', focussing catotelm flow out towards the surface of the peat.

The crown of the mire also drains to the north, along a valley between Lamb Rigg and Hummel Knowe, but a section made transversely (north–south, Figure A 41, Annexe 2) across the crown of the dome just to the east of this shows little evidence of doming across the peatland in that direction, except the surface does rise slightly to form a shallow 'dome' skewed asymmetrically towards the southern side of the deposit. The north side of the deposit, except where it falls into the north-sloping valley, is confined by quite steep hill slopes, separated from them by a lagg with M23 and M25 vegetation. This is also the case along parts of the southern side, but here, in places, as at the southern end of the transverse section, the 'dome' of peat has accumulated to be some 2 m above the lip of the basin and is partly draped over this. Overall, this suggests that the conformation of peat within the trough reflects the drainage pattern imposed by the three main water outlets, with the southern margin opposite the northern valley being particularly poorly drained, especially whilst the level of peat along it was below the lip of the hollow, and that a flattish peat crown has developed to form a flattish watershed between the three main drainage directions, but is now also controlled by some drainage to the south.

4.6.7.1.3 Pundershaw

Pundershaw is quite close to Gowany Knowe and is also roughly isodiametric. It has developed over a basin-like hollow below quite steep hill slopes to the east, north and west. Southwards the hillside slopes away from the mire, but the lower lip of the hollow largely contains the 'basin peat'. The surface of the peat across the basin forms a broad lobe sloping broadly north to south which is independent of the shape of the underlying hollow and which, in effect, forms a shallow tilted dome across this north–south (Figure A 47, Annexe 2). The south-west–north-east section (Figure A 48, Annexe 2) is also gently domed where it crosses the north–south lobe of peat. One end of both sections is confined by rising hill slopes, but has a separating lagg-like feature, marked by soft-rush-dominated M6 vegetation. The other end in both cases is topographically unconfined and slopes away from the basin, down into drainage outlets. The vegetation pattern has been partly disrupted by drains but it essentially similar to that of Gowany Knowe, with a core area of M18 on the flatter crown of the dome, mainly surrounded by M19, even on the northern side of the dome, though here it may be a response to ditching, at least in part. M20 occurs around the fringes of the 'basin peat' and more extensively on the shallow hill peat of the surrounding slopes. A small area of base-rich fen has been reported from a seepage just above the north-eastern part of the lagg area (Davy & Diack, 2019; see also Section 5.9.5.3).

4.6.7.1.4 Grain Heads Moss

Grains Head Moss comprises two more-or-less discrete ombrogenous basins, connected by thin hill peat on a steep afforested slope. The 'upper mire' has formed in a very narrow, east–west elongated trough incised within a narrow mineral ridge which falls sharply both to the south, to Hindleysteel Crags and to the north, to the main area of Grain Heads Moss. It has been furrowed, ditched and forested, but its surface retains some semblance of a shallow dome of ombrogenous peat.

The main area of Grains Head Moss has developed across three basins cut sequentially downslope within the more gently shelving mineral ground beneath the slope from the 'upper mire' (Figures A39 and A40, Annexe 2). Peat accumulation within, and then across, these has produced a partial ombrogenous dome, banked up against and confined by the rising slopes around its upper margin, but topographically unconfined downslope, where it generally continues as a thinning deposit of hill peat down to the main drainage streams. The peat surface is independent of the sub-peat topography except over the shallow marginal peat and forms a partial dome, which is particularly evident in the north–south section. The crown of the dome is more-or-less flat. Northwards it curves downwards to a quite steep ombrogenous slope, with a gradient of around 1 in 17 and with M19 vegetation rather than the M18 of the flatter, wetter crown, though there is little obvious difference in peat type associated with this gradient – both crown and slopes are formed from a dominantly *Sphagnum–Eriophorum* peat. Southwards the peat surface slopes gently from the crown to the foot of the adjoining ridge, which is marked by a partly ditched 'lagg stream', which flows south-westwards around the periphery of the 'dome' to a drainage outlet. It supports M6 and M4 vegetation but has little hydrochemical evidence of minerotrophy. The banking of ombrogenous peat against the steep mineral slope, which has resulted in a partial dome or 'bulge' of ombrogenous peat is likely to be a consequence of poor drainage along the southern mire margin, and of water flow into this from the adjoining slopes.

4.6.7.1.5 The Wou

The Wou is a large, elongate valleyhead trough which feeds westwards to the Crammel Burn. Only the eastern-most end has been examined. The site comprises a valley-bottom trough with axial water flow to the west flanked by ombrogenous peat surfaces of various kinds, which vegetation mapping has referred to M18, M19 and M20. At the eastern end there are two main patches of M18 vegetation, both surrounded by M19 or M20 and both marking the position of sub-peat hollows (Figures A51 and A52, Annexe 2). Their peat surface does not conform with the sub-peat surface, but neither is it conformed into obvious 'domes' of ombrogenous peat. Rather they form gently-sloping 'flat' surfaces which are distinct from the steeply-sloping surfaces above or below, and which mostly support M19 and M20 vegetation, and give a stepped-like appearance to the valleyside. They are evident on Lidar contours as lobes of flattish surface projecting into the valley (Figure B30, Annexe 3), and this configuration is also evident on the areas of M18 further west in the valleyhead not examined as part of this project, suggesting that these also may occupy sub-peat hollows. Some of the steeper slopes outwith the areas of M18 have ditches and flow tracks, typically rich in *Molinia*, though there seems to be some uncertainty as to whether this represents a *Molinia*-rich version of M19 or M25. One quite large *Molinia* soakway seems to occupy a shallow valley which originates between the two M18 areas and curves north-westwards around the western margin of the lower one to feed into the valley bottom. It thereby separates the two M18 areas examined here from the two that occupy similar locations on the hillside further to the west.

NVC mapping indicates that much of the valley-bottom trough, which is very wet and quaggy, is occupied by M4 vegetation, with some M6 and peripheral M20 vegetation, but in the winter conditions of 2023 some of this appeared to be more like a *Narthecium*-rich version of M18. The valley bottom appears to narrow and become more stream-like westwards.

4.6.7.1.6 Felecia Moss

Felecia Moss occupies a curved valleyhead, in a depression surrounded (confined) by higher ground except near the main outlet in the south-west corner; the forest road that surrounds the bog on three sides is likely to partly divert any surface water flow from the adjacent slopes. M19 covers much of the slopes of the mire, but the lower central area is occupied by M18 which is focussed upon a broad hollow with some 5.7 m depth of peat, confined at the southern end of the site by a steep, formerly forested slope. The peat surface of the north–south section (Figure A 35, Annexe 2) broadly follows that of the sub-peat topography with some evidence of slight doming of the deepest peat where this section cuts across what seems to be the main drainage axis. In the north-eastern part of the site Lidar contours indicate a lobes of less steeply-sloping peat extending south-south-west from the north eastern margin, and this forms a gentle sloping dome, but in the south-western part the axis curves to drain westwards to the main outflow, whereupon the slightly convex surface is replaced by a slightly concave one with evident flow tracks (though in both parts the overall slope is around 1 in 110. M18 vegetation occupies both convex and concave surfaces. At the south-western outflow the deep peat is unconfined and is perched, virtually hanging upon the edge of a steep slope of the mineral ground, where it falls to a drainage stream (Figure A 36, Annexe 2). The peat slope here is somewhat steeper than that of the sub-peat surface and its top half is upon deep peat but its bottom half rapidly thins. The slope here is about 1 in 13 and the deep peat at the edge of this seems rather precariously positioned! The peat here was quite well drained with a winter wetness category of ‘rather dry’ – 18 to 40 cm bgl – whilst in most other samples the winter water table was at or near the surface.

Overall, the occurrence and configuration of ombrogenous peats at Felecia Moss has similarities with that found on the southern slopes of The Wou, but they are much more tightly contained by the adjoining hills into a (quite strongly sloping) trough. As suggested by the flow tracks in part of the site, water flow through the trough as a whole seems likely to be dominantly axial.

4.6.7.1.7 Muckle Samuel’s Moss

Muckle Samuel’s Moss is a large peatland site, much of which has been afforested, that occupies part of the interfluve between Drowningholes Sike (the northern margin) and Churn Sike / Blind Well (to the south). The two sections available from the site are not sufficient to characterise it well, though they do illustrate that the topography of the peat surface is in large measure independent of that of the sub-peat surface, which constrains inference about the latter based on surface evidence. Lidar data indicate a lobe of peat of varying slopes extending north-westwards across the site, and possibly corresponding broadly to a sub-peat ridge. The east–west section crosses this obliquely (Figure A 46, Annexe 2) and indicates a substantial and sharp-sided ridge of peat raised some 4 m above the underlying mineral ground. The contours along the axis of the ridge slacken at the point where it is crossed by the section and this is shown by its flat-topped profile. The peat ridge has been deeply furrowed, ditched and afforested and it is not clear whether the mire vegetation (M19) developed since clearance represents the ‘natural’ vegetation type or a product of the forestry activities, though the latter is likely.

The eastern half of the east–west section is formed from some sort of hollow, filled with up to 9 m depth of peat and with a sub-peat surface level some 10 m lower than that of the adjacent mineral ridge. The north–south section (Figure A 45, Annexe 2) shows that this is fairly flat bottomed and supports a 'dome' of peat, which slopes quite steeply (around 1 in 30) both to the north and south. Lidar contours indicate that the crown of this structure is relatively flat, near the point at which it is crossed by the east–west section. However, the low point of the east–west section corresponds with the crown of the north–south section and forms part of a concave surface gently-sloping eastwards to a marginal 'lagg' stream. There is no evidence of a 'lagg' like structure separating this area from the slopes of the peat ridge to the west and, whilst it is possible that the natural drainage features have been disturbed by past forestry activities, it seems very likely that water draining from the ridge feeds into the north–south mound, whence it drains either south or north down its steep slopes or east on the gentle cross-slope to the eastern 'lagg' stream. Much of the crown of the north–south mound can thus be seen as a water collecting area and its occupancy by M18, compared with the M19 of the ridge to the west and the steep sides of the north–south dome, is of interest.

4.6.7.1.8 Butterburn Flow

Butterburn Flow is said to be largest of the 'basin peat' sites in the Roman Wall Country, but has been little investigated.

The site consists of two large areas of peat, broadly separated into two discrete units by the north-east flowing Lawrence Burn. This stream appears to originate from within the peatland, but seems likely partly to drain the mineral ridge west of the mire rather than to be truly endotelmic. Only the south 'lobe' was examined here. This is essentially a north-east-trending ridge of peat, some 2.5 km long, which occupies the interfluve between Lawrence Burn to the north, Butterburn to the south, and the River Irthing (to the east). It slopes gently, and narrows, north-eastwards. Towards the western end the area of un-afforested peat is about 1 km wide. The north–south section (Figure A 31, Annexe 2) was recorded across this part of the site and shows a broad, domed ridge of peat, sloping around 1 in 280 near its crown, but steepening to more than 1 in 20 on the marginal slopes to the north and south. At the point of the section, the crown coincides with a fairly narrow upstanding ridge of underlying mineral ground and the peat is about 2.5 m deep. This ridge falls on either side into more gently sloping mineral material and there the peat may be more than 7 m deep, thinning as its slope steepens towards the margins. It is not known to what extent the mineral ridge underlies, and perhaps helps to conform, the peat deposit along the length of the peat lobe north-eastwards, because the east–west section recorded (Figure A 32, Annexe 2) is slightly oblique to its axis and falls into the steep slopes of the Irthing well short of the north-eastern 'nose' of the lobe. This section suggests the occurrence of broad sub-peat hollows in the mineral ground, one with some 8.8 m of superincumbent peat.

The surface of this site is particularly 'wet', especially in the 'flat' west-central area around sample point 3. It is very likely that this can be attributed to particularly poor drainage of this area, rather than to ingress of significant water from the hilly ridge immediately west of the site. Although not strictly a 'dome' topographically, drainage from this area is likely to be in more-or-less all directions except westwards and on the west–east section, as the slope of the mire margins steepens down to the Irthing, and just before this point of inflection, water flow tracks are evident on the surface. There is also a series of pools aligned across the gradient, on a slope of 1 in 200. It is tempting to interpret them, on account of their location, as tensional features of the mire surface.

Over much of the 'flatter' parts of the mire, both the top and mid-layers of the peat are generally *Sphagnum*-rich (either 'pure' *Sphagnum* or *Sphagnum–Eriophorum.* An exception to this generalisation is provided by point 3 which, although on the 'flat' crown of the mire has relatively thin peat over the top of the underlying mineral ridge. This peat was dominated by *Eriophorum* remains, which may well indicate that it formed quite slowly in drier conditions across the top of the ridge. It is, however, of interest that this peat type has persisted into the top-layer, although the vegetation at this point is referable to M18 and is not obviously different to that which has formed upon *Sphagnum*-rich peat.

4.6.7.1.9 Coom Rigg Moss

Two sections were recorded from Coom Rigg Moss, chosen to complement the eight sections already reported from the site by Chapman (1964a). The sub-peat surface essentially consists of a small, irregular saddle between hills to the north and south with four peripheral basins that form the valleyheads for drainage. Almost all of this area is covered by peat, forming a fairly concentric dome with marginal slopes of varying steepness. Chapman reported deep peat in the basins, which infilled mainly by the process here referred to as 'topogenous accumulation' (see Box 1), but on the higher ground between the basins a thinner ombrogenous peat formed more-or-less directly on the mineral ground by paludification. Both successions resulted in a surface accumulation of *Sphagnum–Eriophorum* peat, to form a dome across much of the site. The conformation of this depends upon the sections examined. In some locations the peat is thin and essentially follows the sub-peat contours; in others, and not exclusively across the basins, it is mounded independently of the sub-peat topography. In the basins, the initiation of fen peat is dated to pollen zone VI (c. 8000 BP), and its transition to superincumbent *Sphagnum–Eriophorum* peat was during pollen zone VIIa (c. 5000 to 7000 BP), around the time when initiation of peat across the paludification surfaces started. The differences between the two seres can be detected in their profiles, but not in the vegetation, which was considered to be uniform across most of the site, much of it as two variants of a *Sphagnum* carpet, and showed little relation either to slope or peat depth. Subsequently, Chapman & Rose (1991), made a repeat vegetation survey in 1986 and found greater differences, with a much-reduced area of *Sphagnum* carpet and a prevalence of vegetation with much *Calluna* or *Eriophorum,* the pattern being more clearly related to peat slope and depth. However, a subsequent *NVC* survey (2021) does not seem to sit very comfortably with the pattern reported for 1986, but essentially shows that the main dome of the site is occupied with M18 vegetation, with M19 on the steeper peripheral slopes, as is commonly the case in these Roman Wall Country sites. Again it is worth noting that most if not all of these sites have been affected by drainage and peripheral ploughing and furrowing as consequence of adjacent afforestation, and it is certainly possible that their current vegetation has been in some way influenced by these activities.

5 CHARACTERISATION AND CATEGORISATION OF 'UPLAND' PEATLANDS

5.1 Approach and rationale

5.1.1 Mire 'types' and the 'Wetland Framework'

As already indicated (Section 2), the present project was intended as a pilot study to examine the potential of applying to upland peatlands the 'Wetland Framework' approach already used for lowland peats (Wheeler *et al.*, 2009).

The 'Wetland Framework' approach was stimulated by the recognition that the essentially topographical wetland categories that were in widespread use at the time (Flood-plain mires, Basin mires, Valley mires *etc.*), whilst useful as broad descriptors of the sort of landscape situation in which a particular wetland site occurred, were too broad, nebulous and heterogeneous in content to provide a more exact basis for distinguishing distinctive wetland types. Moreover, many distinctive 'types' identified occupied a range of the broader topographical categories – thus, for example, 'seepage fens', often with distinctive and recurrent water supply mechanisms and vegetation, could be found within valley mires, basin mires and, to some extent (and mainly along their margins), flood-plain mires.

That this is also an issue in more 'upland' areas, and with ombrogenous mires, was recognised in a comment of Chapman (1964a): "The system of bog classification generally employed in Britain describes sites as either raised bogs, blanket bogs or valley bogs (Tansley 1949; Pearsall 1950). This classification is difficult to apply where the area consists of several raised bog units united by blanket bog and at the present time forming one single area of peat bog." Attempts to remedy this situation have been to regard sites in relevant areas (in Chapman's case, in the Roman Wall Country) as 'ridge-raised mires' (Moore & Bellamy, 1974), which many of them are not (though Coom Rigg Moss, examined by Chapman, could appropriately be thus described) or as 'intermediate mires', which itself raises a plethora of issues, not least the lack of clear compass and definition of the ends of the spectrum between which they are supposedly 'intermediate', especially that of 'blanket bog'. If 'blanket bog' can be regarded as "a conveniently vague term" (Pearsall, 1950), 'intermediate bog' could perhaps be regarded as being inconveniently vague, not least because it is often difficult to know what individual authors mean by it (Lunn, 2004)!

The Framework of Wetland Habitats

Wetland Landscape Type	Hillslope	Valley-head	VH trough / basin	Basin	Lake-side	Trough	Flood-plain	Coastal Plain	Plateau-Plain

Base Richness	Highly acidic (<4.0)	Acidic (4.0 – 5.5)	Sub-neutral (5.5 – 6.5)	Base-rich (>6.5)

Fertility	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic

WETMEC	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20

Management	Un-managed	Winter Grazed	Winter Mown	Summer Grazed	Summer Mown	Burnt

List of WETMECs

1: Domed Ombrogenous Surfaces ('Raised Bogs')
2: Buoyant Ombrogenous Surfaces (quag bogs)
3: Buoyant Weakly Minerotrophic Surfaces ('Transition Bogs')
4: Drained Ombrotrophic Surfaces in Bogs and Fens
5: Summer 'Dry' Floodplains
6: Surface Water Percolation Floodplains
7: Groundwater Floodplains
8: Groundwater-fed Bottoms with Aquitard
9: Groundwater-fed Bottoms
10: Permanent Seepage Slopes
11: Intermittent & Part-Drained Seepages
12: Fluctuating Seepage Basins
13: Seepage Percolation Basins
14: Seepage Percolation Troughs
15: Seepage Flow Tracks
16: Groundwater-flushed Bottoms
17: Groundwater-flushed Slopes
18: Percolation Troughs
19: Flow Tracks
20: Percolation Basins

'Habitats' can be defined by different combinations of units from each layer.

Figure 21. The layers of the Wetland Framework, originally developed for wetlands (fens and bogs) in lowland England and Wales (Wheeler, Shaw & Tanner, 2009).

The real difficulty that underlies the comments of Chapman is that there has been a widespread desire to allocate entire peatland 'sites' into a single, named category, whereas many of them are heterogeneous in character and can contain within their compass a range of different 'types' of mire. The 'Wetland Framework' approach was designed to remedy this, and can be seen not so much as an attempt to characterise and categorise entire mire sites, but to identify distinct 'types' within them, based on recurrent combinations of features. In many ways these can perhaps be conceptualised better as 'mire *habitat* types' than as 'mire types'.

The skeleton of the Wetland Framework, as it was developed for lowland wetlands, is shown in Figure 21. Its most innovative feature was the identification of distinctive 'Water Supply Mechanisms' or 'WETMECs', but other salient variables are also part of the Framework, as separate and independent layers. This is because any single water supply mechanism may supply water with very different base-richness and fertility characteristics in different hydrogeological circumstances.

The 'upland' peatlands examined in the present pilot study were dominantly ombrogenous. These examples mostly belonged to the 'highly acidic' category of base-richness and to the 'oligotrophic' fertility category, but they were not well accommodated by the existing lowland WETMECs. Some minerotrophic surfaces were also recorded in this study, and many of these could be accommodated appropriately within existing lowland WETMECs, with some modifications.

5.1.2 Surface configuration types and WETMECS in ombrogenous peatlands

Two separate, but inter-linked, characterisations of 'upland' ombrogenous peatlands have emerged from the current investigation. One relates to the broad surface configurations observed in individual sites or parts of sites and is based on the levelled sections from the sites examined or, in a few instances, from published sections. The other relates to an assessment of surface conditions in different parts of sites, each representing an individual stand of vegetation, using the sampling and analytical protocols of the original 'Wetland Framework' study, slightly modified for the purpose. This has resulted in the identification of several ombrogenous WETMECs and a layered categorisation of ombrogenous surface conditions. Using the diplotelmic approach to ombrogenous peatlands, as espoused by Ingram (1967) and other workers, the 'Surface Configuration Types' broadly relate to the shape of the catotelm, and the controls upon this, whilst WETMECs broadly relate to ecohydrological conditions within the acrotelm (*i.e.* to 'habitat conditions') and variations in these in different parts of the peatland. The acrotelm and catotelm layers do, of course, have strong ontogenic and hydrodynamic links, but there is also independence between them. In the present investigation this is manifest by the occurrence of different WETMECs in different parts of the same Surface Configuration Type and by the occurrence of the same WETMEC across a range of Surface Configuration Types

5.1.2.1 Surface Configuration Types

In general, but with some exceptions, peat tends to accumulate most readily and rapidly in poorly-drained locations. Topography exerts a very strong influence upon drainage and drainage patterns, and helps determine both the development and conformation of ombrogenous peat surfaces. The 'topography' in question can refer to that of the sub-peat surface beneath the peat deposit, that of the mineral slopes adjoining the deposit, and, very often, the configuration of the peat surface itself (which can often bear little relationship to that of the underlying mineral ground). A range of examples of this has been presented in the preceding section, and exemplars, based on recurrent and distinctive combinations of sub-peat topography and peat surface topography that have been observed, are illustrated in Figure 22 and Figure 23. Some 'sites' consist of more than one surface configuration type, variously juxtaposed.

5.1.2.2 WETMECs

In the original 'Wetland Framework', which was mainly of lowland minerotrophic wetlands, WETMECs were regarded mainly, though not exclusively, as conceptualisations of different water *supply* mechanisms. However, in upland ombrogenous contexts they may be regarded more appropriately as conceptualisations of different water *drainage* mechanisms, because of the ubiquity and dominance of precipitation and of other meteoric exchanges with regard to water supply – though, of course, differences in the volume of water supply and of precipitation:evapotranspiration balances are also important, especially on a regional (rather than a single site) scale.

A series of ombrogenous WETMECs has been identified, using the same methodologies as for the original Wetland Framework. These are outlined below and are related to the categories of the observed Surface Configuration Types. It is important to recognise that the cluster analyses on which the identification of WETMECs was based necessarily rely on the identification of groupings (clusters) of samples. However, it is clear from the DCA ordinations that these represent sub-divisions of a continuum of variation. It is therefore to be expected that some individual samples will be transitional between WETMECs, and that different WETMECs are likely to intergrade.

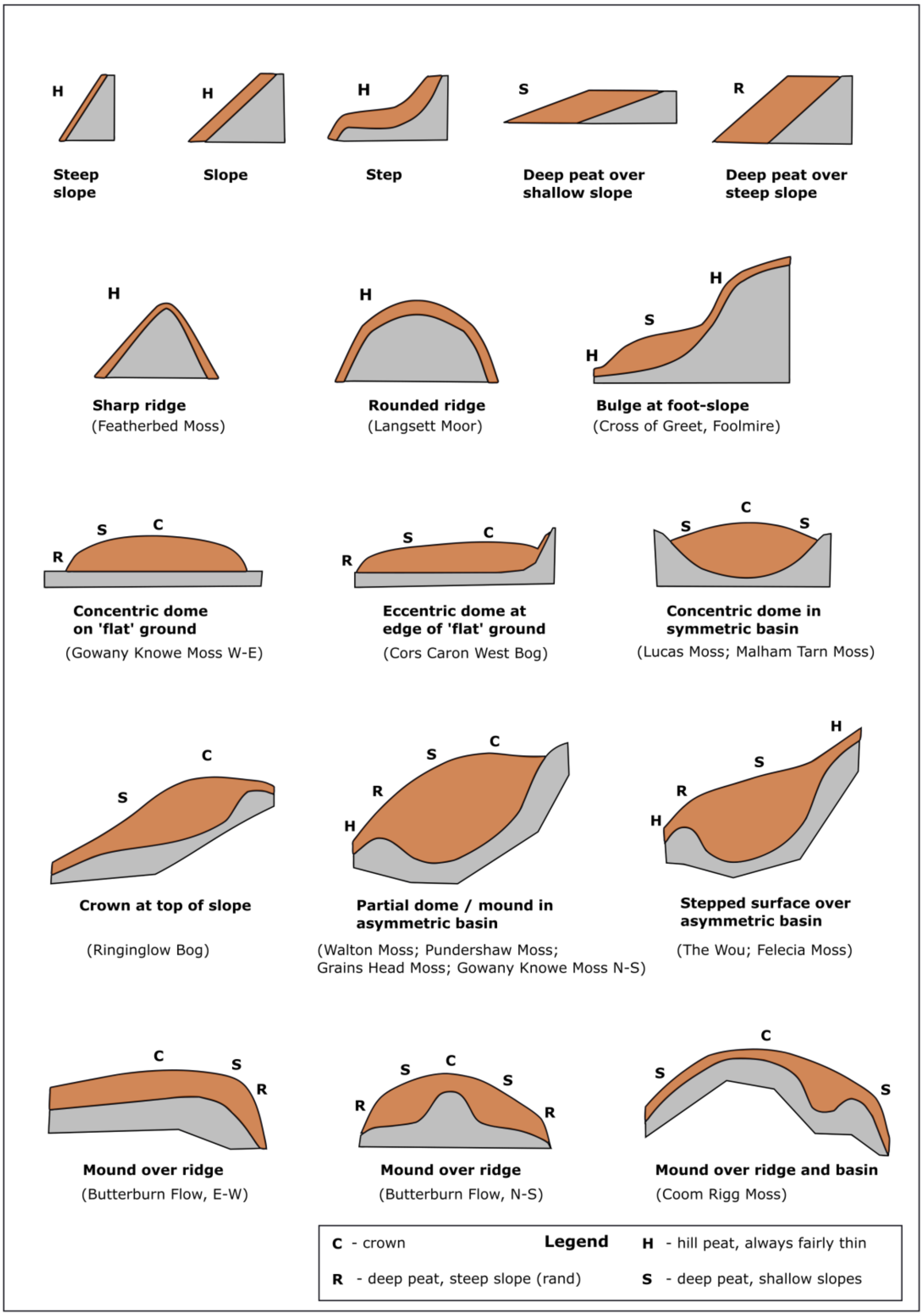


Figure 22. Configurations of ombrogenous peat surfaces in relation to landscape and sub-peat topographies: radial or unconfined flow.

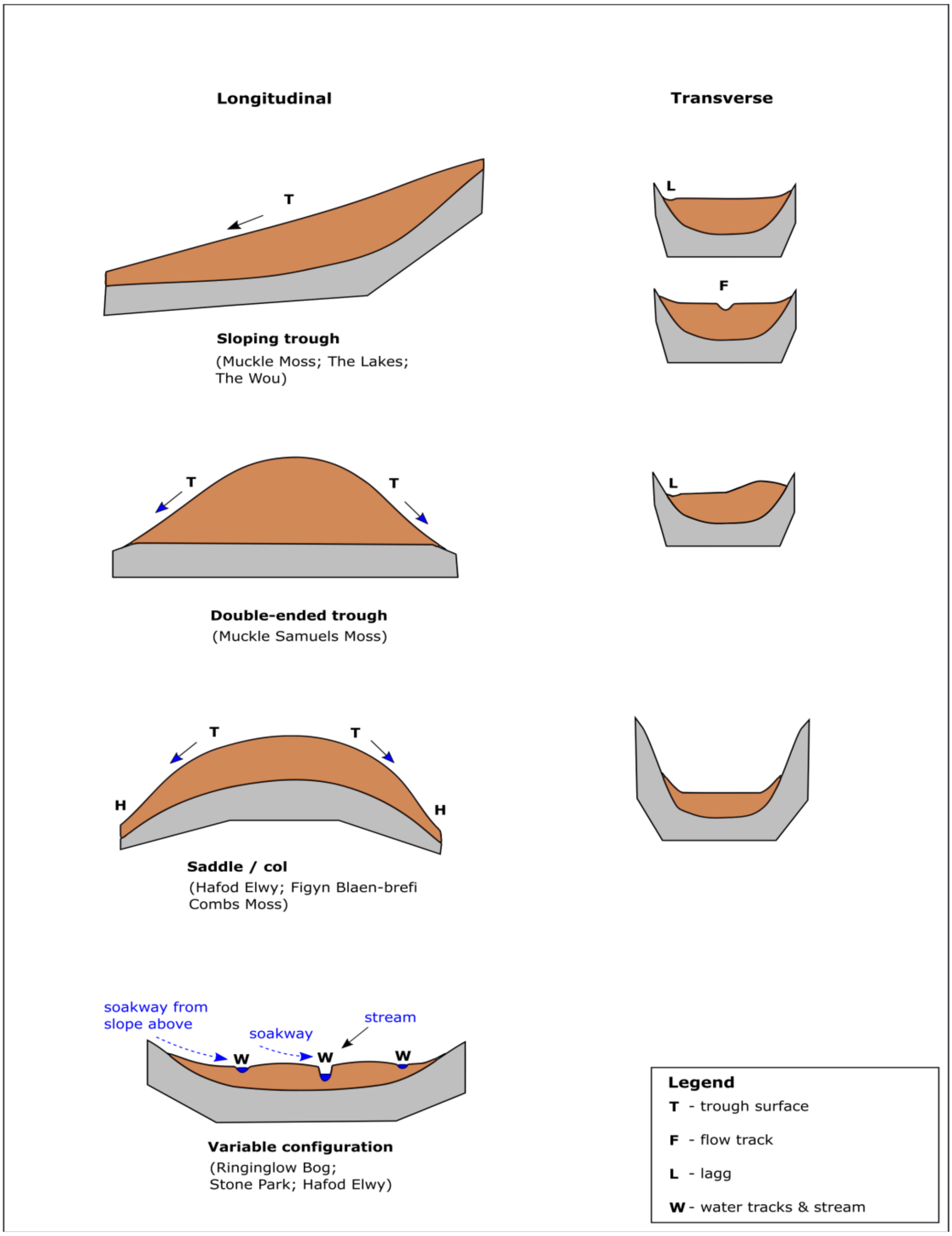


Figure 23. Configurations of ombrogenous peat surfaces in relation to landscape and sub-peat topographies: axial or channelled flow.

5.2 Configurations of ombrogenous peat surfaces

A number of recurrent broad configurations of ombrogenous peatland surfaces have been recognised informally (Figure 22 and Figure 23), based on the sections available. These provide an informal typology of configuration types. It should be recognised that they are based solely on information currently available, and it is possible that additional sections may identify additional configuration types or modify some of those suggested here. It should also be appreciated that the small number of sections available from many sites may have meant that some important stratigraphical features within them have been missed. In view of this, no attempt is made to formalise the typology at present. However, some comment can be made about the nature of the variation observed and the processes that appear to be important in relation to this.

In terms of their configuration, although ombrogenous surfaces intergrade they can be divided into two broad groups – those that essentially follow the topography of the underlying mineral ground and those that are autonomous accumulations of peat and which are in large measure independent of this. This corresponds roughly to the 'old' subdivision of 'hill peats' *versus* 'basin peats' (though this label is often not very appropriate for the latter, see Section 5.10.2). Hill peats tend to follow the topography of the surface beneath them and are often thinner and more humified than the ombrogenous deposits of 'basins'. By contrast, the surface topography of some 'basin peats' frequently bears little relationship to the sub-peat topography, and the peat is often deeper, wetter and generally less humified than that of the slopes. The thinness and high humification of Hill Peat is sometimes ascribed to the high altitudes and climatic conditions in which it forms (*e.g.* Hall & Folland, 1970), but this is inapplicable in areas such as the Border Mires, especially those of the Roman Wall Country, where ombrogenous 'hill peat' and 'basin peat' surfaces can be closely contiguous and a consequence of contrasting topographical and hydrological conditions, not of different altitudes.

In 'basin' circumstances, although 'autonomous', the development, surface topography, character and vegetation of the ombrogenous peat can be influenced by the overall topographical context of the deposit and its surroundings, probably largely in reflection of the constraints on drainage that these present. It is helpful to recognise some of the processes that seem to be responsible for this.

Where an ombrogenous deposit has developed on a flat, low-permeability surface, such as that provided by lake sediments or a tract of fen, its drainage of precipitation excess is often poorest at those locations furthest from its margins (which provide the drainage points). This can result in the accumulation of a more-or-less centric peat deposit, wettest and highest near its middle and draining radially from this (Figure 24). Deposits of ombrogenous peat in the lowlands, where they are frequently referred to as 'raised bogs', are often conceptualised as conforming to this condition, though in truth the former configuration of many examples is not known, especially around their margins, on account of drainage, cultivation and turbary. Even on suitably 'flat' surfaces, the dome can be displaced eccentrically towards one of the margins. This is shown in the topography of the west bog at Cors Caron (Figure A 6, Annexe 2), where the dome is located quite close to the western margin of the ombrogenous deposit, and without a very clear rand or lagg (often regarded as distinctive features of 'raised bogs') separating it from the western-bounding hillslopes. It seems that a greater accumulation of ombrogenous peat has occurred towards the western side, possibly because drainage is poorer there than further east (where the bog surface adjoins the drainage outlet provided by the Teifi), and perhaps because of greater water inflow into the western margin from the hill-slope catchment than is the case elsewhere. Likewise, in partial, or asymmetric, basins, such as Walton Moss (Figure A 53), ombrogenous peat has formed as a partial dome, banked up against the taller 'hanging wall', furthest from the drainage point across the lower lip of the basin (Figure 24). Although clearly somewhat different, the peat surface at Walton Moss has a similar conformation to that of Cors Caron, of which it forms a horizontally-compressed variant.

Where ombrogenous peat has accumulated in a trough, closed at one end and drained at the other, and flanked by higher ground along its length, as at The Lakes and Muckle Moss, peat has become banked against the end furthest from the drainage point and forms a fairly uniform slope down-trough; the peat surface may be more-or-less flat across the trough, with little or no sign of transverse doming, perhaps on account of water inflow into the margins and a dominance of down-trough flow. Instead, there may be a central drainage axis or, perhaps more often, down-trough drainage along the margins.

In the case of a trough open and drained at both ends, as in part of Muckle Samuel's Moss (see Section 4.6.7.1.7), a substantial 'dome' of peat has accumulated along the length of the trough, draining to both ends, but it shows little or no evidence of doming across the trough. At Hummel Knowe Moss (Section 4.6.7.1.2) the development of a 'dome' seems to have been regulated for much of its developmental history by three main drainage outflows, and the peat 'dome' has accumulated at a compromise point furthest from the influence of all three of them. It thus seems that much of the rather bewildering range of ombrogenous conformations encountered in the mires of the Roman Wall Country can be explained and parsed in terms of distance from drainage points.

This is not to suggest that *all* eccentric distributions of ombrogenous deposits or surfaces relate just to distance from drainage points. For example, in the case of a valley head or col with considerably different amounts of telluric water run-off from the flanking slopes (perhaps because they have different catchment areas) there may well be a broader strip of minerotrophic mire along one side of the valley bottom than on the other, resulting in a displacement of any ombrogenous development eccentrically to the side with less telluric inflow. This does not, however, appear to have made an important contribution to the configuration of the ombrogenous deposits in most of the sites considered here.

The rôle of water inflows from adjoining slopes, peat-covered or not, into some of these 'basin' ombrogenous deposits can be less clear. For example, in the Roman Wall Country, Grain Heads Moss forms a clear 'dome' of peat over a basin at the bottom of a steep forested slope (Figure A 39). In this instance, drainage water from the forested slope seems largely to be captured by a lagg-like water track, and there is no reason to suppose it impacts directly upon conditions in the crown of the dome. Nonetheless, such water inflows may affect to some extent the hydrodynamics of the catotelm of the ombrogenous crown, and the overall conformation of this may well in part be a consequence of their influence.

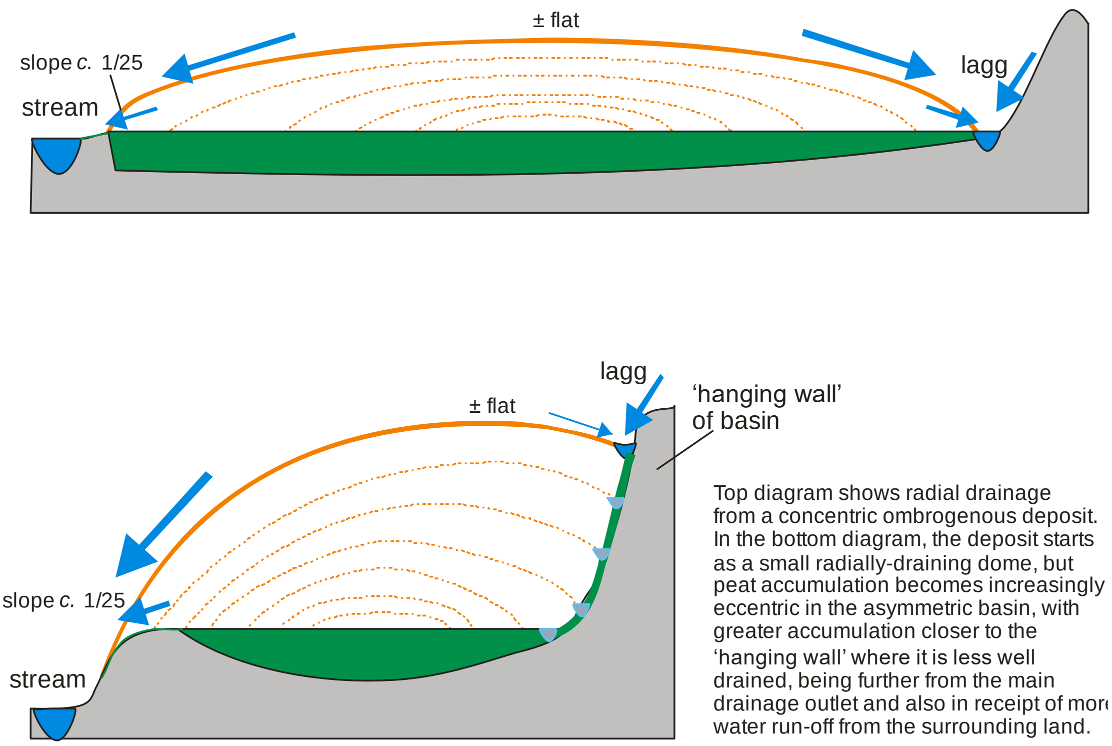
A rather similar topographical situation applies on parts of the south slope of The Wou (Figure A 51). Here the section indicates two main peat-filled depressions, one at the top edge of the site, the other in the middle of the slope. They are connected by thin hill peat, but here there are no obvious features to intercept down-slope flow, nor is the middle basin domed: its peat surface is configured more as a gently-sloping 'step' across the hill slope. It is nonetheless covered by wet M18 vegetation, with M19, M20 and M25 on the steeper parts of the hillslope. The gradient on the M18 'step' (1 in 140,Figure A 52) is much the same as that on a similar surface towards the eastern margin of Cors Caron (1 in 137). A feature of The Wou, and some other mires in the Roman Wall Country, is that the areas over sub-peat basins have a domed or bulging surface topography and also support a distinctive vegetation (very often M18). Thus their surfaces appear to have retained some 'memory' of the sub-peat topography, though not necessarily in a way that might have been expected. This contrasts with the observations of Chapman (1964a) at Coom Rigg Moss, where much of the underlying irregular terrain appears to have become subsumed beneath an over-arching deposit of mostly similar ombrogenous peat and vegetation.

In the rather unusual instance of Muckle Samuel's Moss, water draining from a higher 'dome' feeds into a lower-level 'dome' along the north–south trough referred to above, but in this case there appears to be no soakway or other feature to intercept the flow from upslope (other than forestry ditches). Hence the peat surface of the mound in the trough seems, in effect, to be part of the drainage slope from the 'high-level' dome. Nonetheless, the flattish crown of the mound in the trough supports an example of M18 vegetation, flanked by M19 on the steeper flanking slopes. This suggests that the ecohydrological toposequence across the crown of the lower mound is the same as that found widely in other sites, despite, or perhaps even because of, the probable contribution of drainage water from higher parts of the system.

It is important to recognise that the various peat configuration *schema* identified here do not necessarily relate to entire peatland 'sites': some sites contain several Surface Configuration Types. The complexity of distinct types of ombrogenous surfaces, illustrated particularly in some of the Roman Wall Country mires, points to the great difficulty of generating 'whole site'-categorisations, whereas they can be parsed into a series of distinct and sometimes linked configurations that occur across a range of sites. These same components also exist in some lowland ombrogenous deposits, as is well demonstrated by the mapping of the western bog at Cors Caron by Godwin & Conway (1939). Overall, it would seem that these 'basin'-type ombrogenous deposits differ not so much in their peat surface configurations and the ‘habitat’ conditions their surfaces provide, but in the ‘containers’ within which they have been able to develop, rather like dollops of essentially the same dough baked in trays of different shapes and sizes.

Nonetheless, it is clear that there may be several recurrent and linked components to ombrogenous deposits, as illustrated in Figure 22 and Figure 23 and conceptualised more formally as different ombrogenous WETMECs (Section 5.3). There may sometimes be a reluctance to parse into separate components what is often regarded as a ‘single’, coherent ecohydrological entity, but the indications of the sections presented here are that whilst recurrent components can be recognised, their arrangement and juxtaposition varies even amongst similar and neighbouring sites. For example, at Cors Caron, the ‘South-eastern Bog’ presents a more-or-less concentric dome of ombrogenous peat, whilst on the other side of the Teifi the crown of the dome of the ‘West Bog’ is displaced eccentrically towards the western hill slopes, suggesting an impact of either poorer drainage along the hill-slope side of the bog, or greater run-off into the mire margin along that side, or both. All the components identified can also be found as single, self-standing units in a few locations. As a homely analogy, those who, it is said, ‘like to call a spade a spade’ may purchase one as a single operational unit, but in the event of it requiring repair, it is desirable to know whether it is the handle, the shaft or the blade that needs to be replaced. The same is likely to be the case in the conservation management and restoration of ombrogenous mire systems comprised of linked ecohydrological units.

As has been identified, one important and interesting feature of some of the ombrogenous peat configurations recognised is that quite often the surface topography is not related to the sub-peat topography. This is not always obvious on casual inspection of a site, or by examination of Lidar contours, and identification of Configuration Types may require some simple peat probing, or perhaps remote sensing if it proves to be sufficiently accurate for the purpose.



Dotted lines represent former ombrotrophic surfaces in the development of the deposit.

Figure 24. Schematic conceptual development of ombrotrophic surfaces.

Ombrotrophic surface development (orange lines) over (a – upper diagram) an extensive ‘flat’ deposit of minerotrophic peat (green), and (b - lower diagram) over the minerotrophic peat of an asymmetric basin.

5.3 Ombrogenous WETMECs

5.3.1 Identification of ombrogenous WETMECs

With the exception of samples that appeared to be groundwater-fed, WETMECs were identified by a combination of 'Ward's Method' cluster analysis (Section 4.2) and various univariate statistics. Groundwater-fed samples could generally be related to existing WETMECs (Wheeler *et al*, 2009) (5.9.5).

It is important to recognise that the field sample data used for these analyses were very largely based on variables related to the individual location of the samples. Thus the analyses had no 'awareness' of the wider sub-peat topography, just the measured peat depth at the sample point. They also had but limited 'awareness' of the topography of the peat surface, other than a measurement or estimate of slope and an estimate of its configuration (in terms of the categories outlined in Table 4). Surface 'configuration' has, however, clearly influenced both the classifications and DCA ordinations of the data, as is evident in Figure 9 and Figure 10. The identify of the vegetation type present at the sample point was also not included in the multivariate analyses, so that it could subsequently be related independently to the units extracted, though the two main variables related to surface patterning were included – and these also had a strong bearing on the results (Figure 10). Whilst the clustering of the samples has been strongly influenced by estimates of both surface configuration and surface patterning, they are based on a large number of ranked variables and some others of these, such as the ranked estimates of 'erosion' and 'proximity to gullies' have also been important (Figure 10) and have helped to determine the clustering.

In the earlier 'Wetland Framework' project (Wheeler *et al*, 2009), WETMECs were similarly derived from Ward's Method clusters and sub-clusters, and those identified in the present project have a similar conceptual status to those. It must, however, be recognised that of necessity the present project considered ombrogenous surfaces only across a relatively small range of sites and situations, mostly in various parts of the Pennines (north and south).

The following points should be noted:

- Individual WETMEC categories are not fully discrete entities, but instead can merge into one another. Some samples may therefore have characteristics that are intermediate between two or more WETMECs.
- The WETMECs broadly reflect the structure of the multivariate dendrogram (Figure 11) and have been given names that reflect their main character. However, some individual samples, or even some WETMEC sub-types, do not necessarily conform to the descriptive label.
- WETMECs are composite entities derived by multivariate classification using a wide range of characteristics. They are thus influenced by dominant features within the dataset and do not necessarily correspond exactly to variation in individual characteristics. Some of this could be tidied-up, and the WETMEC classification more clearly structured, simply by relocating aberrant samples beyond that done by the *K*-means analysis in the clustering procedures, but this would be at the expense of the multivariate analysis. This problem is essentially an expression of the difficulty of trying to summarise the multi-dimensional variation of the dataset within a few clear and coherent categories.
- The names of the sub-WETMECs have been formulated to be short and self-standing and therefore do not always incorporate generic elements of the parent WETMEC name.

5.3.2 Summary of ombrogenous WETMECs

Summary details are given of the plant communities (Table 16) and selected habitat variables (Table 17) associated with the five main ombrogenous WETMECs that have been recognised[11]. Further study of ombrogenous bogs and allied minerotrophic habitats in other parts of the United Kingdom, both

[11] Ombrogenous 1 (O1) to Ombrogenous 5 (O5)

upland and lowland, is likely to result in the modification of these WETMECs and the identification of other types or sub-types, and also other surface configuration types.

Table 16. Number of occurrences of *NVC* community types in the main ombrogenous WETMECs (O1–O5) identified.

Details of individual WETMECs are given below.

WETMEC	*n*	H09	H12	M02	M04	M18	M19	M20	M25	U06
O1: Ombrogenous Crowns	33		1			20	8	4		
O2: Deep Ombrogenous Slopes	51		1			14	32	4		
O3: Hill Peats	64	1	7			2	35	11	7	1
O4: Ombrogenous Percolation Troughs	26			2	1	8	12	3		
O5: Ombrogenous Flow Tracks	3						1	2		

Table 17. Details of selected habitat variables associated with the main ombrogenous WETMECs (O1–O5) identified.

Details of individual WETMECs are given below.

Peat Depth (m)					Other variables (values are means of ranked estimates)							
WETMEC	***n***	**Mean**	**Min**	**Max**	**Slope**	**Tussock Diversity**	**Hummock–Hollow Diversity**	***Sphagnum***	**Top Layer Perm-eability**	**Winter Wetness**	**Winter Quagginess**	**Erosion**
O1	33	4.76	0.45	10	1.06	0.76	5.85	3.12	4.33	4.58	2.88	0.18
O2	51	3.78	1.1	8.8	2.35	0.49	5.59	2.92	4.00	4.29	2.55	0.33
O3	64	1.66	0.05	6	2.91	2.16	1.67	1.28	3.59	3.41	1.81	0.77
O4	26	3.99	1	6.8	1.54	1.85	5.08	3.19	4.73	5.15	3.38	0.54
O5	3	3.00	1	4.5	2.33	4.33	1.67	2.00	3.67	5.33	2.00	1.00

5.4 WETMEC O1: Ombrogenous Crowns

5.4.1 Concept and description

CLUSTER: B

This unit includes the uppermost, water-shedding surfaces of autonomous peat deposits, that have developed under the exclusive and direct influence of precipitation. The depth of the underlying peat is variable, but its mean depth is the greatest of all the ombrogenous WETMECs (Table 17), and the height of the Crown above the surrounding peat is also variable. The peat itself is generally either a *Sphagnum* or *Sphagnum–Eriophorum* peat, and some of the deepest deposits of *Sphagnum* peat are associated with this unit. The majority of samples support M18 vegetation and the surfaces are sometimes, but not always, quite well patterned, though most often with a predominance of hummocks rather than pools.

The shape of the Crown ranges from being roughly isodiametric to elongate (usually along the tops of ridges of ombrogenous peat). Although it is clearly water-shedding, the Crown is also typically particularly wet, as its surface is often almost flat and distant from drainage points. In a few instances, in basins or on flattish surfaces, the Crown is shallow and forms almost the entirety of the mire unit, but more usually it grades downslope into Deep Ombrogenous Slopes (WETMEC O2) of varying angle and area, usually still over quite deep peat.

In the original 'Wetland Framework' project (Wheeler *et al.*, 2009) no distinction was made between the crowns of lowland ombrogenous deposits and the slopes that surrounded them. Instead they were considered together as part of a single, domed, ombrogenous unit that in some instances included a Crown surrounded by gentle Slopes and then, in a few instances, a steeper slope (Rand). The failure at that time to discriminate between these three component elements was probably due to a low intensity of sampling, or because the surroundings of the Crown had been much modified by drainage or truncated, and also perhaps, because the entire dome was widely regarded as forming a single hydrological entity. Similar comments can be made for at least some of the sites considered here, but overall it is clear that, whilst often linked, these components are also often clearly distinct and can occur independently of one another. Moreover, ombrogenous 'Crowns' were separated from ombrogenous 'Slopes' into different clusters by the Ward's Method analyses. This had not been a feature of the earlier 'Wetland Framework' clustering.

In a few instances, in basins or on flattish surfaces, the ombrogenous deposits that support crowns are more-or-less concentric or at least roughly symmetrical separately along both longitudinal and transverse axes. However, a good number of deposits with Crowns are roughly symmetrical in one direction but asymmetrical in another. This is particularly the case in some valley-slope units, where the overall ombrogenous deposit forms a sort of tilted, partial dome or bulge so that the Crown forms a shallow dome close to the rising upslope, usually separated from this by a shallow 'lagg'-like flow track or water course, or, in a few instances, overtopping the mineral ridge to fall to an unconfined margin on the other side (Figure 24). In these situations, the down slopes falling from the Crown can be rather long and steep, in steepness sometimes comparing with the 'rands' of some lowland ombrogenous peat deposits. Examination of the sub-peat topography shows that these asymmetric partial domes have typically developed over hollows (basins or troughs), in some instances from a preceding phase of fen. The stratigraphy and profile of Walton Moss (Hughes *et al.*, 2000) shows this arrangement particularly clearly, partly because that basin is not so mixed with other peatland units as is the case in some other parts of the Roman Wall Country where, in places, more than one asymmetric basin may occupy the same slope.

Although the Crowns appear to be water-shedding structures, in those examples in asymmetric basins on hill slopes or valley sides, the height of the dome along its back-wall side may sometimes only be about 1 m or so above the level of flanking peat. In many cases an intervening flow-track or water course is likely to intercept run-off from any slopes above the site, at least in 'normal' rainfall conditions, and there is generally no reason to suppose – based on measurements of pH, EC and vegetation composition – that the domes are influenced by minerotrophic run-off from above. Nonetheless, any water entering the margin of the deposit on which the Crown is located may be expected to contribute in some measure to water flow in the catotelm peat, and the configuration of the deposit.

Crowns also occur on sites, often with shallower (< 4 m) depth peat, upon flattish or somewhat undulating ground, such as Stone Park where there is some limited doming between small streams. Likewise, a flattish Crown occupies the head of Ringinglow Bog, more or less level with the top of an interfluve. Below this, peat forms a long and fairly uniform slope down the side of the gently-sloping valleyhead to drain into Burbage Brook.

Whereas in many instances, such as where developed in asymmetric basins, the development of crowns of peat is clearly independent of the sub-peat topography, in some other cases it is mounded over ridges, though often in such a way as to suggest that the peat ridge is still somewhat independent of the mineral ridge. This is, for example, the case at Butterburn Flow, where the Crown follows a long sub-peat ridge, but still appears to be substantially independent of it. At Coom Rigg Moss much of the ombrogenous peat is draped across a sub-peat eminence and in places, particularly on the slopes, follows the shape of the sub-peat topography fairly closely, but in other parts (over basins) it is independent of it. However, the ombrogenous peat surface forms a 'dome' across the entire site and much of it is occupied by M18 vegetation. This site, perhaps along with Butterburn Flow, could merit its designation as a 'ridge-raised mire' (*sensu* Moore & Bellamy, 1974). Most of the other examples examined in the Roman Wall Country do not.

Some 60% of the Ombrogenous Crowns supported M18 vegetation. Zonations are variable, but in the Roman Wall Country mires, M18 on the Crown often transitions downslope to M19 and then sometimes to M20 on the shallow slopes and steeper slopes respectively. It is not known to what extent this is a natural feature, related to the topographies and natural drainage patterns of the sites, or of partial or peripheral drainage, especially perhaps that associated with afforestation. However, a similar zonation can be observed in some sites that are not surrounded by forested land.

'Crowns' of ombrogenous peat also occur in some higher altitude locations, where they seem generally to be regarded as shallow domes of 'blanket peat', deposited across a mineral ridge of some kind and often somewhat thicker than the more general peats of the hill slopes (*e.g.* Tallis, 1969). In this study some such examples, at Langsett Moor, Moel Eunant and, more questionably, Hafod Elwy, clustered into Cluster B along with the other examples of 'Crowns', pointing to clear similarities between them. However, higher altitude surfaces were under-sampled in this investigation and those examined were generally considerably eroded, and it is thought that they are not sufficiently well characterised to be compared meaningfully with the other examples considered here.

5.5 WETMEC O2: Deep Ombrogenous Slopes

5.5.1 Concept and Description

CLUSTERS: C and D

This WETMEC essentially includes ombrogenous surfaces over quite deep peat (mostly > 2.5 m, maximum depth: 10 m), of variable slope. Most of the top layer peat was either Amorphous or *Sphagnum–Eriophorum* peat (both 28% of the samples) whilst *Sphagnum* peat and *Eriophorum* peat were both found in 16% of samples. The representation of the main peat types lower in the profile were Amorphous (42%), *Sphagnum–Eriophorum* (27%), *Sphagnum* (15%) and *Eriophorum* (3%).

This WETMEC occurs in three main situations:

- Peripheral to an Ombrogenous Crown, usually on steeper (sometimes much steeper) slopes
- As a rather nondescript independent unit, on gently sloping surfaces
- On steps or other slackenings of slopes embedded within a tract of Hill Peat

Samples from the last of these situations have close affinities to those encompassed by the Hill Peat WETMEC (WETMEC O3) and are mainly considered with these.

In the samples allocated to 'Deep Ombrogenous Slopes', the slope varies from nearly flat to around 1 in 13, and it is not always related to peat depth – some of the examples on the steepest slopes are over deep peat (such as sample 5 at Felecia Moss). The main reason for this is that such examples occupy the steep down-slope margin of certain Ombrogenous Crowns[12]. Where this is the case, the thickness of the ombrogenous deposit beneath the WETMEC O2 surface often diminishes rapidly downslope, to grade sometimes into an apron of Hill Peat. Mean peat depth is smaller than beneath Ombrogenous Crowns but greater than beneath Hill Peat. The mean ranked slope value for this WETMEC is some 2.5 times greater than that of the Ombrogenous Crowns. As an example, at Butterburn Flow the slope of the Crown ranges from between about 0 and 1 in 200, whereas that for the Deep Ombrogenous Slope can increase to between about 1 in 80 to 1 in 25.

The mean estimates made of winter wetness and quagginess of the surface, and of Top Layer permeability, were slightly less than those for Ombrogenous Crowns, along with the amount of *Sphagnum* in the vegetation, but the hummock–hollow patterning diversity was slightly higher than that of the Crowns. About 25% of the samples supported M18 vegetation, but the majority (63%) supported M19, and 1% supported M20. In domed contexts, the location and extent of Deep Ombrogenous Slopes is often manifest as a zone of M19 peripheral to (and below) the M18 of the Ombrogenous Crown. However, in some sites, including examples that have been ditched for forestry

[12] In this circumstance, measured peat depth can vary considerably depending on whether the probe is inserted orthogonally to the surface or more vertically.

such as Muckle Samuel's Moss, or at Ringinglow Bog, which is thought to have been much damaged by past industrial pollution (Conway, 1949), the Crown also supports M19 vegetation.

The extent of Deep Ombrogenous Slopes varies considerably from site to site. They are absent from some small sites such as Lucas Moss; at Coom Rigg Moss they form a fairly narrow peripheral fringe around a large Crown of M18 vegetation, whilst at Ringinglow Bog it forms the dominant component of the mire, constituting much of the slope below the relatively narrow Crown. The spatial distinction of such slopes from Ombrogenous Crowns is usually fuzzy and sometimes difficult to determine. In some sites, it may be appropriate to make a proxy distinction based on the type of vegetation – *e.g.* M18 on the Crown, M19 on the slope – though this approach begs a number of interpretative and ecohydrological questions.

5.5.2 WETMEC sub-types

Three main WETMEC sub-types can be recognised from the data, based mainly on vegetation-related variations in slope:

5.5.2.1 Typical sub-type

Undifferentiated examples of Deep Ombrogenous Slopes, corresponding to the unit as described above.

5.5.2.2 Slope Steps and Slackenings sub-type

This represents areas of slackened slope, sometimes shallow hollows, referable to Deep Ombrogenous Slopes, often embedded within Hill Peat. This occurs, for example, at The Wou where a less-steeply sloping step (over a peat filled hollow) supports M18 vegetation with M19 vegetation on a steeper slope beneath it.

5.5.2.3 Steep Marginal Slopes sub-type

This unit accommodates the steep margins of some domes of ombrogenous peat, particularly examples of asymmetric domes in asymmetric basins. The gradient can be 1 in 20 or steeper, and some of the steeper examples support heathy or *Molinia*-based or impoverished (M20) mire vegetation. Some examples, such as The Wou, have runnels flowing downslope.

These three sub-types can also be found in lowland ombrogenous mires, such as the west bog of Cors Caron. The Steep Slope sub-type corresponds with the feature often known as a 'rand' in lowland mires, and has a similar gradient, but it may form a longer slope in some of these examples encountered here than in sites such as Cors Caron, and it is often unconfined.

The hydrodynamics of these marginal slopes seem to have been little explored, though it is recognised that they usually form the main drainage system of the mires and have to handle endotelmic water fluxes that increase down-slope with increasing catchment area, as well as direct precipitation inputs. The diplotelmic model of Ingram (1976) generally posits that most water flow in lowland domed bogs takes place through the more permeable top layer of peat (the acrotelm layer) and that the lower, permanently saturated, layer (the catotelm) is relatively impermeable and water movement through it is small. However, even if this proposition is broadly correct (and it has been challenged), Baird *et al.* (1997) have pointed out that "due to its greater depth, it is indeed possible for the catotelm to be as important a conveyor of subsurface water in mires as the acrotelm, even when the hydraulic conductivity of the catotelm is much lower than that of the acrotelm." In the topographical context of Steep Marginal Slopes, especially in their manifestation as seen in some of the asymmetric basins considered here, it also seems possible that seepage from the catotelm may help augment the water balance of these steep slopes. Moreover, if in such locations the virtual surface of the catotelm comes closer to the topographical surface than is generally the case on less steep surfaces, this may help to explain the emergence and flow of small water tracks that has been noted at some of these sites on slopes whose steepness might otherwise suggest that they should be quite well drained.

5.6 WETMEC O3: Hill Bog

5.6.1 Concept and description

CLUSTER: E

The category of 'Hill Bog' corresponds well with many informal conceptions of 'blanket bog', *viz.* large tracts of relatively shallow ombrogenous peat that 'blanket' large parts of upland Britain, broadly following the topography of the underlying mineral ground, but often filling small irregularities within this, such as shallow hollows and valleyheads. In some instances the coverage of the surface is so complete that the nature of the sub-peat topography can only be determined by probing; in others the shape and sometimes vegetation of the peat surface provides a ghost of topographies past (though not always in the way that might be expected); and in yet others Hill Bog surrounds and grades into some other WETMECs of upland ombrogenous peat which effectively become units embedded within it.

On average, Hill Bog peat is the thinnest of all the ombrogenous peats of the uplands and occupies the steepest slopes. There is a general, but not exact, inverse relationship between peat depth and slope within the unit. It has the smallest amount of surface *Sphagnum*, which also tends to be absent from the steepest slopes, along with the lowest development of hummock–hollow patterning and the highest development of tussockiness. And it has the lowest mean estimates of 'winter wetness' and 'quagginess'. The most frequent vegetation type recorded at the sample points was M19 (52%), followed by M20 (20%) and M25 (12%). A few samples, mainly on the steeper slopes (but not always on the shallowest peats) supported H9, H12, and U6.

Hill Bog peat often appears to be dark and strongly humified, and of those top-layers examined in the samples, most (50%) were categorised as amorphous, with 22% as *Sphagnum–Eriophorum* and 7% as *Sphagnum* peat. Only 4% had a top layer identified as *Eriophorum* peat, but it is possible that *Eriophorum vaginatum* was a dominant component of many of the samples categorised as amorphous. However, it is clear from the work of Tallis (1964a) and others that the top parts of at least the deeper peats may be banded into layers in which *Sphagnum* and *Eriophorum* are differentially prominent (see Section 2.4.2.1.2). Thinner peats on steeper hillslopes have not been well characterised generally and tend particularly to be amorphous in character.

The hydrodynamics of hill peats *per se* have only received limited attention; generally there has been more interest in run-off regimes from hill-peat covered catchments, and its relationship to stream sediment loads and water quality. Water discharge often shows a rapid response to precipitation events. The top-most watershed locations are irrigated more-or-less exclusively by direct precipitation, but below these the precipitation on the slopes is augmented by down-slope endotelmic flows. In 'intact' blanket bogs, drainage is dominated by down-slope water movement, mainly as overland flow and near-surface seepage through the peat (Holden *et al.*, 2008), but there is also a strong tendency for flow to become concentrated into flow-tracks and small streams, and eroding gullies and sub-surface pipes can occur widely. The rôle of pipes in these systems is not well known, not least because of uncertainties about their occurrence and distribution. Holden & Burt (2002) pointed out that pipes can develop routes that are at variance with the surface topography and can sometimes open up to become runnels between hummocks before becoming closed in as pipes again. As suggested early on by Johnson & Dunham (1963), they may also provide a mechanism for the introduction of bases and nutrients from the underlying mineral ground to nearer the surface.

In the present investigation there was considerable field evidence for down-slope flow tracks and gullies, rather less for pipes. 'Hill Bog Gullies' have been recognised as a separate unit (Section 5.6.3.1), distinctive in its own right, and one that can exert a local influence upon adjoining 'intact' areas of Hill Bog. Apart from such local variation, there was no general evidence for a material change in vegetation and habitat down-slope on 'intact' hill peat surfaces, such as might relate to increased volumes and rates of down-slope water flow. In a few instances however, for example near the bottom of the slope of the Cross of Greet and The Wou, the M19 surfaces were particularly tussocky, which could well be indicative of higher rates of water flow though the vegetation was still recognisably M19. But more generally, any evidence of down-slope differentiation of the vegetation related primarily to differences in slope and the occurrence of 'water collecting' areas. These form the basis of a separate WETMEC sub-type, and one that is transitional in concept to Deep Ombrogenous Slopes.

The properties of these ombrogenous deposits across the summits of the hills, where the degree of slope may also be rather low, have not been well characterised in this investigation, due partly to constraints of access, but also to the widespread erosion of areas of summit or near-summit peats. In some instances, such as where the summit is rather narrow and pointed, as along the course of the Featherbed Moss section (Figure A 9, Annexe 2), there seems to have been rather little erosion and there is little material change in the character of the Hill Bog across the watershed – where it appears to be essentially the same as that on the slopes, apart from its topographical location. In other instances, where the summit watershed is more rounded or flatter, there is evidence, in the sites examined, of rather different conditions from the main hill slopes, with somewhat deeper peat and some surface patterning, though often in the form of shallow pans, pools and tumps of vegetation rather than as a well-developed hummock–hollow surface. Yet others are marked by the occurrence of considerable erosion, generally of the rather intimate, anastomosing (Type 1) variety rather than the gullying (Type 2) type of the slopes. The occurrence and localisation of erosion surfaces across the tops of some of the hills suggests that this feature may be indicative of a rather different ecohydrological circumstance than that associated with un-eroded surfaces, but it also constrains identification of the character of this – in particular the original depth of un-eroded peat and its surface configuration. For example, the residual depth of the eroded peat on the flattish summit of Moel Eunant (Figure A 5) is clearly greater than that of the Hill Bog on the slopes, and it occupies a water-shedding location, but it is not clear to what extent it represents an Ombrogenous Crown or just a flattish accumulation of deeper peat. Such remnants of the deposit that persist suggests it has, or once had, some surface (hummock–hollow) patterning, which seems largely absent from the peat on the slopes. However, because of these uncertainties no attempt has been made here to characterise the summit surface of Moel Eunant – more comparative information from less disturbed surfaces is needed for this to be feasible. The same applies also to Kinder Scout (Figure A 10).

5.6.2 WETMEC sub-types

5.6.2.1 Hill slope sub-type

This represents the ‘typical’ form of Hill Bog – sloping, thin, well-humified peat with little surface patterning. *Sphagnum* was not generally much present in this sub-type in the areas examined both on the surface and, macroscopically, in the peat.

5.6.2.2 Ombrogenous Plateaux, Hill Slope Steps and Slackenings sub-type

This differs mainly from the Hill Slope sub-type by its lesser slope and by having somewhat patterned surfaces with shallow pans and pools and often some evidence of *Sphagnum*, even in some of those South Pennine areas where there is otherwise currently little *Sphagnum* in the ombrogenous vegetation. Examples on plateau surfaces can be localised on account of erosion. These peats largely follow the overall trends in the sub-peat contours but in some instances may be slightly domed above them, but it was not possible to examine this well in the present investigations. Informal observations suggest that on the plateaux, patterned surfaces may be localised for no very obvious reason, but that they are generally associated with areas of deeper peat and gentler slopes. Small depressions, steps and flats on the slopes and on parts of the plateau also support somewhat patterned surfaces with shallow pans and pools and some evidence of *Sphagnum.* This same sort of surface also occurs in some cols, hollows and on slackenings of slope, in what are essentially ‘water collecting’ locations. In these situations peat depth is generally greater than that on the slopes within which these units are embedded, and more similar to that associated with the plateau tops. Whereas some of the plateau surfaces occupy watershed locations, examples of this unit can form part of a chain of down-slope flow, but in terms of their vegetation and peat characteristics there seems to be little that distinguishes the ecohydrological conditions of these two types of situation.

At Cross of Greet, a gradient slackening of the foot-slope of a hillside spur has resulted in a bulge of Hill Bog which, unusually for this WETMEC, has been referred to M18a. The section made across this site was almost entirely over Brennand Grit, here close to its lower contact with underlying Pendle Grit and close laterally to a faulted contact with Dure Clough Sandstone. As all three of these rocks are potentially water bearing, it raises a question as to whether the groundwater head here may be within the lower layers of the peat, perhaps influencing their hydrodynamics (but not their surface conditions – there is no reason to suspect minerotrophy).

5.6.2.3 Steep, Thin-peat, Slope sub-type

This sub-type is superficially similar to its counterpart in Deep Ombrogenous Slopes, but it differs significantly from this in that it can occur on steeper slopes (sometimes as steep as 1 in 5), that it is usually thinner (measured orthogonally to the sub-peat surface) and that it is underlain by mineral ground rather than being backed by a substantial deposit of ombrogenous catotelm peat. It often represents the down-slope limit of Hill Bog peat accumulation. A good example is provided by the thin (< 1 m depth) layer of peat on the steep (*c.* 1 in 10) slope below the western edge of Red Sike Moss (Figure A 28, Annexe 2). The initiation, development and hydrodynamics of such peat surfaces seems unclear. It is possible that they are essentially rheogenous in character, in the sense of receiving much of the water required for their maintenance by downslope flow of endotelmic water from above. Thus they may perhaps be conceptualised as extensive, unconfined 'ombrogenous flushes'.

5.6.3 Flow tracks and erosional features

Hill-top locations of Hill Bog are irrigated more-or-less exclusively by direct precipitation *in situ*, but below these water flow on the slopes increases with the increasing catchment area. Whilst much water flow in intact examples of Hill Bog is thought to be by overland flow and near-surface seepage through an 'acrotelm-like' layer, downslope surface flows tend to become concentrated into often ephemeral flow tracks, runnels and small streams. In periods without much rainfall, some flow-tracks can be difficult to distinguish from their surroundings, both in terms of water level and, sometimes, vegetation, and water tracks, runnels and streams may sometimes run dry, reflecting rapid rates of water discharge following precipitation events. However, the general association of Hill Bog with 'wet' climatic conditions means that any episodes of 'dryness' are generally short-lived.

Concentrated water flow has resulted in the development of erosional gully systems on many Hill Bog slopes, but these are variable feature of such slopes and their causation, ontogeny and naturalness is not fully understood. They are an important feature of Hill Bogs in many parts of the South Pennines, where they seem to have been promoted by moor burning (Tallis, 1973).

Although erosional gullies are a particular and distinctive feature of some Hill Bog slopes, they are not confined to these. Similar, and perhaps analogous, dendritic channels have been reported as occurring towards the periphery of some large lowland deposits of ombrogenous peat on flattish ground where, as in Hill Bogs, they are a product of the dissipation of large volumes of meteoric water falling onto an extensive ombrogenous catchment. Examples in the German lowlands have been termed *Rüllen* ('Rills') (Overbeck, 1975) and, as is the case with 'rands', their occurrence and character in the large lowland bogs of Britain is not well known because of turbary and agricultural conversion around their margins.

5.6.3.1 Hill Bog Gullies

Hill Bog Gullies are a conspicuous erosional feature of many sites, incised into Hill Bog peats of varying depths and slopes. Their depth and 'wetness' is variable: in some locations they have cut down to the underlying mineral ground; in some they remain separated from this by a layer of intact peat; and in others they are floored by re-deposited peat of varying depth. Their vegetation is likewise variable, some consisting of little more than eroding surfaces, others partly re-vegetated, particularly with species of *Eriophorum.*

Water supply to the gullies is primarily by downslope channel flow, either as a small stream or water track, supplemented by surface flows and seepages draining from adjoining banks of ombrogenous peat. In some instance, seepages appear to support the growth of some non-bog-building species of *Sphagnum*, such as *S. fimbriatum*, sometimes within steep slopes of Hill Bog from which *Sphagna* are otherwise generally excluded.

All of the examples of gullies specifically sampled in this investigation supported weakly minerotrophic vegetation along the bottoms of the gullies or in flushed areas. Although embedded within Hill Bog, the ecohydrological characteristics of such areas are not ombrogenous, reflecting their proximity to, or exposure of, mineral ground along the floor of the gullies. An additional WETMEC may be needed to accommodate minerotrophic gullies within Hill Bog (see section 5.9.6). Examples that are still essentially ombrotrophic could be regarded as an eroding variant of WETMEC O5 (Ombrogenous Flow Tracks) (section 5.8).

5.6.3.2 Summit and 'Flat Area' Gullies

This form of gullying is associated with shallow slopes and covers large areas of summit or near-summit situations, in locations such as Kinder Scout in the Peak District. It is more intimate and anastomosing than down-slope gullying and results in a highly variable 'hagged' surface of steep bare peat slopes and runnels with some residual blocks of vegetation-covered peat. It can also occur in some flattish below-summit areas, such as in some shallow valleyheads and cols.

This type of surface has been little-examined in the present investigation, nor is it clear to which of the less eroded WETMECs it may correspond (if any). If the proposition of Tallis (1998) has substance, that these areas represent eroded former pool and hummock systems, then it is possible that they may represent former examples of Ombrogenous Crowns or Deep Ombrogenous Slopes. Cluster Analyses placed the example examined near the summit of Moel Eunant within Cluster B, which is dominated by Ombrogenous Crowns, whereas that from Langsett was placed within Custer D along with the other Deep Peat Slopes. Because of the uncertainties involved, these samples have not been allocated to any WETMEC until more data and a better characterisation of their status is available.

5.7 WETMEC O4: Ombrogenous Percolation Troughs

5.7.1 Concept and Description

CLUSTER: A (note: some other members of this cluster are minerotrophic)

WETMEC O4 is an analogue of WETMEC 14 (Seepage Percolation Troughs) and WETMEC 18 (Percolation Troughs) (Wheeler *et al.*, 2009), differing from these mainly in having a largely or entirely ombrogenous surface. Examples are located in topographical troughs and valleyheads and appear mainly to have developed over former shallow lakes or some form of fen. The label of this unit relates to the configuration of the peatland, and not all ombrogenous deposits in topographical troughs are referable to it – examples of ombrogenous domes occur in some examples of 'troughs'.

Peat depth may be as much as 10 m and typically slopes and thins down-trough. Water flow (percolation) is very largely axial (down-trough). The configuration of the peat surface across the trough may be more-or-less flat, slightly concave, or gently sloping to a lower margin. Although the relationship is not exact, the flatter cross-trough examples seem to be associated with diffuse down-trough flow, the concave ones with axial flow and the slightly sloping ones with preferential flow along a lower marginal 'lagg'-like soakway or water track. Some examples may have a 'lagg' at different levels along either side of the trough, but in these cases the separating percolation surface, whilst raised slightly above the levels of the laggs, is usually not obviously much elevated or significantly domed.

Down-trough flow tracks in Ombrogenous Percolation Troughs are more often evident as water tracks than as soakways. Some of these appear to be natural, but in others they may represent former ditches, now occluded or blocked. Active ditches may also occur.

The main vegetation types recorded for this WETMEC were M18 (30%), M19 (42%), and M20 (15%). M19 can be particularly prominent in partly drained examples, such as Hafod Elwy, or at the drier heads of troughs, such as The Lakes. At Muckle Moss, M2 is locally prominent in particularly wet surface locations, including some roughly crescentic depressions and pools. At Hafod Elwy, M2 has developed in some blocked forestry ditches. At Coom Rigg Moss, the valley in the south-west corner of the site, between Little Samuel's Crags and Muckle Samuel's Crags, and described by Chapman (1964a) as lying at much lower level than the rest of the bog surface and with "a system of deep pools", appears to provide an example of WETMEC O4 in that part of the site. It contained what was described by Chapman as a 'flushed' version of what is now known as M18, with more *Andromeda, Vaccinium oxycoccos* and *Sphagnum magellanicum* and far fewer leafy liverworts than was found in the more widespread ombrogenous vegetation [but also M18] of the site. This he attributed to greater rates of water throughflow towards the outflow points. It was revealed subsequently (Chapman & Rose, 1991) that this area also contained *Carex magellanica* and *Drosera anglica* (though the latter was not refound in 1986). This trough has been damaged significantly by nearby afforestation.

The topographical context of some examples of WETMEC O4, at sites such as Muckle Moss, is rather similar to that of troughs in southern England where the surface is dominated by M21. However, the vegetation pattern at Muckle Moss essentially consists of a central wet axis dominated by M18, flanked by M19 in slightly drier conditions. M21 has been mapped there, but only along a narrow axial soakway (partly an occluded drain). It is not known if its occurrence reflects slightly enhanced ionic concentrations or greater rates of water flow. The topographical context of Muckle Moss suggests that the trough is potentially vulnerable to minerotrophic influences from its surroundings but, apart from the axial track of M21 there is no known floristic or hydrochemical evidence to suggest that this is the case, or if it is the case, that it has had a significant impact on the character of the main area of the mire. There is, however, evidence of some minerotrophy along some of the mire margins, marked in places by thin stands of W4 or M25.

The mire at Hafod Elwy has been considerably drained for forestry, and also has a deep drainage channel marking a minor geopolitical boundary. This appears party to be artificial, partly to follow the course of a natural water flow track. Parts of the ombrogenous surface are split by a large soakway, sourced from an adjoining hillslope, which supports M21 vegetation and which introduces weakly minerotrophic conditions across the mire, but the flanking lobes of ombrogenous peat appear to be referable to WETMEC O4. This site is developed mostly in a south-west–flowing valleyhead but north-eastwards the head of the trough occupies a col, which also drains (in small measure) north-eastwards.

A rather similar circumstance pertains at Figyn Blaen-brefi, where an ombrogenous deposit at the head of a north-westwards–draining trough occupies a broad col, which also drains in smaller measure south-eastwards. The top of the 'dome' of the peat deposit along the length of the col (Figure A 1) corresponds to the bottom of the trough in transverse section, and it appears overall to occupy a 'water-collecting' location. Whilst partly domed over the length of the col, the ombrogenous deposit does not show cross-trough doming (based on Lidar contours), nor was any feature observed that would intercept surface run-off from the flanking slopes of the col. But neither was the composition of the ombrogenous vegetation (referred, despite the local prominence of *Trichophorum cespitosum*, on the winter field visit to M18, *Molinia*-rich M19, and M2) obviously influenced by any inflows from the slopes. Whilst this south-eastern, highest end of Figyn Blaen-brefi seems referable to WETMEC O4, the status of the main area of trough that sinks north-westwards from this is much less clear, partly on account of what appears to be very substantial erosion. It is not even certain to what extent that part of the trough can be regarded as ombrogenous – the vegetation types on the transverse section recorded were mainly M21, M25 and M4, with M19 on a mound of – probably slumped – deeper peat at the base of the slope on the north-east side. There is some evidence for groundwater outflows at the margins of the peat deposit on both sides of the valley.

In certain locations in the Roman Wall Country, as in part of Muckle Samuel's Moss, 'double-ended' troughs occur (Figure A 45). These are essentially more-or-less flat-bottomed troughs or cols in which a distinct and often deep mound of peat has accumulated, domed autonomously along the length of the trough but more-or-less flat, or concave, across its width. Down-trough flow occurs in different directions on either side of the summit. At Muckle Samuel's Moss, the vegetation of the flatter top of the dome is M18, with M19 on the steeper, lower slopes. The top of the dome is clearly transitional conceptually to WETMEC O1.

Ombrogenous Percolation Troughs have not been identified widely. It seems likely, based on the stratigraphical data provided by Moore & Chater (1969) and, particularly, by Slater (1976), that Gors Lwyd may fit this category, and possibly also Cors Goch (Ciloerwynt) (Fojt, 1985), though in that case stratigraphical data have not been available. In England, the upper part of the slope of Fen Bog, on the south-flowing side of the col, provides an example of this WETMEC. In the absence of the wider characterisation now available, the ombrogenous surface at Fen Bog was referred to WETMEC 2a ('Ombrogenous Quag') by Eades *et al.* (2017), but it is clear that the new WETMEC O4 is more appropriate for it.

5.7.2 WETMEC sub-types

Only a few examples of Ombrogenous Percolation Troughs have been examined and, although some sub-types are likely, it seems premature to try to identify them with the limited amount of data available. It would be particularly desirable to identify the relationship between the examples of WETMEC O4 considered here and the character of ombrogenous deposits in troughs and cols in higher-altitude locations.

5.8 WETMEC O5: Ombrogenous Flow Tracks

CLUSTER: A (note: some other members of this cluster are minerotrophic)

5.8.1 Concept and description

A WETMEC of the bottoms of valleyheads and troughs, often on fairly deep peat, and on some hillslopes. It is an analogue of the WETMEC 19 'Flow Tracks' of Wheeler *et al,* (2009) but differs in that water flow is thought not to have a significant minerotrophic component, which means that it is essentially endotelmic in origin. Flow Tracks are a feature of some Ombrogenous Percolation Troughs, but they can also occur as surface features and subdivisors of other ombrogenous WETMECS.

Examples of flow tracks with much open water, representing the transition between mire and true streams, are designated here as water tracks, whereas soakways essentially represent more consolidated water tracks, with less open water, and occur either alongside streams or watertracks or, in some situations, replace water tracks as the main axial flow path. Laterally, Ombrogenous Flow Tracks often grade into the Ombrogenous Percolation Troughs of WETMEC O4. The distinction between them can be difficult to make, but here Ombrogenous Percolation Troughs are considered usually to support a fairly typical version of the main ombrogenous vegetation types (particularly M18 and M19), whereas in Ombrogenous Flow Tracks, such vegetation-types may occur but in a less typical form, such as with a dominance of tussock-forming species (principally *Molinia* and *Eriophorum vaginatum*), and in some cases their vegetation is referable to M20 or M25. In some instances, M21 may also mark the courses of Flow Tracks.

Narrow soakways and water tracks are widespread around the margins of some of the peat deposits considered here, where they can form a sort of 'lagg'. However, these are generally minerotrophic, though sometimes only weakly so (see section 5.9.3). Only a small number of the Flow Tracks examined in basin situations appeared to be fairly clearly ombrogenous and endotelmic in character, and even in these instances (Muckle Moss, Ringinglow Bog) some doubt about their water-source status exists. Of the several Flow Tracks at Ringinglow Bog, most, including the Flow Track that helps to separate Ringinglow Bog from the adjoining White Path Moss, are clearly minerotrophic, fed in part by groundwater outflow from Carboniferous sandstones. The putative ombrogenous examples are occupied by *Molinia*-rich versions of M19 and M20.

Flow Tracks on ombrogenous slopes (WETMECs O2 and O3) are usually on steeper slopes and may be more ephemeral and less clearly defined than in WETMEC 04. Down-slope flow tracks with much *Narthecium ossifragum* and *Molinia* or *Eriophorum vaginatum* may mark such features, and represent a form of ombrogenous flushing. These Flow Tracks may drain into gullies or into the heads of small streams. No examples were sampled as part of the present project, in which all of the hillside Flow Tracks examined were minerotrophic in character (see sections 5.9.2 and 5.9.6).

5.9 Minerotrophic Surfaces and WETMECs

5.9.1 Minerotrophic surfaces within 'upland' areas of ombrogenous peat

The upland peat deposits of England and Wales are dominantly ombrogenous, but minerotrophic conditions are also present quite widely. All the ombrogenous peat is likely to have originated from a preceding minerotrophic condition, whether this has been provided by aquatic sediments, surfaces of fen peat or by peaty-gleyed or peaty-podsolic mineral soils, though the last two starting-points may have been only very weakly minerotrophic. Likewise, the ombrogenous peat deposits are likely to be bordered by minerotrophic deposits of some kind. The nature of the transition to these depends upon the characteristics of the deposits in question and upon local topography, both of the landscape context and of any autonomous topographical characteristics of the peat deposits themselves.

5.9.2 Minerotrophic features associated with Hill Bog

The down-slope margin of Hill Bog deposits is marked by a transition to mineral soils, often some form of podsol or gley. In this situation, the mineral ground is unlikely to have much impact on the peats above it – rather it is likely itself to be irrigated by run-off or seepage from the ombrogenous peats above. However, where such mineral ground is exposed above the ombrogenous peats, or within them, both circumstances which have sometimes arisen by erosion of former ombrogenous peat surfaces, there is some potential for local enrichment of areas of ombrogenous peat downslope of the exposures to create weakly minerotrophic conditions (section 5.9.6). In some instances, gullying appears to have exhumed small valleys that pre-dated the widespread development of ombrogenous peat, and its impact upon the ombrotrophic status of these features depends partly on the amount of ombrogenous peat residual within them. In other cases, the features are expressed as narrow, shallow, weakly-minerotrophic flow tracks within, or entering, ombrogenous slopes, which may or may not dissipate gradually into the ombrogenous mass. To the purist, such surfaces may not be considered to be truly, or at least certainly, 'ombrotrophic', but the weakness (in practise, though not in concept) of the ombrotrophic–minerotrophic boundary is such that such views may be more conceptual than practical.

This same issue arises in some 'basin' deposits where the ombrogenous peat in a water-collecting area is not obviously separated from any potential run-off from adjoining 'mineral' slopes. This is the case, for example, at the south-eastern end of Figyn Blaen-brefi, where there is no obvious floristic reason to suppose that the 'ombrogenous' vegetation (M2, M18 and M19) along the bottom of the col is affected by any minerotrophic inputs from the flanking slopes, though these must to some extent drain into it.

5.9.3 Peripheral minerotrophic features associated with ombrogenous domes, partial domes and bulges

Minerotrophic features can be expressed particularly clearly in some upland 'basin' ombrogenous peat deposits. One widespread feature is a narrow marginal minerotrophic zone in topographically 'confined' circumstances which separates the ombrogenous deposit from adjoining mineral ground (sometime covered by thin hill peat) upslope of it. This is expressed most frequently as a flow track complex which may contain soakways and water-tracks (WETMEC 19) and small streams, sometimes clearly groundwater fed (WETMEC 15: Seepage Flow Tracks). In other instances there may be just an indeterminate and rather nondescript zone of minerotrophic conditions which may not obviously referable to any existing WETMEC. In many instances, these marginal zones of minerotrophic conditions have been ditched to greater or lesser degree. They may receive water draining both from the adjoining mineral slopes and from the ombrogenous deposit, the surface of which is typically elevated in some measure above the minerotrophic flow tracks.

In the lowlands, flow tracks of some sort, or some other minerotrophic feature, can also provide an interface between ombrogenous peat deposits and their surrounding mineral ground. Such features are frequently referred to as 'laggs', though as often used this is not a particularly cohesive concept. It most typically refers to a moat-like feature that encircles, in whole or part, an ombrogenous deposit, especially within some topographically-confined basins but, as sometimes used, it can also include features such as watercourses and their associated fens which have originated outwith the area of ombrogenous peatland and, far from being a feature of the ombrogenous mire, are often an 'external' influence that has constrained the lateral expansion of this.

Peripheral zones of minerotrophy are particularly marked and obvious where water from the adjoining mineral deposits is of a contrastingly different chemical character to that sourced from the ombrogenous peat. In upland examples this can be seen clearly around the confined parts of Malham Tarn Moss, where the 'lagg'-like minerotrophic margin is effectively occupied by a small limestone stream (which in part originates outwith the peatland area) and its associated base-rich fens, with a character determined primarily by outflows from calcareous springs (sourced by Fluvio-glacial deposits rich in limestone clasts, and from Garsdale Limestone). A similarly obvious drainage feature occurred along the confined (eastern) side of Red Sike Moss (Upper Teesdale), in that case fed by groundwater sourced from "sugar (Melmerby Scar) limestone". By contrast, along the southern side of Ringinglow Bog, a marginal soakway, apparently fed by water sourced from the flanking Chatsworth Grit, is marked just by a strip of M20 vegetation, which is not so very different from the M19a surface that flanks it on the ombrogenous side of the mire margin.

The more asymmetric mires of the Roman Wall Country typically have some sort of flow track along any topographically-confined margins (*i.e.* beneath up-slopes of mineral ground). The most characteristic vegetation of such flow tracks is M6, but some examples have M20 or M25. Many such lagg-like features in the RWC have been ditched, and they may well have become enriched, or otherwise influenced, by the deposition of mineral downwash from adjoining slopes disturbed by drainage and other operations associated with their afforestation. However, the pre-afforestation condition of these minerotrophic margins is not known (to us), and it is clear that similar vegetation units can occur elsewhere in 'laggs' in contexts that have not been associated with forestry. That M20 and M25 (in particular) are incoherent vegetation units also hampers any assessment of possible causations unless detailed species data are available.

Where the ombrogenous margin is not confined but occupies a down-slope, as along the south side of Hummel Knowe Moss (or as illustrated in Figure 24, Annexe 2), the ombrogenous peat generally peters out down the mineral slope, in much the same way as occurs below deposits of Hill Bog peat, sometimes (but not always) grading down-slope into a minerotrophic peat surface. In some other 'partial domes' or 'bulges', the bottom margin of the ombrogenous deposit may be marked by a flow track or a drainage stream, that may be endotelmic or which may originate from outwith the limit of the 'site'.

As Day (1970) commented, at Butterburn Flow "the peat area is not limited by higher ground, except locally on the west". Nonetheless, the ridge to the west, though broken by small peat-filled valleys, does rise above the level of the mire surface, by about 15 m in places, and it drains into the western end of the Flow. In this area, as Barber (1981) observed, surface conditions seem to be excessively wet and quaggy, but it is not clear to what extent this is a consequence of run-off from the mineral ground to the west or of particularly poor drainage in this part of the mire. The 'landward' end of this wet area appears to be weakly minerotrophic and can perhaps be regarded as forming a very broad lagg zone (up to about 200 m wide). Its vegetation (at sample point 1) was given as M19a, which is generally regarded as on ombrotrophic vegetation-type, but as the water pH was 5.1, some weak minerotrophic influence seems likely.

Although the 'Ombrogenous Crowns' of some of the asymmetric domes may be raised only slightly above the level of any minerotophic flow-tracks that separate them from flanking up-slopes of mineral ground, in general there is little floristic evidence for the spread of telluric water beyond the limits of any shallow 'laggs' or other marginal features. One exception to this generalisation may be provided on the western side of Gowany Knowe Moss, where fingers of M25, including a strip of stunted *Phragmites*, drain down the relatively steep north-western slope from within an area of M19 vegetation, and feed into a broad and variable, north-west–draining soakway. The origin of this is uncertain, but it is possible that it emanates partly from water percolating through fen peat below the ombrogenous M18 / M19 cap of the mire in a manner reminiscent of that at Malham Tarn Moss (see 5.9.5.3).

At Coom Rigg Moss, Chapman (1964a) regarded patches of stunted *Phragmites* within ombrotrophic vegetation as being relict from their earlier occurrence within 'basins' in the mineral ground. They occupied locations where minerotrophic peat (with much *Phragmites*) had persisted to within a short distance of the surface, in one instance to around 50 cm sub-surface (Chapman, 1964b). Chapman considered that this was probably because the sub-peat topography in this area was essentially that of an eastward-draining valleyhead "with the natural drainage running down the centre of the valley. Thus the peat was subjected to water from the higher non-peat-covered ground until comparatively recently when the bog surface was about 1 m lower than at present" (Chapman, 1964b).

It should also be recognised that down-slope minerotrophic flow-tracks of one form or another occur in a number of contexts in the RWC complexes. For example, at The Wou a broad strip of *Molinia*-rich

(M25) vegetation slopes diagonally down a shallow side valley on the southern slope of the peatland area sampled here, and separates two ombrogenous deposits, each with crowns and bulges of M18 vegetation. This flow track was sampled near its head (sample point 5) where the peat was very shallow (0.6 m depth) and it is almost certainly partly minerotrophic. In places there are narrow axial strips of M6 within it. Further west, a particularly broad swathe of M25 vegetation, again with some axial M6, separates another set of M18 surfaces from those to the east. Although this area was not examined, it seems that at The Wou the southern slopes of the valley are occupied by a series of ombrogenous partial domes or bulges, perhaps associated with basins on the valleyside, separated by bands of weakly-minerotrophic, and perhaps quite shallow, peat, to form a linear series of ombrogenous deposits that is reminiscent of that found at the Silver Flowe (though on a considerably smaller scale). This proposition requires field confirmation, but it seems very likely that the differences between the south slope of The Wou and, for example, Gowany Knowe are primarily a reflection of the local topography: hollows along the slopes of the Wou support a series of ombrogenous deposits each separated by a down-slope band of weakly minerotrophic conditions, whereas Gowany Knowe, within a flatter basin, represents a single, more centric ombrogenous unit, and the associated minerotrophic mire is essentially peripheral to this.

Drainage streams, sometimes ditches, can be found along the base of a number of ombrogenous domes, partial domes and bulges. They are well illustrated, for example, by the sections from Muckle Samuel's Moss (Figure A 43 and Figure A 44, Annexe 2), a site which also includes an apparent 'lagg'-like feature along with numerous furrows and ditches associated with afforestation. The northern side of this composite deposit is marked by the valley of Drowningholes Sike, the bottom of which is largely occupied by M6 vegetation. Towards its head, at sample point 11, the stream bottom is separated from the underlying mineral material by only a thin layer of peat; lower down (sample point 6) the Sike has cut down into the mineral ground, and the thin 'peat' present there contains a significant mineral fraction (silt and sand). This is also the case on the south side of Muckle Samuel's Moss, at the head of the Blind Well valley (sample point 1). These flanking streams and soakways have been ditched to some degree in recent times but appear to be natural drainage features that have helped to constrain the lateral expansion of the ombrogenous deposits rather than peat-erosional features, or features 'produced' by the mire itself. They are clearly influenced by minerotrotrophic conditions but are also much supplied with water from the flanking ombrogenous slopes, and in this regard they are conceptually not very different from some of the erosional 'Minerotrophic Gully-Bottoms' within Hill Bog slopes (section 5.9.6), though with much slighter gradients.

5.9.4 Minerotrophic conditions in ombrogenous troughs and similar situations

In view of their topographical situation, the bottoms of small valleys and troughs would seem likely to be particularly susceptible to ionic enrichment associated with adjoining mineral slopes. Moreover, the ombrogenous WETMEC that is particularly associated with such troughs (WETMEC O4, 'Ombrogenous Percolation Troughs') generally shows little across-trough doming, which may increase its susceptibility to inflows from higher ground along the margins.

Minerotrophic conditions are especially obvious at The Wou, where the valley-bottom is extremely wet and quite wide, and contains stands of M4, M6, M23 and M25 and, near the base of the sloping ombrogenous peat of the hillside, M18 and M20. These last areas have been regarded here as examples of WETMEC O5 (Ombrogenous Flow Tracks), but the rest of the trough is referable to the minerotrophic soakways and water tracks of WETMEC 19. The trough here is partly supplied with water from a small stream which originates outwith the main peatland 'site'.

By contrast, the trough at The Lakes is largely filled with 'ombrotrophic' vegetation (M18, M19 and M20), with obviously minerotrophic conditions (mostly marked by M6) largely confined to a (partly ditched) narrow 'lagg'-like strip along the margins, especially along the northern side. There are also soakways within the ombrogenous deposits, particularly in the lower half of the trough, which appear to represent locations of enhanced flow of endotelmic water. In one particularly wet location (sample point 10) water flow tracks situated between the M18a centre and an M4 fringe along the southern margin support an area of M21 vegetation, notable partly for the occurrence of *Carex magellanica*. It is not known to what extent this is a feature of enhanced flow *per se* or of weak minerotrophy associated with proximity to the mire margin.

In terms of its topography and vegetation pattern, Muckle Moss has many similarities with The Lakes peatland, but its minerotrophic margins are for the most part wooded (W4)[13]. It also has what appears to be a fairly narrow and discontinuous axial soakway, marked in part by M21 and again raising the same question of the importance of enhanced flow *versus* weak minerotrophy in regard to this. It is well possible that this rather straight flow line marks a former drainage feature. The cross-trough sections provide no indication of significant surface doming such as might be expected to constrain penetration of minerotrophic inflows from the (higher) margins, but along much of the length of the mire there is a clear vegetation zonation in which much of the central axis of the site, occupied by M18, is flanked by a band of M19 vegetation of varying width, which separates it from the minerotrophic margins.

The south-west part of Hafod Elwy Moor also occupies a shallow trough which forms the valleyhead of the Nant y Gors-goch and is occupied mainly by ombrogenous deposits that have here been referred tentatively to WETMEC O4. The areas of deep peat appear to support M18 and M19 vegetation (an *NVC* survey has not been available) subdivided into three main ombrogenous lobes by soakways with M21 and M6 vegetation. Sample point 8 represents a particularly broad M21 soakway, which seems to be a product of the significant penetration of weakly minerotrophic conditions into an ombrogenous surface and provides an example of WETMEC 19. These conditions appear to originate from inflows sourced from the slopes of Cerrig Caws to the north-west. A soakway also occupies the part of the western margin of the trough, with M6 vegetation at sample point 5.

The Fen Bog col has some patches of M18 vegetation along the valley bottom on either side of the watershed, but particularly on the more extensive southern slope. Much of the peat infill here, which is up to around 10 m deep, consists of a 'swampy' monocot peat over a basal wood-rich layer, but has a fairly thin (*c.* 1 m) surface layer of *Sphagnum* peat, particularly over and near the saddle of the col (Atherden, 1972; Eades *et al.*, 2017)[14]. This forms part of a 'dome' of peat longitudinally across the saddle, but there is little cross-trough doming of the apparently ombrogenous surface. It is flanked, particularly on the eastern side, by groundwater outflows on the valleyside slope (WETMEC 17, Groundwater-Flushed Slopes). These are generally well above the level of the ombrogenous surface (WETMEC O4 Ombrogenous Percolation Trough) of the valley bottom, but for the most part they are captured by a long seepage flow track (WETMEC 15a) which in places broadens into small areas similar to WETMEC 13b (Seepage Percolation). Their further relationship with the ombrogenous surface is considered below (section 5.9.5.5).

5.9.5 Groundwater outflows associated with ombrogenous peatlands

In some locations in the uplands, groundwater outflows (springs, flushes and seepages) occur embedded within, marginal to, or in the close proximity of deposits of ombrogenous peat. At Moor House, Johnson & Dunham (1963) recognised the occurrence of *lime-rich flushes* and *iron-rich flushes*, produced where groundwater emerging from bedrock (mainly from limestone or sandstone respectively) drained "over the blanket-bog surface". It must be presumed that the "blanket-bog surface" over which they drained was not (or was no-longer) ombrotrophic in character, but these authors provided few details about such features or of their relationship to 'normal' blanket-bog peat; and, as no comparable examples were knowingly encountered during the present field work, no further comment can be made. Nonetheless, in certain sites some rather different groundwater outflows were observed in the present investigation, giving rise to groundwater-fed flow-tracks or small streams as well as creating patches of groundwater-fed mire. Very often, such groundwater outflows formed discrete flow tracks that subdivided flanking ombrogenous units, or were confined topographically to 'lagg'-like structures, but in other instances they penetrated into, and seemed to

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[13] Some of this site has been drainedand occupied by a plantation, and some of the margins have been planted.

[14] Atherden (1972) considered that "Within the last 150 years drainage schemes have lowered the water table and changed the mire from a topogenous to an ombrogenous one. This change has resulted in the extension of *Sphagnum* spp and the establishment of a more acid-tolerant flora on the main part of the mire, while the reedswamp community has become confined to the wetter and more base-rich environment of the drainage channels at the southern end of the mire." However Chiverrell (1998) subsequently suggested that "the mire was colonized by an ombrogenous mire flora *circa* cal. AD 1100". Consideration of both of these accounts indicates the need to make a careful distinction of acidification leading to the spread of *Sphagnum* from the establishment of ombrogenous conditions.

disperse within, adjoining ombrogenous deposits. All three of these circumstances can be illustrated in the area around Malham Tarn.

5.9.5.1 Tarn Moss and Ha Mire, Malham Tarn

At Tarn Moss, a marginal 'lagg'-like feature around the confined margins of the ombrogenous deposit is fed by springs – some of them strong springs – from the adjoining Garsdale Limestone and limestone-rich glacio-fluvial deposits. These outflows are contained within the narrow marginal 'lagg' trough and do not feed the ombrogenous surface (but doubtless receive surface flows or seepage of bog water from this). In addition, the ombrogenous deposit is punctured at one point by a glacio-fluvial hillock (Spiggot Hill), and what appears to be groundwater outflow from this feeds into narrow soakways which flow across the dominantly ombrogenous deposit and penetrate this as a ribbon of minerotrophy. The main soakway flows north from Spiggot Hill. Pigott & Pigott (1963) commented that "it is clear that this separates the two domes of the moss which grew up one on either side."

On the other (eastern) side of Malham Tarn, Ha Mire is similarly sandwiched between Garsdale Limestone (north-east side) and glacio-fluvial deposits (south and south-west sides) and also receives base-rich groundwater outflows from these. These form seepages (WETMEC 10) and strips of percolating groundwater (WETMEC 13) along the margins of the mire, and flow into it as a series of sinuous flow-tracks and runnels (WETMECs 15 and 17d). However, much of Ha Mire consists of a shallow, apparently-ombrogenous surface elevated slightly above the level of the telluric water inflows, which becomes increasingly coherent towards the centre of the mire. The margins of this site could therefore be interpreted as forming a 'proto-lagg', surrounding a young ombrogenous deposit with only a thin layer of ombrogenous peat – or perhaps a thin layer of ombrogenous peat remnant from past turbary. This site well illustrates the small degree of vertical separation (less than 0.5 m) needed to permit the development of a seemingly-ombrogenous surface over calcareous groundwater.

5.9.5.2 East Moors of the Peak District

Small groundwater outflows are a feature of some of the East Moor sites, and are generally associated with discharges from sandstone units exposed in the layered Carboniferous sequence across the boundary between Namurian and Westphalian deposits. Springs, where they are associated with miry deposits at all, generally give rise to examples of WETMEC 17 (Groundwater-flushed Slopes), *i.e.* where outflows from a discrete point flow down across the surface of a low-permeability slope, rather than WETMEC 10 (Seepage Slopes), though surfaces that seem to be referable to these latter have been noted upon aprons of permeable Head, fed by outflows from the Carboniferous bedrock.

Some examples of spring-fed slopes in the Eastern Moors area are relatively base-rich, such as a stand (referred to M23b; pH 5.1) embedded within Big Moor on the banks of Sandyford Brook and notable for the occurrence of *Thelypteris thelypteroides* along with *Carex paniculata*. A large patch of *C. paniculata* is also associated with the margins (western corner) of Leash Fen, on very wet ground (pH 5.5) between a spring and the outflow stream. On the western side of White Path Moss a strong spring sources a quite extensive associated flush and a water-track, referable to M6. This is associated with a fault line that juxtaposes Chatsworth Grit with a mudstone unit and the water pH of the outflow ranges between 4.1 and 5.5. White Path Moss itself is separated from Ringinglow Bog by a fairly narrow flow track, which appears to be sourced by groundwater outflow from Friar's Ridge (Rough Rock, partly buried by peat). Its head is marked by an extensive rushy area (referable to M4 / M6) flanked by ombrogenous peat, from which it flows south, with a form of M6 vegetation. Although fed by groundwater at its head, this cannot be regarded as a form of 'Seepage Flow Track' (WETMEC 15) but as WETMEC 19 ('Flow Track'), fed by groundwater at its source and by seepage from flanking ombrogenous peat lower down. It is thus conceptually rather similar to some of the erosional Gully Bottoms within Hill Bog. It appears to be a derivative of a water course that led to accumulation of woody peat in this valleyhead part of the mire in the early phase of its development (Conway, 1947).

There are also good examples of groundwater-fed flow tracks at Stoke Flats. These are associated with an outcrop of Redmires Flags, which here forms a valleyside bench that stretches diagonally down the hillslope below White Edge and has groundwater outflows associated with its boundary against (partially Head-covered) mudstone. The lower part of the mire has quite deep peat (*c.* 2 m) and is apparently fed by springs, nearby upslope or *in situ*, and supports much *Eriophorum angustifolium* (referred, perhaps dubiously, to M3), flanked by *Molinia*-dominated vegetation, whilst higher up the bench, but still over Redmires Flags, conditions are less wet, at least in summer, and the vegetation is a form of M25.

5.9.5.3 Roman Wall Country (Border) Mires

Little evidence was found in the field for obvious groundwater outflows associated with most of the mires of the Roman Wall Country that were examined in this project, though this may in part have been because such marginal features have been considerably obliterated or otherwise obfuscated by afforestation around the mires. The bedrock associated with many of these sites is a 'Yoredale Series'-like sequence of Dinantian deposits (the 'Upper Border Group' of earlier authors, now 'Tyne Limestone Formation'), in which some sandstone and limestone units are likely to be significantly water bearing, apparently sufficiently so as to sustain local domestic water supplies at Spadeadam (Day, 1970) and the village of Stonehaugh (Frost & Holliday, 1980). However, over much of the RWC area there is a cover of Till, in places apparently deep.Details of its depth or composition in the vicinity of the mires considered here have not been available, with the fortuitous exception of Gowany Knowe Moss. Nonetheless, Swan (1993) reported both *Carex dioica* and *Pinguicula vulgaris* to be "common" in the Roman Wall Country, and some, perhaps many, of these records may relate to groundwater outflows, either from bedrock or Till.

Some of the sites examined here are clearly associated with mapped sandstone units, which can form narrow cuestal ridges flanking the mires, sometimes conformable with, sometimes faulted against, less permeable units but generally at outcrop only over small areas. Coom Rigg Moss has developed adjacent to an exposure of Seven Linns Sandstone ('Little Samuel's Crags') but is mostly over a superincumbent Till-covered mudstone unit. Chapman (1984a & b) commented that for a considerable part of its developmental history, part of the eastern side of this mire had a topography and drainage that was "in many ways similar to valley bog systems more often found in lowland areas", and contained a considerable accumulation of minerotrophic peat, some of which comes to within about 0.5 m of the present-day mire surface. It is conceivable that this area may have been fed partly by groundwater from the Seven Linns Sandstone, but surface run-off from Till or Mudstone is perhaps more likely. The mapped area and eminence of the Sandstone outcrop is small, though it is very possible that the Till mapped around this outcrop is thin and possibly transmissive.

More extensive areas of sandstone at rockhead, but only in places at outcrop, are mapped in association with the quartet of sites of Gowany Knowe Moss, Pundershaw Moss, The Lakes and Felecia Moss. Gowany Knowe Moss is partly developed over sandstone, faulted beneath the site against lower-permeability units and with a thin limestone rockhead mapped locally in places. It is partly flanked by (mostly Till-covered) low sandstone ridges and hills. BGS Borehole NY77NW, just off the eastern end of the Moss at NGR NY 7354 7893, proved 0.45 m of peat over 1.25 m of Boulder Clay, all over a thick unit of sandstone of the Tyne Limestone Formation. Another borehole (NY77NW/6), in a small peaty valley just south-west of the site, at NGR NY 7272 7835, also had some 0.5 m of peat and 1.5 m of Boulder Clay, over a layered mudstone unit with some thin limestone.

At Gowany Knowe Moss some quite broad bands of minerotrophic mire (mostly M25 and M23) surround the ombrotrophic core and form soligenous slopes along some of the western side of the site, extending both downslope towards the north-western outflow and, in smaller measure, penetrating uplope into the ombrotrophic periphery as fingers of M25, including a seemingly anomalous '*Phragmites* soakway' embedded within ombrogenous peat. The north-west area of fen is notable for the occurrence of *Carex lasiocarpa* and, at least in the past, for various 'brown mosses' (O'Reilly, 2022). Some of this specific area appears to be located where a limestone unit is at, or just below, rockhead, and it could conceivably be influenced by this. It is also apparently fed by a small (and now ditched) stream flowing in from the south-west, and another from the south, which join to form a north-flowing soakway down the western side of the main area of mire (and doubtless mix with waters derived from that). However, it seems likely that much of the 'north-west fen' is fed by groundwater outflow from the sandstone hill to the south of the Moss and perhaps by the influence of fen peat beneath the ombrotrophic cap, in a manner vaguely reminiscent of that at Malham Tarn Moss. Some peat stratigraphical investigations might help to resolve this issue, but the limited hydrochemical data available (pH 5.8 measured in this investigation – (O'Reilly (2002) reported 4.6–6.2)) strongly suggest a groundwater influence in this area of fen.

Pundershaw Moss is mostly located over a mudstone unit but is flanked by sandstone. Davy & Diack (2019) reported the occurrence of groundwater outflow near the base of a forested slope just above the eastern minerotrophic margins of the mire "at roughly NY7781279276, which supported various basicolous bryophytes including *Campylium stellatum*, *Scorpidium revolvens*, *Ctenidium molluscum*, *Breutelia chrysocoma* and *Riccardia chamaedrifolia*. Various sedges were present, including frequent *Carex rostrata* which extended some way up the slope well into the plantation, and *C. panicea, C. demissa/lepidocarpa* and probably *C. hostiana*." This outflow coincides very closely with the mapped contact between a mudstone and a sandstone unit of the Tyne Limestone Formation and probably represents an outflow from the latter. It appears to be captured by a narrow peripheral lagg with M4 / M6 / M25 vegetation.

5.9.5.4 Stone Park, Lonsdale

Stone Park occupies the bowl-like valleyhead of Burns Beck between two hills of Till-covered Silurian sandstones (Kirkby Formation), and is itself situated upon this rock. A number of small streams, apparently fed by springs, originate in the valleyhead, mostly outwith the mire, and cross the site flanked by a fringe of minerotrophic mire of variable extent. In the south of the site there is a substantial area of somewhat domed ombrogenous mire flanked by two streams and crossed by a third to produce two unequal mounds of M18 mire. The transition from the streams to ombrogenous conditions is most typically marked by a strip of M6 or M23 vegetation. However, in the north of the site, separated from the rest by a narrow mineral ridge, there is a smaller area of M18 vegetation, sloping from below acidic grassland to the main outflow stream, and which is separated from this by a strip of fen referred to M22–M24 (on a silty peat) and with a species-rich soakway referred to M14 (over 'brown-moss' peat). It is not clear, from the information available, if the soakway is a consequence of seepage from the nearby ombrogenous peat flushing over fen peat or whether it receives telluric groundwater outflow either directly or from beneath the M18 area. The western side of the Stone Park basin partly supports fen vegetation, with small streams and soakways, but these do not penetrate the southern ombrogenous unit as they are intercepted by the stream along its western flank.

5.9.5.5 Fen Bog, North York Moors

At Fen Bog, the rather thin surface layer of apparently ombrogenous peat is 'domed' longitudinally across the watershed of the col in which it occurs, but shows no cross-trough doming beyond the development of a surface which is slightly elevated above that of adjoining minerotrophic mire. Overall, the Fen Bog trough is considerably influenced by groundwater outflows from the adjoining valley slopes, especially from the rather steep eastern slope.(mostly WETMEC 17, 'Groundwater-Flushed Slopes), but much of their outflow is captured by a long seepage flow track (WETMEC 15a) along the base of the slopes. However, in places they show some penetration into the central, apparently-ombrogenous, 'axis' of the trough, with inter-digitating strips of vegetation referable to M14 and M21 (depending on their location and base-richness) extending into areas of M18. Some of these cross-trough flow tracks may be a consequence of former ditching (and in one case a trackway) made across the mire, but in other places, particularly on the north side of the watershed, relatively base-rich water from the marginal springs and seepages meanders into the base-poor areas and seems to disperse within them. Westward flow of telluric water in places across the trough is likely to be encouraged by a westward tilting of its surface. The 'naturalness' of this is not known, but it could well be a relatively recent development, consequent upon deep drainage associated with the construction of a railway along the western edge of the mire in the first half of the 19th century. If this is the case then whether or not this drainage was a stimulus for ombrotrophication, as Atherden (1976) has suggested, it may have enhanced secondary penetration of telluric water across the centre of the mire.

M18 surfaces are particularly a feature of the central axis of Fen Bog, especially on the south side of the watershed within the trough, where they appear to have been truncated westwards at the railway fence line – which is at some considerable distance from the railway tracks themselves – and replaced by a more *Molinia*-rich vegetation nearer the railway. There are several (six or more) separate large patches of M18 in this part of the site. These may represent the independent development of separate ombrogenous nuclei along the spine of the mire, but it is also possible that a once more continuous strip of M18 has been dissected by westward flow of minerotrophic flow tracks and M21 soakways, encouraged by recent westward tilting of the surface.

5.9.6 Minerotrophic Gully-bottoms in Ombrogenous Peat

All of the gullies in Hill Bog that were sampled in the present investigation were weakly minerotrophic in character, and typically supported a form of M6 vegetation. Examples of this were particularly evident in parts of the slopes of Moel Eunant and Langsett Moors. The minerotrophic component of these surfaces reflects their proximity to, or development upon, mineral ground along the floor of the gullies, coupled with down-channel flow of drainage water often influenced by similar conditions upslope. The gully bottoms are also likely to receive significant drainage water inflow from the flanking deposits of ombrogenous Hill Bog. Although this combination of features, topographical and hydrological, provides the Minerotrophic Gully Bottoms incised within Hill Bog slopes with distinctive characteristics, it has already been observed (section 5.9.4) that similar water supply processes can be associated with flow tracks and small streams in the different topographical circumstances of some ‘basin’ sites, such as Muckle Samuel’s Moss. Moreover, although this unit has clear affinities with WETMEC 19 of more lowland peatland locations, it is quite distinctive from that found in any of the lowland mires examined in the original Wetland Framework study, and it seems very likely – though it has not yet been demonstrated – that if the relevant samples were examined together with those from the lowlands, they would form a separate and distinctive cluster, but one that is not exclusive to Hill Bog slopes.

5.10 Synthesis of categorisation

Table 18. Main categories of peatland in relation to the principal reasons for the wetness of their sites or surfaces.

Reason for wetness	Telluric and meteoric water supply **(Minerotrophic) FEN**	± exclusively meteoric water supply **(Ombrogenous) BOG**
Wetness due considerably to topographical impedance of drainage	**Topogenous Fen** Lakesides, basins, floodplains *etc*	**Topogenous Bog** Accumulations of ombrogenous peats in basins *etc*, often autonomously mounded and frequently developed from Topogenous Fen
Wetness due mainly to high and consistent rates of water supply (often sloping)	**Soligenous Fen** Seepages, minerotrophic flushes and flow tracks *etc.*	**Hill Bog** Ombrogenous peat surfaces and flow tracks on hillsides *etc.*

5.10.1 Broad categories of peatlands

Peatlands in England and Wales, both in the uplands and lowlands, develop primarily in locations that are (or once were) persistently wet. The causes of their wetness are normally either because of detention (impeded drainage) of water in their location or a consequence of high and consistent rates of water supply, or both. The water that helps to provide these conditions at the surface may be more-or-less exclusively meteoric (precipitation) or meteoric mixed in varying proportions with telluric water (of variable hydrochemical character). This simple categorisation of peatlands can be related to some terms widely used by telmatologists, *viz. topogenous* (‘topography made’), *ombrogenous* (‘rain made’) and *soligenous* (‘soil made’). These terms are not always used with exactly the same compass by different workers (especially in the case of *soligenous*), but a simple rationalisation of their meaning and use is suggested in Table 18.

The categories of topogenous and soligenous fen can to some extent intergrade with regard to their water supply and retention characteristics, both in concept and in the field, as do also those of topogenous bog and hill bog. There is generally considered to be a sharp conceptual distinction, between ombrogenous peats and those peats that are irrigated with telluric water as well as by rainfall, but this demarcation can be difficult to detect in some field circumstances.

The work presented here relates to a pilot survey, made necessarily quickly during the winter of 2022–23, to examine the categories and characteristics of some upland peatlands in England and Wales, using protocols similar to those of Wheeler *et al.* (2009) for the categorisation of lowland wetlands. It was restricted to an examination of various 'upland' sites along the length of the Pennines and to three sites in Wales. The sites examined were at various altitudes (Table 3) but, with the exception of Stone Park (which was chosen as a little-known lowland comparator), all were considered to possess some 'hill peat'.

In all the areas examined ombrogenous mires were the dominant peatland type, with minerotrophic surfaces occupying generally small and often peripheral locations. Attention was focussed upon the ombrogenous surfaces, which included both examples of topogenous bog and hill bog. The minerotrophic areas examined were all soligenous.

5.10.2 Categorisation of ombrogenous peatlands

The primary sub-division of the ombrogenous areas examined was found to be between those in which the peat surface topography was autonomous – *i.e.* largely independent of the sub-peat topography – and those where the surface topography largely followed that of the underlying mineral ground. These latter were often, but not always, on slopes whilst the former generally occupied 'flat' surfaces or, more usually, hollows, which were water-collecting, primarily through topographically-impeded drainage (at least in the early stages of the development of the mire). This split corresponds broadly with the pre-existing subdivision of peatlands into 'hill peats' and 'basin peats'. As in both cases 'peat' can potentially refer to minerotrophic peat as well as ombrogenous peat, and as the term 'basin' can have various connotations, both specific and general, the terminology outlined in Table 18 has been used, *viz.* the ombrogenous mires examined can be divided into topogenous bogs and hill bogs.

5.10.3 Topogenous bogs

The principal sub-division of topogenous bogs was into those which had some form of surface doming ('ombrogenous mounds') and radial flow (insofar as this was compatible with the nature and extent of the dome), and those which were trough-like, had little if any cross-trough doming and had dominantly axial water flow ('ombrogenous troughs').

5.10.3.1 Ombrogenous mounds

'Ombrogenous mounds' had a range of topographical configurations, including ± complete concentric domes, eccentric domes, tilted domes, partial domes and bulges (Figure 22), but the character of their mire surfaces was generally similar and each presented essentially the same range of surface conditions and 'habitats' except in those instances where they had been much modified by drainage, afforestation, burning and, in a few instances probably, by industrial pollution. In the less-damaged examples, the vegetation of their crowns was most typically M18, grading into M19 or similar on the steeper flanking slopes.

Ombrogenous mounds have most often developed upon minerotrophic peat formed during an earlier phase of topogenous fen, but some examples have developed more-or-less directly upon mineral ground. In some instances, a preceding topogenous fen phase had developed by the terrestrialisation of open water but, despite frequent assertions otherwise, this was by no means always the case. [The term 'topogenous accumulation' has been used to refer to situations in which open water was not involved or where the accumulation occurred long after the 'terrestrialisation' process had completed.]

The ombrogenous peat deposits of the mounds are often quite deep (sometimes in excess of 5 m, reaching 10m in a few cases) and are stratified to various degrees. Above any fen peat, there is a widespread subdivision of the ombrogenous peat into two distinct layers, with a lower, humified and often rather sticky peat, rich in remains of *Eriophorum vaginatum* and *Calluna vulgaris*, and an upper, fresher peat with more, sometimes much more, *Sphagnum.* This subdivision appears to be widespread in Topogenous Bogs, both in the uplands and lowlands. The upper peat is also often layered, but the consistency of these layers across different sites generally remains to be established.

The variable topographical configuration of the ombrogenous mounds was strongly related to the nature of the landscape 'containers' in which they were situated (Figure 22). Within these, the specific configuration of the peat can be interpreted in large measure in terms of variable constraints on drainage, in particular distance from the main drainage outflow(s); those locations that were least well drained, usually those furthest from the outflow(s), tended to have the deepest ombrogenous peat (Figure 24). Natural drainage of the peat mounds appears normally to be radial, within the limits imposed by their configurations. It is possible that the various configurations observed could be categorised into a formal typology based upon recurrent features, but this exercise would benefit from more examples than are available at present and has not been attempted.

The interface between ombrogenous mounds and their surrounding (sometimes peat-covered) mineral ground is variable. In some discrete basins the ombrogenous mound is surrounded by a moat-like 'lagg', more-or-less continuous but usually with an outflow, and it can be said to be 'confined' topographically, but many examples are 'confined' along some margins and 'unconfined' along others. This condition is perhaps particularly evident around deposits in asymmetric basins, but it occurs widely elsewhere, including deposits on 'flat' surfaces, such as floodplains or lake deposits (Figure 24). In a few instances, deposits can be topographically unconfined around their entire perimeter and do not possess a 'lagg' in a specific, meaningful sense of the term.

5.10.3.2 Ombrogenous Troughs

Only a few examples of 'ombrogenous troughs' were encountered. The term refers to the configuration of the peat deposit (Figure 23), not to that of the landscape in which it is situated. Whilst all of the ombrogenous troughs recognised were in trough-like landscape situations (mostly valleyheads), ombrogenous mounds can sometimes also occur in such contexts.

Apart from their typically elongated character, ombrogenous troughs differ from mounds in that their water flow and drainage is primarily axial. In a trough open at one end, deepest ombrogenous peat often accumulates at the closed end and thins down-trough. There is little evidence of cross-trough doming and a 'flat', slightly sloping or even concave cross-trough profile can be found. In some circumstances, in a trough open at both ends, the deepest ombrogenous peat has accumulated at a point more-or-less equidistant from both, and can form an autonomous deposit similar to a ombrogenous mound within the trough, but differing in that there is little cross-trough doming at the Crown of the deposit. The Crown effectively forms an autonomous water shed from which drainage occurs to both ends of the trough. Some ombrogenous deposits located over cols can be similar to these, but in these any along-trough doming of the peat 'saddle' may conform broadly with the shape of the underlying mineral 'horse'. The distinction between such deposits and similarly-conformed units within Hill Bogs remains to be clarified.

The ombrogenous troughs examined appear to have formed in part, but no means in entirety, over former lakes and can have deep accumulations, in some places well over 5 m of sometimes rather unconsolidated, apparently-ombrogenous peat. The surfaces of some undrained examples can be especially wet and treacherous and typically support M18 vegetation, often with bog pools and hollows with M2 vegetation.

The topographical context of ombrogenous troughs, coupled with a lack of significant cross-trough doming suggests that they may be particularly susceptible to influxes of telluric water from the margins, and some examples occupy topographical troughs within which the ombrogenous troughs are in close juxtaposition with minerotrophic flow-tracks and similar. However, others appear – on the basis of floristic and hydrochemical evidence – to be ombrotrophic across most of their width, with minerotrophic conditions seemingly confined to lagg-like features running along the length of the trough margins. These systems raise rather acutely the great difficulty, if not impossibility, of distinguishing between ombrotrophic and weakly minerotrophic conditions without detailed hydrometric or hydrochemical investigations (Proctor, 1992; Proctor *et al.*, 2009). However, it appears that only a slight elevation of the peat and vegetation surface, such as may be provided by the coalescence of vegetation tussocks or hummocks, may be sufficient to isolate the surface from minerotrophic influences. Nonetheless, Ombrogenous Troughs seem likely to be particularly sensitive to changes in water supply conditions with regard to their ombrotrophic status.

5.10.4 Hill Bogs

Hill Bog is much more widespread in upland landscapes than Topogenous Bog and relates particularly to what is often widely regarded as 'blanket bog'. Its peat surface typically conforms to the sub-peat topography and, whilst most characteristically a feature of hill slopes, it also occurs across hill crests and occupies some plateaux and cols *etc.*

On average, the peat of Hill Bogs is the thinnest of all the ombrogenous peats examined in the uplands, but there is considerable overlap with the thickness range of ombrogenous peat found in ombrogenous mounds. There is a general, but not exact, inverse relationship between peat depth and slope within the unit. It has the smallest amount of *Sphagnum* in the vegetation, and *Sphagnum* also tends to be absent from the steepest slopes. It also has the lowest mean estimates of 'winter wetness' and 'quagginess'. The most frequent vegetation type recorded at the sample points was M19 (52%), followed by M20 (20%) and M25 (12%). A few samples, mainly on the steeper slopes (but not always on the shallowest peats) supported H9, H12, and U6.

Hill Bog peat often appears to be dark and strongly humified, but it can show strong layering and variation in character and composition. Overall, in general terms and in the deeper examples at least, Hill Bog peat can have a gross stratigraphy broadly similar to that of some Topogenous Bog peat. There can often be a basal minerotrophic peat of varying thickness and character, sometimes with quite thick layers of monocot-, *Phragmites*- and/or wood-rich peat, presumably formed in what were originally 'soligenous' conditions or similar. This layer may be absent, or at least reduced to a very thin deposit, in thin or strongly sloping examples, and ombrogenous hill peat can develop more-or-less directly upon mineral ground. Above this is usually a well-humified peat with much *Eriophorum vaginatum* and *Calluna* and in which any *Sphagnum* can often only be found microscopically. In some sloping situations with thin peat, this may be the main, perhaps the only, layer represented. On deeper peats at least, this humified peat layer is typically topped by a fresher peat, often rich in macroscopic remains of *Sphagnum*, still usually with some *Eriophorum* and often banded with more *Eriophorum*-rich layers. Very similar profiles can be found in some Topogenous Bogs. Hill Bog peat is not normally associated with the terrestrialisation of open water, but nor are some examples of Topogenous Bog.

Hill Bog peat is irrigated by direct precipitation, with down-slope overland flow and near-surface seepage of often endotelmic water. Water flow tends to become focussed into often ephemeral soakways and water tracks, and thence small streams. Erosional gullies can develop, and in some locations there can be considerable, if unpredictable, pipe flow. Both of these features can also occur in the peat of Topogenous Bogs, particularly towards their margins, but generally, it is thought, to a lesser degree. Overall, hill-slope peats can be conceptualised as very extensive, unconfined ombrogenous flushes.

The nature of Hill Bog peat across the summits of the hills, or in potential water-collecting locations such as cols, has not been well characterised in this investigation, partly due to constraints of time and access, partly because some of the seemingly appropriate areas examined were heavily eroded. The differential sensitivity locally of Hill Bog surfaces to erosion is itself a feature which would merit more examination and there is a need to extend field sampling into less damaged examples.

5.10.5 Some wider considerations

The categories of Topogenous Bog and Hill Bog undoubtedly intergrade to some degree, both in concept and in the field. But they do show differences, with regard to vegetation composition, surface configuration, sub-surface topography and, in some measure, stratigraphy and, probably also, hydrodynamics.

The hydrodynamics of the ombrogenous types has not been considered here, due to a lack of available hydrometric data of widescale applicability and because the field surveys were made in winter. Nonetheless, field experience indicates that areas of Topogenous Bog are generally 'wetter' than Hill Bog. This assessment is evident practically in the Border Mires, where 'Hill Bog' corresponds broadly to those surfaces which have been drained quite easily and afforested, and Topogenous Bog to those which have proved more difficult to drain and which have 'survived' the worst excesses of afforestation (though not necessarily without damage) (Lunn, 2004).

In some situations, Topogenous Bog units are embedded within Hill Bog and may seem on casual inspection to join seamlessly with this. However, differences in surface configuration – moundings and bulgings – are often evident to careful visual inspection or by examination of Lidar contours, and peat depth probing may also be revelatory. Moreover, except in situations where the vegetation has been much modified, for example by burning or draining, they can often be distinguished readily by vegetational differences.

The *Nature Conservation Review* (Ratcliffe, 1977) generally treated 'blanket mires' as a blanket category, and did not formally recognise different types within them, though it did give some tacit recognition of this. For example, in Wales, Cors Goch (Ciloerwynt) was described (despite partly being "strongly eroded"), as "the best example of actively growing blanket mire yet seen in Wales". In this instance, and probably others, "active" blanket mire appears to be a feature of a Topogenous Bog unit and stands in contrast to the more general "degraded" surfaces of Hill Bog. The ecohydrological distinctions between the two types may be important when it comes to assessing, or setting restoration targets for, areas of "degraded" Hill Bog.

In similar vein, in the Border Mires, Butterburn Flow was described as "the most important *Sphagnum*-rich blanket mire outside Scotland" (Ratcliffe, 1977), but the analyses here grouped it with samples of Topogenous Bog not with Hill Bog. Ratcliffe also commented that "The Flow contains one of the most extensive undamaged Sphagneta in Britain, of a type once widespread in the Scottish Borders and the Pennines, but now rare and still diminishing", but neither supporting evidence nor citations were provided to substantiate this.

There can be no doubt that the character of Hill Bog in the Pennines has been much modified, by burning, grazing, drainage and by atmospheric pollution, over at least the last 300 years and in some cases probably for very much longer, and not only in the badly-damaged southern Pennines. This is evident in the stratigraphy of the peats and also in the observations of workers such as Pearsall (1938, 1941) and, before him, Lewis (1904). In the Stainmore area, Lewis mapped a broad swathe of '*Sphagnum* Bog' on the upper slopes of the headwaters of the Balder and its tributaries. These areas would probably constitute Hill Bog as categorised here. Unfortunately, he provided little indication of the species composition of these *Sphagnum* stands. Pearsall re-examined the area, considered that there had been a diminution of the area of *Sphagnum*, in favour of *Eriophorum vaginatum* and *Calluna,* and provided some species data sufficient to suggest that some, though not all, of the then [pre-war] remaining *Sphagnum* surfaces may have been referable to what is now known as M18 (Rodwell, 1991), but he did not indicate the exact location or topographical situation of these 'M18 areas'. A rapid examination of part of the *Sphagnum* area, in the vicinity of Shacklesborough Moss (thought have been one of Pearsall's 'better' locations) during January 2023 indicated that the mire, partly gripped and managed for grouse, supported a vegetation with some Sphagna (including some *Sphagnum papillosum*) and *Erica tetralix*, but which seemed to be referable to M19 rather than M18. It would be of considerable interest to examine that area more thoroughly, both with regard to the current character of its bog vegetation and the relation of this to the sub-peat topographies.

The data collected here indicate that, in the sites examined and at the present time, M18 is preferentially associated with areas of Topogenous Bog and is not well represented on Hill Bog. A salient question is whether such areas of Topogenous Bog form the remaining refuges of a vegetation that was once much more widespread in upland peatlands than it is now – because of their particular ecohydrological characteristics and because they were less-easily drained – or whether they were always distinctive units floristically. As noted above, there is a particular need to examine some of the characteristics of intact higher altitude examples of Hill Bogs, particularly in potential water-collecting areas, such as cols and plateaux, to establish better their relationships with Topogenous Bogs.

6 COMMUNITY ACCOUNTS

A list of the vegetation types known to be associated with blanket bog landscapes was provided in the Scoping Study report (Wheeler, *et al.*, 2020), with a brief description of their floristics and habitat conditions, largely based on NVC plant community descriptions (Rodwell 1991). Those vegetation types that were encountered in the present survey are listed in Table 19, and more detailed descriptions are provided below, focussing on the types that were encountered most frequently. This should be extended in scope as part of future phases to encompass other vegetation types commonly found in bogs in regions not covered by this pilot project.

Communities encountered at very low frequency comprised H9 dry heath, M3 bog pool, M14 mire, M22–M26 fen meadow, M23 rush pasture, S3 swamp, S27a tall-herb fen, and U6 acidic grassland. These are not discussed further here.

Table 19. NVC plant communities, sub-communities and sub-types sampled in the present survey.

Rows highlighted in grey show plant communities encountered at very low frequency in the surveyed areas; these are not discussed further in this report. Total number of samples = 235

NVC plant community / sub-community / sub-type	Summary description	Samples
H9 *Heather (Calluna vulgaris) – Wavy hair grass (Deschampsia flexuosa)* community	Species-poor dry heath on shallow peat on gully sides, dominated by heather, with scattered crowberry and cowberry, some *Hypnum jutlandicum*.	1
H12 *Heather (Calluna vulgaris) – bilberry (Vaccinium myrtillus)* heath	Dry heath vegetation typically on dry, well-drained, firm peat on flat to moderate slopes, often actively drained either as a result of the proximity of deep erosion gullies or by former afforestation (ridge and furrow).	9
M2 *Sphagnum cuspidatum / fallax* community	Pools dominated by *Sphagnum cuspidatum* with some *Sphagnum fallax*, sometimes with white-beaked sedge and sundew, often some cotton grasses, sometimes with scattered bog asphodel, heather, cross-leaved heath, and deergrass. May also mark out very wet flow paths that link pools and wet hollows. One of these two samples was in a dammed and flooded forestry ditch.	2
M3 *Eriophorum angustifolium* community	One location dominated by common cottongrass, with some scattered *Sphagnum fallax* and *Molinia*.	1
M4 Bottle sedge (*Carex rostrata) – Sphagnum fallax* community	Usually small patches dominated by bottle sedge mixed with *Sphagnum fallax*, sometimes *Polytrichum commune* or *Sphagnum denticulatum* or *Sphagnum cuspidatum*, can be mixed with other species such as common cottongrass, lesser spearwort, soft rush, purple moor-grass. May be on quaking raft or in lagg zones. Some examples may be irrigated by base-poor springs.	8
M6 Star sedge (*Carex echinata)–Sphagnum fallax / denticulatum* mire		
M6a *Carex echinata* sub-community M6b Common sedge *(Carex nigra)* – mat grass *(Nardus stricta)* sub-community	These are generally sedge- and bryophyte dominated with affinity to both M6a and M6b, typically with much star sedge, common cottongrass, Sphagnum subnitens, and rushes at low cover, also scattered tormentil, heather, *Molinia*, short sedges and marsh thistle.	3
M6c Sharp flowered rush / soft rush *(Juncus acutiflorus / effusus)* sub-communities	Usually very species-poor and dominated solely by soft rush, *Sphagnum fallax*, *Sphagnum palustre*, and *Polytrichum commune*, but may also support scattered plants of *Molinia*, hare's tail cottongrass, marsh bedstraw, tormentil, bent grass, tufted hair grass, and a few other associates.	23
M6d Sharp flowered rush / soft rush *(Juncus acutiflorus / effusus)* sub-communities	Typically also species-poor though can be richer than M6c, usually dominated by sharp flowered rush, sometimes also with soft rush, with much *Sphagnum fallax* and *Sphagnum palustre*, sometimes also a range of other associates at low cover.	4
M14	Soakway vegetation	1
M18 Cross-leaved heath (*Erica tetralix)–Sphagnum papillosum* community		
M18a *Sphagnum magellanicum*–bog rosemary *(Andromeda polifolia)* sub-community	Wet *Sphagnum*-dominated bog, with a range of dwarf shrubs including heather, cross-leaved heath, cranberry, bog rosemary, crowberry, also cotton grasses, sometimes deer-grass, and sundews and bushy lichen species. Can also support frequent to locally abundant *Molinia*.	39

NVC plant community / sub-community / sub-type	Summary description	Samples
M18-n sub-type	As M18a but very wet, often with abundant hare's-tail cottongrass and locally abundant bog asphodel, and also sometimes deer-grass. May have obvious flow-paths.	6
M19 heather (*Calluna vulgaris*)–cottongrass *(Eriophorum vaginatum)* community		
M19a Cross-leaved heath (*Erica tetralix)* sub-community	Supports a mixture of dwarf shrubs and cotton grasses with frequent *Sphagnum* mosses and pleurocarpous mosses, may include some cross-leaved heath, bog rosemary and cranberry. Similar in many ways to M18a but less diverse and typically less wet, not dominated by *Sphagnum* species.	59
M19b Crowberry (*Empetrum nigrum)* sub-community	Supports a mixture of dwarf shrubs and cotton grasses with abundant pleurocarpous mosses and occasional *Sphagnum*, especially species tolerant of drying out *e.g. S. capillifolium*. Generally quite species-poor.	13
M19-p species-poor sub-type	Very species-poor heather- and hare's-tail cottongrass dominated bog. Often burned. Typically wetter than M19-h but likely to be surface-dry in summer.	7
M19-m Molinia-rich sub-type	Heather, hare's-tail and common cottongrasses, some *Sphagnum* species (*S. fallax, S. subnitens*, potentially some *S. papillosum*), but distinctively includes frequent to abundant *Molinia*. Can be species-poor or moderately diverse.	8
M19-h heather-dominated sub-type	Blanket bog dominated by heather with few other species (*e.g.* scattered tufts of cottongrasses and pleurocarpous mosses), usually a dry surface, damaged by repeated burning and drainage. Typically found adjoining gullies with dry peat. [Floristically indistinguishable from H9]	9
M20 hare's tail cottongrass (*Eriophorum vaginatum)* community	Generally dominated by hare's-tail cottongrass; very species-poor, but can include occasional *Sphagnum*, wavy hair-grass, pleurocarpous mosses, *Polytrichum commune,* and a few other scattered associates.	20
M20-m *Molinia*-rich sub-type	M20 but with frequent to abundant *Molinia*.	4
M21 bog asphodel (*Narthecium ossifragum)–Sphagnum papillosum* community	With abundant *Sphagnum papillosum*, and/or *Sphagnum fallax, S. subnitens*, also much bog asphodel mixed with a range of sedges, scattered dwarf shrubs, cotton grasses and *Molinia*.	4
fen meadow (M22-M26)	Species-rich fen meadow vegetation, mixed affinities.	1
Rush pasture (M23a)	Sharp-flowered rush fen / rush pasture, moderately diverse.	1
Rush pasture (M23b)	Soft rush-dominated fen / rush pasture, generally quite species-poor.	3
Purple moor grass (*Molinia*) dominated vegetation (M25 *Molinia caerulea–Potentilla erecta* mire)	A poorly defined vegetation type; in bog situations it is always strongly dominated by *Molinia* with only a few associate species.	14
S27a	Swampy vegetation.	1
S3	Dominated by greater tussock sedge with few other species; associated with spring outflow.	1
U6	Species-poor damp acidic grassland on thin peat or peaty soils, usually with abundant heath rush.	1

Some plant communities which are important components of blanket bog landscapes in the UK were encountered at very low frequency or were not encountered during the present survey (including M1, M2, M3, M6, M15, M17, and M21); this may be because they have a geographical distribution which was not captured by the present survey. Many of these plant communities also occur in lowland situations and the differences in vegetation along the lowland–upland continuum have not been fully studied. Future surveys and data collection should aim to capture representative datasets from all regions.

6.1 M2 *Sphagnum cuspidatum / fallax* bog-pool community

6.1.1 Vegetation features

In this vegetation type, *Sphagnum cuspidatum* and/or *S. fallax* form extensive carpets in hollows and pools, often associated with extensive bog vegetation (particularly NVC community M18), in hummock–hollow complexes. *Rhynchospora alba* (white beak sedge), *Andromeda polifolia* (bog rosemary) and *Drosera* spp. (sundews) are frequent in some examples. Occurs as a component of mire complexes (M18 but also found in extensive examples of M21) in various UK locations (Rodwell 1991, Averis *et al.* 2004).

Only two samples were recorded during the present survey, one of which was in a dammed and flooded forestry ditch.

6.1.2 Ecohydrological conditions

- Winter water level above ground (usually >10cm).
- Peat depth: very deep.
- Acrotelm comprises highly permeable, fresh moss peat.
- Moderate hummock–pool diversity, no tussocks.
- Little or no erosion, but gullies may be present nearby (<30m).

6.1.3 Summary description and water supply mechanisms

Associated with flat ground or very gentle slopes that support very wet hollows and pools where water collects. Also can mark out very wet flow paths that link pools and wet hollows. In the present survey this community was associated with WETMEC O4 Ombrogenous Percolation Troughs.

6.2 M4 Bottle sedge (Carex rostrata)–Sphagnum fallax mire

6.2.1 Vegetation features

In upland situations, this vegetation type usually occurs as small patches of very wet mire habitat dominated by bottle sedge (*Carex rostrata*) mixed with abundant *Sphagnum*, typically *S. fallax* (sometimes with *Polytrichum commune*, *Sphagnum denticulatum* or *Sphagnum cuspidatum*). Other species such as common cottongrass, lesser spearwort, soft rush and purple moor-grass are sometimes present.

May occur as a quaking raft or in lagg zones. Some examples may be irrigated by base-poor springs and in some places these may grade into M6 vegetation.

6.2.2 Ecohydrological conditions

- Situated in troughs, typically 'lagg' zones.
- Winter water level near or above ground (–5 to +10cm).
- Peat depth moderate to fairly deep.
- Acrotelm comprises highly permeable, loose fresh moss & herbaceous peat.
- Surfaces are mostly very gently sloping.
- Often irrigated by marginal inflows from surface runoff or groundwater outflow from the adjacent slopes.
- No erosion, gullies or drains mostly 30–100m away.

6.2.3 Summary description and water supply mechanisms

Many examples of this type of vegetation associated with blanket mire landscapes occur in lagg zones or large axial troughs. They may be influenced both by direct runoff from adjacent mineral slopes or peat slopes (WETMEC 19 Flow Tracks), by axial flow along broad flooded valley troughs (WETMEC O4 Ombrogenous Percolation Troughs), and some may be irrigated directly by base-poor springs upwelling at the edge of the bog (WETMEC 10 Permanent Seepage Slopes).

6.3 M6 Star sedge (Carex echinata)–Sphagnum fallax / denticulatum mire

6.3.1 Vegetation features

Examples of vegetation categorised as M6 are generally sedge- and bryophyte-dominated habitats with affinity to both M6a and M6b, typically with much *Carex echinata, Eriophorum angustifolium, Sphagnum subnitens*, and rushes such as *Juncus acutiflorus*, *Juncus effusus*, or *Juncus bulbosus* at low cover, also scattered *Potentilla erecta, Calluna, Molinia, Carex demissa, Carex panicea*, and *Cirsium palustre.* Generally these are spring-fed areas adjacent to the main areas of bog habitat. They are widespread in the uplands but not as frequent (or as frequently recorded) as the rush-dominated types M6c and M6d.

M6c and M6d: Sharp flowered rush / soft rush *(Juncus acutiflorus / effusus)* sub-communities are usually very species-poor and dominated by rushes.

M6c is dominated by *Juncus effusus, Sphagnum fallax, Sphagnum palustre*, and *Polytrichum commune*, but may also support scattered plants of *Molinia, Eriophorum vaginatum, Galium palustre, Potentilla erecta, Agrostis canina*, and *Deschampsia cespitosa*, and a few other associates.

M6d is usually dominated by *Juncus acutiflorus*, sometimes also with *Juncus effusus* and / or *Juncus conglomeratus*, with much *Sphagnum fallax* and *Sphagnum palustre*, sometimes also *Carex panicea, Agrostis canina, Molinia, Galium saxatile, Cirsium palustre*, and *Aulacomnium palustre*, and a range of other associates at low cover.

6.3.2 Ecohydrological conditions

- Mostly present in trough situations.
- Winter water level mostly near surface.
- Peat depth moderate to fairly deep.
- Acrotelm layer mostly comprises firm moderately decomposed herbaceous and moss peat.
- Slope is generally very gentle.
- Mainly irrigated by surface water flow, either along water flow tracks or from adjacent slopes.
- Can be associated with erosion and some examples may be situated within drains or gullies.

6.3.3 Summary description and water supply mechanisms

Many examples of this type of vegetation associated with blanket mire landscapes occur in lagg zones or large axial troughs. They may be influenced both by direct runoff from adjacent mineral slopes or peat slopes (WETMEC 19 Flow Tracks), by axial flow along broad flooded valley troughs (WETMEC O4 Ombrogenous Percolation Troughs), and some may be irrigated directly by base-poor springs upwelling at the edge of the bog (WETMEC 10 Permanent Seepage Slopes).

6.4 M18 Cross-leaved heath (Erica tetralix)–Sphagnum papillosum mire

6.4.1 Vegetation features

Two NVC sub-communities **of M18 *Erica tetralix–Sphagnum papillosum* mire** were sampled in the present survey, M18a and M18-n; the latter is a locally distinctive vegetation type found in the Border Mires (O'Reilly, 2020).

M18a is a type of wet *Sphagnum*-dominated bog vegetation. The *Sphagnum* layer typically includes a range of species (*S. papillosum, S. magellanicum, S. cuspidatum, S. fallax, S. tenellum*, sometimes with rare species such as *S. austinii, S. balticum, S. fuscum, S. pulchrum*), with a range of dwarf shrubs forming an open canopy, including heather, cross-leaved heath, cranberry, bog rosemary, and crowberry; also cotton grasses, sometimes deer-grass, and sundews and bushy lichen species. *Molinia caerulea* is frequent and locally abundant in some examples.

M18-n is similar to M18a but often very wet with abundant *Eriophorum vaginatum* [examples during the present study were localised in the Border Mires, only being recorded at Butterburn Flow, The Wou, and Hummel Knowe].

Hummock–pool diversity was the greatest of all plant communities sampled in the present survey, whilst tussock diversity was generally low (though highest in trough samples, and one sloping sample at Hummel Knowe with abundant tussocky *Molinia*).

6.4.2 Ecohydrological conditions

- Mainly associated with water-shedding crowns, gentle slopes, and trough situations.
- Winter wetness was mostly near surface or slightly sub-surface.
- Mostly deep or very deep peat, occasionally relatively shallow (0.5 to 1.5m).
- Acrotelm permeability was mainly fresh moss peat or firm moderately decomposed moss peat.
- Slopes are generally more-or-less flat or very gently sloping.
- Usually quite remote from adjacent mineral slopes.
- Stands in troughs generally have possible or probable flow within the stand, with little or no flow on crowns, and possibly slight flow on sloping stands.
- Erosion features are generally absent, though a few stands occur where past shallow erosion features have revegetated.
- Gullies and drains are generally absent or at least 30–100m distant.

6.4.3 Summary description and water supply mechanisms

M18 is generally associated with deep wet peat on very gentle slopes or flat surfaces, with poorly decomposed surface peat layers, and lacking significant marginal water influence, though some (typically trough sites) may experience within stand surface flow, presumably mostly endotelmic. Usually little affected by surface erosion.

Can comprise either a carpet of *Sphagnum* species with hummocks, hollows, and lawns and stunted dwarf shrubs, or may be visually dominated by dwarf shrubs that form an open canopy above a diverse and near continuous carpet of Sphagnum, also with hummocks, lawns and hollows.

6.5 M19 heather (Calluna vulgaris)–cottongrass (Eriophorum vaginatum) mire

Four sub-types of NVC community **M19 heather–cottongrass mire** were sampled in the present survey:

- **M19a Cross-leaved heath (*Erica tetralix)* sub-community**
- **M19b Crowberry (*Empetrum nigrum*) sub-community**
- **M19-m *Molinia*-rich sub-type**
- **M19-p Species-poor sub-type.** Very species poor vegetation co-dominated by heather and cottongrass
- **M19-h Heather-dominated sub-type**

6.5.1 Vegetation features

Vegetation representing NVC sub-community M19a supports a mixture of dwarf shrubs and cotton grasses with frequent *Sphagnum* mosses and pleurocarpous mosses; the dwarf shrub layer is usually made up of an open canopy of moderate to tall heather accompanied by a range of other species, which may include *Erica tetralix, Andromeda polifolia* and *Vaccinium oxycoccos*. Similar in many ways to M18a but less diverse and typically less wet, with a rather more impoverished and patchy *Sphagnum* layer. Many examples exhibit moderate hummock–pool diversity with generally little tussock diversity, though a significant proportion of samples were associated with steeper slopes, low hummock–pool diversity and were slightly more tussocky. There is generally little or no erosion in these stands, though there are some examples of revegetated erosion surfaces.

M19b supports a mixture of dwarf shrubs and cotton grasses with abundant pleurocarpous mosses and only very occasional *Sphagnum*, generally species tolerant of drier conditions, *e.g. Sphagnum capillifolium*. Heather tends to be quite tall, often forming a dense canopy. The vegetation is generally quite species poor. Often with a slight degree of either hummock–pool diversity or tussock diversity. Often associated with signs of former erosion that has revegetated, with some small areas of bare peat.

M19-m is a variable type of vegetation made up of mixtures of tall heather, hare's-tail and common cottongrasses, sometimes with *Sphagnum*, which can be frequent to abundant (*S. fallax, S. subnitens*, potentially some *S. papillosum*), but distinctively always includes abundant *Molinia*. It can be species-poor or moderately diverse. Mostly with very low hummock–hollow diversity and moderate tussock diversity. Signs of erosion either absent or some revegetated shallow erosion.

M19-p represents species-poor bog vegetation co-dominated by heather and hare's-tail cottongrass. This type of vegetation is typically managed by rotational moorland burning and is common in the South Pennines. Typically wetter than M19-h heather dominated sub-type but likely to be surface dry in summer. Little or no *Sphagnum*, tall or very tall heather forming a dense canopy. Some signs of erosion typically present.

M19-h is an extremely species-poor variant that is completely dominated by tall heather, on a dry peat surface strongly influenced by drainage and burning, and floristically indistinguishable from H9 dry heath community. Again very common in the South Pennines.

6.5.2 Ecohydrological conditions

M19a sub-community

- Most examples are found on slopes, a few on crowns or troughs.
- Winter wetness is often sub-surface (*i.e.* drier than M18a).
- Peat is mostly fairly deep to deep.
- Acrotelm mainly comprises firm moderately decomposed peat, relatively few comprise fresh peat.
- Most examples are situated on very gentle or slight slopes, with a few on flat surfaces.
- Most examples are a moderate distance from the bog margins (30–100m), though closer than M18 stands and often peripheral to those.

- Generally little or no erosion, though some examples of revegetated erosion surfaces.
- The majority of stands are less than 100 m from drains or gullies, often closer than 30m.

M19b sub-community

- Most examples are on slight slopes.
- Winter wetness was generally rather dry to sub-surface and the surface peat layer tended towards well-decomposed firm peat.
- Peat is typically of moderate depth, with some exceptions.
- Often with a slight degree of either hummock–pool diversity or tussock diversity.
- Most examples were closer to the margins than either M18 or M19a stands.
- Often associated with signs of former erosion that has revegetated, with some small areas of bare peat.
- stands were generally less than 30m from a drain or gully, sometimes less than 10m away.

M19-m sub-type

- Surfaces either troughs or on gentle slopes.
- Winter wetness either near surface or sub-surface.
- Peat generally fairly deep.
- Acrotelm generally fresh or moderately decomposed peat.
- Mostly very low hummock–hollow diversity and moderate tussock diversity.
- Usually there is some probable within-stand flow.
- Signs of erosion either absent or revegetated shallow erosion.
- Gullies or ditches often very close.

M19-p sub-type

- Surfaces mostly slightly to moderately sloping.
- Winter wetness mostly rather dry to sub-surface; acrotelm either well-decomposed firm peat, or moderately decomposed.
- Peat depth moderate to fairly deep.
- Moderate tussock diversity or hummock–hollow diversity.
- Some signs of erosion typically present.
- Often less than 10m from a ditch or gully.

M19-h sub-type

- Very few samples recorded, those on quite steep slopes or close to the edge of deep gullies, with very dry surfaces.

6.5.3 Summary description and water supply mechanisms

M19 is ombrotrophic bog vegetation that often occurs on hill bog slopes (WETMEC O3 Hill Bog), but also on more gentle slopes on deep peat deposits (WETMEC O2 Deep Ombrogenous Slopes), and on some crowns that have been affected by drainage (WETMEC O1 Ombrogenous Crowns).

M19a vegetation is similar to M18 but is associated with slightly drier surface conditions, firmer and less deep peat than M18, on slightly more steeply sloping surfaces that may be closer to marginal mineral or peat slopes, with more likelihood of proximity to drains or gullies.

M19b is usually present on fairly dry, well-drained, slightly sloping surfaces with firm well decomposed surface peat, often quite close to bog margins.

M19-m Typically with abundant *Molinia* mixed with a range of other bog species. Occurs on gently sloping ground, with some evidence of gentle water flow through the surface peat layer.

M19-p Generally quite dry, firm peat with few obvious water inputs, often influenced by drainage. Species-poor vegetation.

M19-h Very dry firm peat on steep slopes or adjacent to deep gullies, very species-poor.

6.6 M20 hare's tail cottongrass (*Eriophorum vaginatum)* mire

6.6.1 *Vegetation features*

Generally dominated by hare's-tail cottongrass and very species-poor, but can include occasional *Sphagnum*, wavy hair-grass, pleurocarpous mosses, *Polytrichum commune*, and other scattered associates. *Sphagnum* is locally frequent to absent, heather absent or stunted. Shows some slight hummock–hollow and tussock diversity. Either no signs of erosion or revegetated former shallow erosion. Examples with frequent–abundant *Molinia* were assigned to the M20-m sub-type.

6.6.2 *Ecohydrological conditions*

M20 community

- Peat generally Moderate to Fairly deep.
- Mostly gently sloping but a few examples on flat ground or in troughs.
- Winter wetness generally sub-surface.
- Acrotelm peat comprises firm, moderately to well-decomposed peat.
- Rarely any sign of within-stand flow.
- Either no signs of erosion or revegetated former shallow erosion.
- Gullies or drains more than 30m away, often much more.

M20-m community

- Generally as M20 but examples were much closer to gullies, with abundant *Molinia*.

6.6.3 *Summary description and water supply mechanisms*

Ombrotrophic vegetation dominated by *Eriophorum vaginatum* on variable depth damp, firm peat, mostly gently sloping, few signs of water flow. M20 is typically associated with WETMEC O3 Hill Bogs and WETMEC O4 Ombrogenous Percolation Troughs. M20-m is associated with WETMEC O4.

6.7 M21 bog asphodel (Narthecium ossifragum)–Sphagnum papillosum mire

6.7.1 *Vegetation features*

Wet bog vegetation with abundant *Sphagnum papillosum*, and/or *Sphagnum fallax* and *S. subnitens*, also much *Narthecium* mixed with a range of sedges (*Carex rostrata, C panicea, C. echinata*). Scattered short or stunted *Calluna* and other dwarf shrubs including *Erica tetralix* and *Vaccinium oxycoccos*, and frequently some *Eriophorum angustifolium, E. vaginatum*, and *Molinia*. Low hummock–pool or tussock diversity.

6.7.2 *Ecohydrological conditions*

- Found on gentle slopes and in trough situations.
- Winter wetness near or above surface.
- Fairly deep to deep peat, with an acrotelm of fresh moss peat.
- Little erosion, and drains or gullies typically quite distant.

6.7.3 *Summary description and water supply mechanisms*

Generally quite species-rich, wet sites with soft and transmissive peat, influenced by axial water flow from outside the stand. WETMEC O4 Ombrogenous Percolation Trough.

6.8 ‘*Molinia* sociation’

This very species-poor vegetation dominated by *Molinia* is often classified as NVC plant community M25 *Molinia caerulea–Potentilla erecta* mire. It occurs in blanket mire landscapes in various situations.

6.8.1 Vegetation features

A poorly defined vegetation type; in bog situations it is always strongly dominated by *Molinia* with only a few associate species. Where *Molinia* is a distinctive part of other vegetation types, this has been indicated by allocating a *Molinia* sub-type.

6.8.2 Ecohydrological conditions

Variable, because this type of vegetation can be derived through the degradation and homogenisation of several different plant communities.

6.8.3 Summary description and water supply mechanisms

Not applicable.

6.9 H12 Heather (Calluna vulgaris)–bilberry (Vaccinium myrtillus) heath

6.9.1 Vegetation features

Uniform expanses of heath usually dominated by tall heather with frequent bilberry, locally abundant crowberry, occasional wavy hair-grass, (sometimes with patches of hare's-tail or common cottongrass), and abundant pleurocarpous mosses. Bryophytes typically comprise *Hypnum jutlandicum* and *Pleurozium schreberi*, often also with some *Dicranum scoparium, Rhytidiadelphus loreus, Plagiothecium undulatum*, and, and Sphagnum is generally absent or very rare. Generally found on either shallow dry hill bog peat, or on deep peat of gully sides or gullied and hagged deep peat areas.

6.9.2 Ecohydrological conditions

- Associated with moderate slopes to flat surfaces.
- Winter wetness dry or rather dry, typically no water flow within stands.
- Peat depth moderate to very deep.
- Acrotelm comprises firm, moderately to well-decomposed peat.
- Associated with some eroded peatland edges on sloping stands, and generally 10m or less from drains or gullies.

6.9.3 Summary and water supply mechanisms

Typically on dry, well-drained, firm peat on flat to moderate slopes, often actively drained either as a result of the proximity of deep erosion gullies or by former afforestation (*i.e.* ridge and furrow).

7 DISCUSSION

7.1 Synopsis

One of the central aims of this pilot study has been to characterise the range of habitat and topographical conditions associated with the main vegetation types and peat surfaces found on blanket bogs and allied minerotrophic habitats. This has been done using data gathered during field investigations at a range of sites from several regions of the UK: central and northern Wales, the Southern Pennines, the Forest of Bowland, the Northern Pennines and the Roman Wall Country of Northumberland and Cumbria. These datasets have been used, in combination with selected data taken from published sources, to begin the development of a new typology of upland mire types by the identification of distinctive water supply mechanisms (WETMECs), as was done for lowland wetlands of England and Wales by Wheeler *et al.* (2009).

Field data were analysed using multivariate clustering and ordination procedures, and univariate correlations. The outputs from these were used alongside schematic sections for each site to develop a conceptual understanding of the various mires encountered. Insights from this process have enabled the recognition of relationships between the peat surface topography, sub-peat topography, and vegetation types; an informal characterisation of peatland surface configurations in relation to the topography of the landscapes in which they occur; and the development of a series of WETMECs using the same methodology as for the original Wetland Framework. Vegetation types as observed during this work have also been described in relation to the features with which they were associated.

In the original 'Wetland Framework' study, which was mostly of lowland minerotrophic wetlands, WETMECs were mainly conceptualisations of different water supply mechanisms. However, in upland ombrogenous contexts, because of the ubiquity of precipitation, they may be regarded more appropriately as conceptualisations of different water drainage mechanisms. In general, peat tends to accumulate most readily in poorly-drained locations; topography exerts a very strong influence upon drainage and drainage patterns, and thus helps to determine both the development and conformation of ombrogenous peat surfaces.

Ombrogenous surfaces appear to be broadly divisible into two groups: those that follow the topography of the underlying mineral ground and those that are independent of this, corresponding very roughly to a pre-existing subdivision of 'hill peats' *versus* 'basin peats', though the latter is a very variable and imprecise division.

Hill slopes or hill peat surfaces roughly follow the slope of the underlying terrain, and correspond to much of the ombrogenous peat deposit that covers huge expanses of upland Britain. In contrast, ombrogenous mounds have formed on more-or-less flat surfaces in both lowland and upland situations, whilst a few examples of ombrogenous mounds have developed on gentle slopes in broad, shallow valleyheads in upland locations. In other situations, ombrogenous surfaces have formed within basins or partial basins, the latter with a lip at a lower level on one side, and giving rise to either an asymmetric dome or a flat or gently sloping surface. In some locations ombrogenous mires have developed within troughs between low ridges or hills, sloping in either one or both directions, and usually supporting rather wet surface conditions. A particular feature of many of the Border Mires of the Roman Wall Country has been the accumulation of peat across ridges and hollows to varying depths, sometimes completely obscuring these, whilst in other situations the underlying mineral slopes or ridge may contribute to the shape of the mire surface.

Broadly speaking, the topographical character of peat deposits relates to the configuration of the catotelm (lower peat layer), whilst WETMECs relate primarily to surface conditions and to the acrotelm (surface peat layer). Five main Ombrogenous WETMECs have been recognised:

- WETMEC O1: Ombrogenous Crowns
- WETMEC O2: Deep Ombrogenous Slopes
- WETMEC O3: Hill Bogs
- WETMEC O4: Ombrogenous Percolation Troughs

- WETMEC O5: Ombrogenous Flow Tracks

WETMEC O1: Ombrogenous Crowns include the uppermost, water-shedding surfaces of autonomous peat deposits that have developed under the exclusive influence of precipitation. The depth of underlying peat is variable, but often deep (> 3 m) and the height of the Crown above the surrounding peat is also variable. The majority of samples support M18 vegetation and the surfaces are sometimes quite well patterned, though most often with a predominance of hummocks rather than pools. M18 often transitions downslope to M19 and then sometimes to M20 on the steeper slopes.

WETMEC O2: Deep Ombrogenous Slopes include ombrogenous surfaces over quite deep peat (mostly > 2.5 m), of variable slope, typically supporting M19 vegetation (though with some M18 and rarely M20), and occur in three main situations: a) peripheral to an Ombrogenous Crown, often on steeper slopes; b) as a rather nondescript independent unit, on gently sloping surfaces; c) on steps or other slackenings of slopes embedded within an area of hill peat. Three sub-types can be recognised: 1) Typical; 2) Slope Steps and Slackenings of Slope; 3) Steep Marginal Slopes.

WETMEC O3: Hill Bogs probably correspond well with informal conceptions of 'blanket bog', *i.e.* large tracts of fairly thin ombrogenous peat covering large parts of upland Britain, broadly following the topography of the underlying mineral ground, and often filling in small irregularities in this, such as small hollows and valleyheads. Hill Bog may surround and grade into other WETMECs of upland ombrogenous peat which effectively become units embedded within it. The most frequent vegetation types recorded were M19, followed by M20 and M25, with some H9, H12 and U6. Three sub-types have been recognised: 1) Typical; 2) Ombrogenous Crests, Hill Slope Steps and Slackenings; 3) Steep Thin-peat Slope.

In addition, two erosion features have been described: **Hill Bog Gullies** are a conspicuous erosional feature of many sites, incised into Hill Bogs of varying depths and slopes. In some locations they have cut down to the underlying mineral ground; in some they remain separated from this by a layer of intact peat; and in others they are floored by re-deposited peat of varying depth. **Summit and 'Flat Area' Gullies:** this form of gullying is associated with shallow slopes, and covers large areas of summit or near-summit situations such as in some shallow valleyheads and cols, and results in a highly variable 'hagged' surface of short, steep bare peat slopes, runnels, vegetation-covered hagg tops, and sometimes larger areas of sheet erosion and bare peat.

WETMEC O4: Ombrogenous Percolation Troughs are located in topographical troughs and valleyheads and appear mainly to have developed over former shallow lakes or some form of fen. Peat depth can reach 10 m and typically slopes down-trough, often partly following the configuration of the underlying mineral ground, and water flow is very largely down-trough. Across the trough the peat surface configuration may be more-or-less flat, slightly concave, or gently sloping to a lower margin. The main recorded vegetation types were M18, M19, and M20, with some M2 and M21.

WETMEC O5: Ombrogenous Flow Tracks occur at the bottoms of valleyheads and troughs, often on fairly deep peat, and on some hillslopes. It is an analogue of WETMEC 19 (Flow Tracks) of Wheeler *et al,* (2009) but differs in that water flow is thought not to have a significant minerotrophic component, which means that it is essentially endotelmic. Flow Tracks are a feature of some Ombrogenous Percolation Troughs, but they can also occur as surface features or subdivisors of other ombrogenous WETMECS. They may support vegetation such as M21 and *Molinia*-rich examples of M19 and M20.

Narrow soakways and water tracks are widespread around the margins of some of the peat deposits considered here, where they can form some sort of 'lagg'. However, these are generally minerotrophic, though sometimes only weakly so, and can be accommodated appropriately in existing lowland WETMECs (*e.g.* WETMEC 19: Flow Tracks).

It is important to recognise that the WETMECs identified above represent sub-divisions of a continuum of variation, and individual WETMECs are likely to intergrade. However, they serve as a useful initial attempt to distinguish between different upland ombrogenous mire types, which can be built upon in future work.

It should also be noted that there are some deficiencies in this pilot study: fieldwork was carried out during the winter, thus precluding the collection of summer hydrological, hydrochemical, and vegetation data. Also, dipwell water level data series were lacking because very few upland sites have such installations, and those that do were either not in appropriate locations, had only just been installed, or the data could not be obtained. In addition, many regions of the UK that support extensive ombrogenous peat deposits were not visited as part of this study.

Future studies of ombrogenous bogs and allied minerotrophic habitats in other parts of the UK, both upland and lowland, are likely to result in the modification of these WETMECs, and the identification of other WETMECs or sub-types, and also other surface conformation types. Furthermore, whilst upland blanket mires have been the focus of this project, there is likely to be much value obtained from broadening this work to include comparisons with lowland ombrogenous peatlands.

7.2 Data acquisition strategy

During this project there have been some barriers encountered with regard both to gaining access to sites for fieldwork, and obtaining permission to view existing datasets. For example, one organisation was initially reluctant to provide raw water level monitoring data because of sensitivities around landownership and relationships with the statutory agencies. Another organisation required consent from local Natural England teams at two separate sites before giving permission to undertake peat coring and this ultimately led to one of those being removed from the list of survey sites. The same organisation failed to give permission for the use of peat depth and vegetation data gathered by them at relevant blanket bog sites. Other issues have included the provision of survey reports that lack the actual data upon which they were based, meaning that they could not be used as part of this project.

Partly because of these problems, efforts have been made to develop relationships with potential data holders by the survey team and by members of the Technical Advisory Group, and this work should be continued. Obtaining access to data held by research groups and conservation organisations should be prioritised as part of any further phases of this project.

For a detailed summary of potential contacts and information gaps, refer to sections 3.3 and 3.4 of the Scoping Study report (Wheeler *et al.*, 2020).

It is considered that initial contact with potential data holders would be best carried out by staff from within the various country agencies, as they are generally more likely to be able to develop a level of trust with the data holders than would consultants (although this may not always be the case).

With this in mind, a strategy to facilitate data sharing between stakeholders should involve the following steps:

1) Identify potential data-sharing partners.
2) Determine which staff from the relevant agencies would be best placed to contact potential data-sharing partners.
3) Contact data-sharing partners to explain the project and discuss their attitudes and concerns toward sharing some of their data with the project.
4) Find out what types of data they collect and hold.
5) Determine which datasets are likely to remain of restricted access and which are likely to be published soon.
6) Ascertain which datasets would require payment for their collation and release, and which might be covered by existing funding agreements with the Agencies and other partners.
7) Determine the lead-in time that would be necessary to request and obtain data from them.
8) Consider offering some data from this project as a gesture of good will.
9) Develop a mechanism for funding the payments required for obtaining relevant datasets and the time required to make and manage these data requests.
10) Investigate opportunities for locating ‘old data’ that may have become lost in storage following office moves, staff changes, end of projects, etc., *e.g.* WALRAGs in the Border Mires.

As an adjunct to the above, it would be extremely useful to create a UK-wide GIS catalogue of peatland NVC vegetation surveys, peat depth surveys, locations of peat stratigraphic data, and hydrological monitoring points, so that the overlaps and gaps can be seen clearly.

Some of the highest priority datasets for acquisition are likely to be:

- James Hutton Institute Flow Country research projects
- University of the Highlands and Islands Flow Country research projects

- RSPB Flow Country research projects
- Natural Resources Wales' Lowland Peatland Survey reports from M18 blanket bog sites
- Natural Resources Wales SAC sites with vegetation and hydrology datasets
- Moors for the Future Partnership research projects
- Yorkshire Peat Partnership peatland survey datasets
- South West Water Ltd / Exeter University 'Mires on the Moors' research project

Organisations that generally might hold relevant data include:

- NatureScot
- Natural Resources Wales
- Natural England
- DAERA-Northern Ireland
- Environment Agency
- Scottish Environment Protection Agency
- Academic institutions (*e.g.* University of Leeds, University of Exeter, University of Manchester, University of Aberystwyth, University of the Highlands and Islands)
- North Pennine AONB Peat Partnership
- National Trust
- National Park authorities
- Water companies
- Power companies (*e.g.* windfarms on peatlands)
- The Wildlife Trusts
- Exeter University (Peatland mapping)

7.3 Future work

If funds become available later in 2023 for 'Phase 3' of the project, they could be used to:

- Refine the pilot fieldwork protocol to streamline data collection in the field and for future work by other fieldworkers.
- Initiate planning for fieldwork opportunities for summer 2024.
- Develop data sharing strategies.
- Carry out a brief literature review of recent relevant research [*e.g.*Prof. Andy Baird, Leeds University]
- Create a photographic resource of different peat types to assist with future surveys.

If funds are made available sufficiently early in 2024 for another phase of the project to be undertaken, this should aim to expand the dataset through a combination of fieldwork and acquiring external data, to include field investigations of regions not examined during this phase of the project, *e.g.*:

- Scotland: Flow Country, Hebrides, Central Highlands, Silver Flowe, Dumfries & Galloway, Scottish Borders
- Wales: North Wales, Central Wales, South Wales
- Northern Ireland
- North Yorkshire: North Pennines, North York Moors
- South-west England: Dartmoor, Exmoor, Bodmin Moor
- Northumberland: 'hill bog' examples from the Border Mires region.

Other suggested work to be undertaken during the next phase of the project should include:

- targeted field investigations to clarify or verify datasets gathered during this phase of the project (*i.e.* summer water levels, pH and electrical conductivity).
- Systematic hydrological modelling of selected bog sites using the DigiBog programme developed at the University of Leeds.

It will be important as part of any future work to investigate bog vegetation types not covered during the present study (*e.g.* M17, M21), including any regional variations, and also to explore the upland–

lowland continuum of ombrogenous bog types, in order to properly join-up the developing bog typologies and WETMECs.

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9 ELECTRONIC OUTPUTS

The following electronic outputs have been provided:

- This report in pdf and editable MS Word format ('BlBogGuidelines_FinRep_08Sept2023').
- Report without Annexes 2 and 3 in pdf and editable MS Word format ('BlBogGuidelines_FinRep_text_08Sept2023')
- Annexe 2 schematic drawings as pdf ('BlBogGuidelines_FinRep_Annx2_08Sept2023')
- Annexe 3 location maps as pdf ('BlBogGuidelines_FinRep_Annx3_08Sept2023')
- Annexe 4 site photos as zipfile ('BlBogGuidelines_FinRep_Annx4_03-07-2023')

10 GLOSSARY OF TERMS

These definitions relate to the usage of terms in this document and are not necessarily general definitions. Words underlined are defined elsewhere in the glossary.

Term	**Definition**
Acidic	here used for wetlands with water strongly dominated by H^+ (and usually SO_4) (pH < 4.5)
Acropetal	Development upwards from the base.
Acrotelm	the uppermost, 'active layer' of a peat deposit, most often used with regard to an undamaged raised bog, comprising the living plant cover passing downwards into recently-dead plant material and thence to fresh peat. It forms the largely oxygenated surface layer with high hydraulic conductivity, within which the water level fluctuates and the main water movement occurs (cf. catotelm).
Allogenic	Induced by external factors.
Autogenic	'self-made' [caused by reactions of organisms themselves]
Blanket mire landscape	where the land surface is covered ('blanketed') to a large extent by mire habitat, including a mixture of ombrotrophic bog and minerotrophic fen habitat. The term 'blanket bog landscape' is often used as a synonym. The Flow Country of Scotland is a classic example of a blanket mire landscape.
Catotelm	the lower, so-called 'inert' layer of a peatland. The catotelm underlies the acrotelm, and is permanently saturated, mainly anoxic and usually of lower hydraulic conductivity and storage capacity than the acrotelm
Centripetal	Movement from the periphery towards the centre.
Diplotelmic	literally 'two marshed' (*Gr.*), *i.e.* 'two layers of mire'. In raised bogs, this refers to the typical occurrence of an uppermost 'active layer' (the acrotelm) and a lower so-called 'inert layer' (the catotelm).
Endotelmic flow	flow of water sourced from within the wetland itself (rather than from external sources).
Eutrophic	nutrient-enriched (not necessarily also base-rich, but often so).
Evapotranspiration	loss of water from the soil by evaporation from the surface and by transpiration from the plants growing thereon; the volume of water lost in this way.
Fen	often used as a generic term for all minerotrophic mires (see rich fen and poor fen); can include mires on peat and normally-wet mineral deposits (tufa *etc*.). The everyday, and place-name, usage of 'fen' is nowadays particularly associated with East Anglia, but the Old English 'fenn', cognate with the Old Frisian 'fenne' and the Middle Dutch 'venne' seems to have had a much wider usage and compass, being the common word for marshy ground and including habitats that would now often be called 'bog' – a breadth of use which is preserved in the modern Dutch 'veen'.
Floristic	relating to the distribution, number, types and relationships of plant species in an area or areas. (www.dictionary.com)
Flow track	used as a generic term for distinct, linear zones of focussed surface or near-surface water flow within wetlands, and includes runnels, soakways and water tracks.

Term	**Definition**
Groundwater	used primarily to refer to water in, or sourced from, a bedrock or drift aquifer; although peat may form a local aquifer, in this report 'groundwater' is not normally used for the water within wetland substrata, to avoid possible confusion with regard to peat deposits which are groundwater-fed and those that are not.
Humification (von Post scale)	degree of decomposition (of peat) [production of humus from the decay of organic matter as a result of microbial action].
Hummocks	elevated mounds created by the growth of bryophytes, especially *Sphagnum* species.
Hydraulic conductivity [K; K_{sat}]	the rate at which water moves through a material. K_{sat} denotes saturated hydraulic conductivity – *i.e.* the rate at which water moves through a saturated material.
Hydraulic gradient	the change in hydraulic head or water surface elevation over a given distance.
hydraulic head	the difference in pressure-head between two hydraulically-connected points.
Hydrotopographical element	unit with distinctive water supply and, sometimes, distinctive topography in response to this. Many wetlands contain a number of such elements, and the same element may occur in wetlands belonging to different situation types.
Interfluve	the land area separating adjacent stream valleys (www.dictionary.com)
Lagg	a moat-like strip of fen around the margins of some raised bogs; normally used to refer to a distinctive (often wet) structure rather than just the minerotrophic fringe which normally occurs where any ombrogenous deposit contacts adjoining mineral ground or minerotrophic peat.
Lawn	noticeably even (level) surfaces on flat or sloping ground
Limnic	Relating to bodies of fresh water.
Lowland	an ill-defined term, in the UK often considered to correspond to land that is either below about 300 m in altitude, or below the boundary of enclosure.
Macrofossils	plant or animal remains preserved in peat which can be identified without the use of a high-powered microscope (*e.g.* stems, leaves and roots but not pollen grains).
Macrotope	mire macrotope; large-scale units, consisting of complexes in which peat bodies originating as different hydrological units have become either closely juxtaposed or merged together, *e.g.* the Silver Flowe in Galloway. *(from Bog SSSI Guidelines, based on Lindsay et al. 1988; Lindsay 1995)*
Mesotope	mire mesotope; in which a peat body can be identified as a single hydrological entity (though, in the case of blanket bog mesotopes, these may have hydrological links with other mesotopes), *e.g.* Cors Fochno (Borth Bog) in central Wales or Brishie Bog in the Silver Flowe. The lagg fen around a raised bog is a distinct mesotope, with its own hydrological requirements, so a complete raised bog system, with its lagg fen, should be classed as a macrotope. *(from Bog SSSI Guidelines, based on Lindsay et al. 1988; Lindsay in press)*
Meteoric water	precipitation

Term	**Definition**
Microform	mire microform; relating to single surface feature, such as pool or hummock. (See Lindsay et al. 1988, pp. 23–24) *(from Bog SSSI Guidelines, based on Lindsay et al. 1988; Lindsay 1995)*
Microtope	mire microtope; relating to the arrangement of surface features, especially into a pattern which alternates aquatic and terrestrial elements, *e.g.* pool and hummock, or terrestrial features alone, *e.g.* hollow and ridge (*Lindsay et al. 1988)*
Minerotrophic	fed by telluric water.
Minerotrophic mire	mire whose surface is irrigated both by precipitation and telluric water.
Mire	a general term for habitats with consistently high, but rarely above-surface, water tables; it is sometimes applied specifically to peat-producing ecosystems but here used more broadly as a synonym for 'permanent telmatic wetlands'
Moorland	'moorland' is a term often used in the UK to describe open habitat that is generally characterised by acidic, low nutrient, often waterlogged soils, supporting a mixture of acidic grassland, heathland (both dry and wet), and bog vegetation. Moors are generally upland, but some lowland areas are also called 'moors'.
Oligotrophic	low fertility, nutrient poor (not necessarily also base poor).
Ombrogenous	wetland developed under the exclusive influence of precipitation
Ombrotrophic	wetland surface that obtains nutrients and water directly and exclusively from the atmosphere (rain, snow, fog *etc*.).
Ombrotrophic bog	bog with surface irrigated more-or-less exclusively by precipitation inputs.
Ontogeny / ontogenesis	history of development.
Paludification (paludosere/paludology)	the development of wetland directly over formerly 'dry' ground through impeded drainage or an increase in water supply.
Pedogenic	Processes relating to soil formation.
Percolation	used to refer to diffuse water flow through a (usually topogenous) wetland deposit.
Permeability	the capacity of a porous medium for transmitting water.
Poor fen	minerotrophic mire, typically of pH less than c. 5.5.
Precipitation	deposition of water on the earth's surface by rain, snow, mist, frost, condensation *etc*.; the quantity of water so deposited.
Raised bog/raised moss	name given to a dome or domes of ombrogenous peat formed above the regional groundwater table, mainly in basins and floodplains; dome may be bordered by a rand and lagg
Rand	a 'rim, margin, or border', cognate with the Swedish and Danish 'rand' of similar meaning. Following Swedish telmatologists, 'rand' is used here specifically to refer to the rather dry, and often steeply-sloping. margin of a raised bog, which often directly adjoins a peripheral lagg
Rheo-topogenous*	Topogenous surfaces with significant lateral water movement (percolation)
Rich fen	minerotrophic mire, typically of pH more than c. 5.5.
Runnel	small lines of water flow on fairly steep slopes and often on a skeletal substratum.
Sedentary	Formed in place, without transportation, by the disintegration of the underlying rock, or by the accumulation of organic material.

Term	Definition
Sedimentary	Formed by the deposition of particles by the action of water, ice or wind.
Seepage	groundwater 'seepage' is considered to be groundwater outflow from a mineral aquifer to the surface of a wetland (cf. flush).
Situation type	the position the wetland occupies in the landscape, with especial emphasis on principal water supply. May include several different hydro-topographical elements.
Soakway	water flow tracks within wetlands which can be detected by the contrast in their vegetation and wetness relative to the flanking mire; distinguished from a water track by having little or no obvious surface water.
Solifluction	The gradual movement of wet soil or other material down a slope.
Soligenous	literally 'made by soil'; here used to refer to wetness induced primarily by moving supply of telluric water sourced from mineral deposits adjoining a wetland (such as seepage slopes).
Soligenous wetlands	wetlands primarily kept wet by supply of telluric water with little impedance to outflow; most typical of relatively steep slopes where groundwater or run-off input produces surface-wet conditions – wetlands on ± flat surfaces are not usually classified here unless characterised by rates of water through-flow comparable to that on the steeper slopes; often have thin deposits of peat and water movement is often more by surface flow than percolation through the peat.
Spring	Used to refer to a discrete focus of groundwater outflow from a mineral aquifer onto the ground surface, usually with visible water flow into a stream, runnel(s) or soakway; may occur as an area of enhanced outflow within a more diffuse seepage system
Stagno-topogenous	topogenous surfaces which have little water throughflow (percolation).
Stand	a relatively uniform patch of vegetation of distinctive species composition and appearance; can vary in size from very small (*e.g.* 2m^2) to very large (*e.g.* 1 ha). The internal 'uniformity' can sometimes encompass small scale, repeated heterogeneity, such as is created by a microtopographical mosaic.
Stratigraphy (peat)	description of the layering within a peat deposit based on the composition and character of the peat and mineral content
Sub-neutral	wetlands with pH range c. 5.5–6.5.
Surface run-off	water that reaches (or leaves) a mire either by overland flow or percolation through the upper layers of the adjoining substratum (due to gravity).
Surface water	water from pools and lakes, water courses, land-drainage, surface run-off *etc*. (cf. groundwater).
Swamp	wetlands with emergent vegetation in shallow standing water (summer water table typically more than c. 25 cm above ground level); note that in North American terminology, swamp is more often used to refer to forested wetlands.
Telluric water	a generic term for water that has been in contact with the mineral ground, as opposed to direct precipitation inputs (*meteoric water*); includes both groundwater and surface water.

Term	**Definition**
Telmatic wetland	wet, semi-terrestrial wetlands (*i.e.* not aquatic wetlands), subdivided into 'permanent', 'seasonal' and 'fluctuating' types; derived from the Greek *telma* (telma), meaning 'pond, marsh, swamp'; 'paludal' and 'paludic' are Latin-derived equivalents. *Only used once, but should probably stay*
Telmatology, telmatologist	the study of, or one who studies, telmatic wetlands, derived from the Greek telma, meaning 'pond, marsh, swamp' , and ολογία. Some workers prefer these terms to 'paludology' (*etc*) because the latter is of mixed Latin and Greek derivation. *Only used once, but should probably stay*
Terrestrialisation	the transition of open water to 'dry', 'solid' ground by the process of hydroseral succession, which occurs by gradual infilling with accumulating organic (± mineral) material, or sometimes by the initial formation of a floating raft of vegetation.
Topogenous	wetness induced by topography and poor drainage of telluric water (such as hollows)
Topogenous wetlands	telluric wetlands in which high water level is maintained by impeded drainage (detention) of water inputs.
Trough	the unqualified term 'trough' is used to refer to elongate, mostly valley-bottom contexts which are neither valleyheads nor floodplains.
Turbary	The cutting and removal of turf or peat for fuel.
Tussocks	elevated mounds created by the growth of caespitose vascular plants, such as *Molinia caerulea* or *Schoenus nigricans*; tussocks can sometimes coalesce to form elevated platforms.
Upland	an ill-defined term, in the UK often considered to correspond to land that is either above about 300 m in altitude, or above the boundary of enclosure. In northern and western areas, particularly in Scotland, Wales and Ireland, unenclosed land often descends close to sea-level, and the upland–lowland dichotomy becomes meaningless.
Valley mire	a term so widely used and in a variety of different ways as to be a source of much confusion; it is perhaps most often used by UK workers to refer to valleyhead wetlands, but it has also been used in a quite different sense: *e.g.* Haslam (1965) specifically used this term in almost the opposite sense to refer to floodplain systems (she used headwater fen to refer to the valley fens of some other UK workers).
Valleyhead wetland/fen	wetlands associated with the headwaters and upper reaches of valleys; mainly soligenous (*e.g.* New Forest valley mires).
Water level	a generic term for water surface and water table.
Water mound	refers to the water mound developed within a raised bog as a result of impeded drainage and storage of water derived solely from precipitation (*i.e.* perched above the level of regional groundwater levels).
Water table	below-ground free water surface
Water track	trackways of preferential water movement through wetlands; distinguished from a soakway by having more open water.

11 ANNEXES

11.1 Annexe 1. Field sampling categories, variables, and rank scores

Wetland substratum variables

<u>Peat Depth categories</u> [calculated from measured peat depths]

rank	*description*
1	Very thin (< 0.2 m)
2	Thin (< 0.5 m)
3	Moderate (0.5 – 1.5 m)
4	Fairly deep (1.5 – 3.0 m)
5	Deep (3.0 – 5.0 m)
6	Very deep (> 5.0 m)

<u>Peat permeability categories</u> [Surface and lower layers]

rank	*description*
1	Stiff clay or silt
2	Dense, solid, well-humified peat
3	Well-decomposed, firm peat (includes much catotelm peat in bogs)
4	Firm, moderately decomposed peat (typically herbaceous / moss peat)
5	Fresh herbaceous / moss peat (includes much acrotelm peat in bogs)
6	Loose plant material / fresh herbaceous peat (may be semi-floating hydroseral mat)
7	Very loose plant material, usually at edge of water bodies; effectively water with rhizomes

<u>Basal substratum permeability categories</u> [mineral ground beneath peat infill]

rank	*description*
1	Heavy silt/clay; low-permeability bedrock
2	silt/clay loam
3	sandy clays/silts
4	Sandy clay/silt loams
5	Sandy loams
6	Sand/gravel; high permeability bedrock
7	Coarse gravel

Surface Features

<u>Sample Surface Configuration</u> [Applies specifically to the sample area]

rank	*description*	*examples*
1	water shedding	Dome, ridge or top of slope
2	water shedding & receiving	Downslope flow
3	water collecting on slope	small 'flat' areas on slopes
4	Flat unconfined	plateau or other more or less level ground
5	axial trough	trough-like site or 'lagg' zone
6	water collecting	Hollow or shallow basin

<u>Wetness categories</u>

rank	*description*	*water table depth*
1	very dry	<–75cm
2	dry	–75 to –40 cm
3	rather dry	–40 to –18 cm
4	sub-surface	–18 to –5 cm
5	near surface	–5 to +1 cm (water readily oozes from footprints)
6	above surface	+1 to +10 cm
7	shallow swamp	+10 to +25 cm
8	swamp	+25 to +50 cm

<u>Stability of surface (quakiness)</u>

rank	*description*
1	Solid
2	Firm
3	Soft
4	Very soft
5	Semi-floating/quaking
6	Floating

Sphagnum abundance

rank	*description*
0	absent
1	rare
2	occasional
3	frequent
4	abundant

Heather height

rank	*description*	*equates to*
0	absent	
1	low (1cm to 10cm)	pioneer
2	moderate (10cm to 25cm)	building
3	tall (25cm to 50cm)	mature
4	very tall (50cm+)	late mature / degenerate

Patterning

type	*description*
0	No obvious patterning (this would probably include most tussock surfaces?)
1	Weak surface patterning, irregular, variable or ‘random’
2	Patterning mostly isodiametric
3	Isodiametric or indeterminate patterning plus some linear (across slope) features
4	Strong linear (across slope) features
5	Crescentic (across slope) features

Erosion features

rank	*description*
0	No visible erosion features
1	revegetated former haggs, peat flats, shallow gullies, forestry furrows (≈ E1)
2	scattered small areas of bare peat (≤4m2) (≈ Em1/2)
3	eroded ditches, shallow gullies, narrow strips of eroded peatland edges
4	large areas of bare peat and upstanding haggs – actively eroding
5	numerous deep, actively eroding gullies (≈ E2)

Microtopography

Pool diversity

type	*description*
A1	wet hollows (≤10cm)
A2	shallow pools (10cm to ≤20cm)
A3	moderate pools (20cm to ≤40cm)
A4	deep pools (40cm to ≥100cm)
A5	very deep pools (1m to 400cm+)

Hummock diversity

type	*description*
T1	slight undulations (0cm to ≤15cm)
T2	low hummocks (Sphagnum/Polytrichum ± Eriophorum/ericaceous spp) (15cm to ≤25cm)
T3	tall hummocks (Sphagnum/Polytrichum ± Eriophorum/ericaceous spp) (25cm to ≤50cm)
T4	very tall hummocks (Sphagnum/Polytrichum ± Eriophorum/ericaceous spp) (50cm to ≤100cm)

Tussock diversity

type	*description*
U2	low tussocks (Molinia/Trichophorum/Eriophorum vaginatum) (15cm to ≤25cm)
U3	tall tussocks (Molinia) (25cm to ≤50cm)
U4	very tall tussocks (Molinia) (50cm to ≤100cm)

Microtopographical diversity indices

type	*description*	
Pool + Hollow diversity	∑ A1 – A4	
Hummock diversity	∑ T1 – T4	
Pool + Hummock diversity	∑ A1 – T4	
Tussock diversity	∑ U2 – U4	
Total Microtopographical diversity	∑ A + T + U	Not used because of contra-indications

Erosion amplitude [score this regardless of whether revegetated or not]

type	*description*
E1	shallow erosion features (0cm to ≤15cm)
E2	low haggs and edges, forestry furrows (15cm to 50cm)
E3	tall haggs and edges, small gullies (50cm to 100cm)
E4	very tall haggs and edges, deep gullies (100cm to 200cm+)
E5	mineral ground exposed

Microtopographic frequency

rank	*description*
0	absent
1	rare
2	occasional
3	frequent
4	abundant

Hydrochemistry

Base-richness categories — These are based on the pH boundaries recognised by Wheeler and Proctor (2000) and relate broadly to subdivisions used by some other workers

rank	*description*	*pH*
1	Base-rich	pH 6.5 – 8.0
2	Sub-neutral	pH 5.5 – 6.5
3	Base-poor	pH 4.0 – 5.5
4	Acidic	pH < 4.0

Slopes

Slope (flatness) — [stand and adjacent slope]

rank	*description*	*gradient*
1	More or less flat	0 to 1 degrees
2	Very gentle	1 to 3 degrees
3	Slight	3 to 6 degrees
4	Moderate	6 to 10 degrees
5	Steep	10+ degrees

Extent of stand (upslope)

rank	*description*
1	very small (3–10m)
2	small (10–20m)
3	moderate (20–50m)
4	large (50–100m)
5	very large (100m+)

Adjacent slope (height) — [Typically an 'adjacent slope' refers to a difference of slope and ideally vegetation compared with the sample stand] ['None' if sample stand is at the top of slope/hill/ridge, or if 'adjacent' slope is too far away to see]

rank	*description*
0	none
1	very low (0–5m)
2	low (5–10m)
3	moderate (10–50m)
4	large (50–100m)
5	very large (100m+)

Inflows/Outflows

Proximity to upland margin (where mineral) — [Edge of peatland, typically change in gradient and/or vegetation. If bog continues to top of hillslope then '0' for no upland margin]

rank	*description*
0	None
1	> 100 m
2	30–100 m
3	10–30 m
4	3–10 m
5	Adjoining / within

Proximity to upland margin (where peat) — ['Hill bog', usually marked by change in slope from ± flat to sloping. Also where stand is below sloping edge of deep mire *e.g.* M25 'outflow' area]

rank	*description*
0	None
1	> 100 m
2	30–100 m
3	10–30 m
4	3–10 m
5	Adjoining / within

Marginal surface water inflows (mineral slope) — [The types of inflow that might enter the stand from adjacent mineral slope, including where a continuation of sample slope but changes from hillbog to mineral]

rank	*description*
0	No known inputs or inputs trivial (includes occasional surface run-off from permeable soils)
1	Within drains (includes water in drains that is normally below the mire surface in summer)
2	Surface run-off (likely occurrence judged on basis of soil/rock in catchment, HOST category and so on)
3	Under-drainage inflow
4	Surface Flow Tracks into or near stand (focussed water flow that can be seen / inferred from veg, includes forestry furrows)
5	Stream / ditch discharge from adjacent slope

Marginal surface water inflows (peat slope) [The types of inflow that might enter the stand from adjacent peat slope, including where a continuation of sample slope but different veg type/stand]

rank	*description*
0	No known inputs or inputs trivial (includes occasional surface run-off from permeable soils)
1	Within drains (includes water in drains that is normally below the mire surface in summer)
2	Surface run-off (likely occurrence judged on basis of soil/rock in catchment, HOST category and so on)
3	Under-drainage inflow
4	Surface Flow Tracks into or near stand (focussed water flow that can be seen / inferred from veg, includes forestry furrows)
5	Stream / ditch discharge from adjacent slope

Proximity to surface run-off water tracks from mineral slopes

[This may or may not be identical to 'Proximity to upland margin' and can include forestry furrows where they run downslope into the mire]

rank	*description*
0	None
1	> 100 m
2	30–100 m
3	10–30 m
4	3–10 m
5	Adjoining / within

Proximity to surface run-off water tracks from peat slopes

[This may or may not be identical to 'Proximity to upland margin' and can include forestry furrows where they run downslope into the mire]

rank	*description*
0	None
1	> 100 m
2	30–100 m
3	10–30 m
4	3–10 m
5	Adjoining / within

Level of stand surface relative to base of mineral slope [Rank values 0 – 3 should also be used where there is higher ground of those magnitudes between the slope base and the stand / sample area.

rank	*description*
0	Much above run-off inflow
1	1–2 m above run-off inflow
2	< 1 m above run-off inflow
3	Slightly above run-off inflow
4	More or less level with run-off inflow
5	Downstream of run-off inflow

Level of stand surface relative to base of peat slope [Rank values 0 – 3 should also be used where there is higher ground of those magnitudes between the slope base and the stand / sample area.

rank	*description*
0	Much above run-off inflow
1	1–2 m above run-off inflow
2	< 1 m above run-off inflow
3	Slightly above run-off inflow
4	More or less level with run-off inflow
5	Downstream of run-off inflow

Surface runoff water flow tracks [Where surface-water flow tracks enter the stand (could be telluric). Weak flow tracks may be suggested only by differences in vegetation, aligned linearly. *e.g.* if furrows enter stand but no visible flow, enter '1']

rank	*description*
0	no obvious flow
1	Former flow line
2	Winter-only surface flow (dry in summer, or a soakway)
3	Summer pools (disconnected pools along apparent flow line)
4	probable flow or winter only flow (wet flow-lines without visible surface flow, but with distinctive vegetation)
5	Visible summer flow
6	Strong summer flow

Stand level below surface runoff water flow track level [*e.g.* if furrowed, enter 3]

rank	*description*
0	No inflows or much above run-off inflow
1	1–2 m above run-off inflow
2	< 1 m above run-off inflow
3	Slightly above run-off inflow
4	More or less level with run-off inflow
5	Downstream of run-off inflow

Endotelmic flows [± visible features that originate within the peatland (can be outside the stand) May be indistinguishable from 'Surface water inflows', in which case leave blank]

rank	*description*
0	no obvious flow
1	Former flow line
2	Winter-only surface flow (dry in summer, or a soakway)
3	Summer pools (disconnected pools along apparent flow line)
4	probable flow or winter only flow (wet flow-lines without visible surface flow, but with distinctive vegetation)
5	Visible summer flow
6	Strong summer flow

Water flow (within stand) [refers to visual evidence for water flow within the stand, from whatever source]

rank	*description*
0	no obvious flow
1	possible flow (where some flow seems likely but no visible evidence)
2	probable flow or winter only flow (wet flow-lines. without visible surface flow, but with distinctive vegetation)
3	visible summer flow
4	strong summer flow
5	streaming (in or alongside streams or strong water tracks)

Water flow (from stand) [visual evidence of water flow out of the stand (runnels or streams draining stand)]

rank	*description*
0	no obvious flow
1	possible flow (where some flow seems likely but no visible evidence)
2	probable flow or winter only flow (wet slopes without visible surface flow)
3	visible summer flow
4	strong summer flow
5	streaming (in or alongside streams or strong water tracks)

Drains & Waterbodies

Furrowed surfaces [leave blank if not in an area of forestry furrowing

type	*description*
0	pools present,<10 cm below level of adjacent surface
1	wet furrow bottoms, 10–20 cm below adjacent surface
2	damp furrow base 20–30 cm below adjacent surface
3	damp/dry furrow base 30–40 cm below adjacent surface
4	dry furrow base 40–50 cm below adjacent surface
5	dry furrow 50 cm+ deep, actively draining adjacent peat

Proximity to Furrows

rank	*description*
0	None
1	> 100 m
2	30–100 m
3	10–30 m
4	3–10 m
5	Adjoining / within

Level of adjacent surface above furrow water level

rank	*description*
0	No furrows
1	More or less level with furrow water level
2	Slightly above furrow water level
3	< 1 m above furrow water level
4	1–2 m above furrow water level
5	Very much above furrow water level

Proximity to drains / erosion gullies

rank	*description*
0	None
1	> 100 m
2	30–100 m
3	10–30 m
4	3–10 m
5	Adjoining / within

Level of surface above drain / gully water level [Includes forestry furrows where likely to be acting as a drain]

rank	*description*
0	No drains nearby or lower than drain/gully water level
1	More-or-less level with drain/gully water level
2	Slightly above drain/gully water level
3	< 1 m above drain/gully water level
4	1–2 m above drain/gully water level
5	Very much above drain/gully water level

<u>Distance from waterbody</u>

['Water body' refers to features such as lakes, large pools (*e.g.* lochans), watercourses and some dykes with a potential water supply function, at least during part of the year. Not small peatland pools, which are part of the system being sampled]

rank	*description*
0	Adjoining / within
1	3–10 m
2	10–30 m
3	30–100 m
4	> 100 m
5	no water body

<u>Level of surface above waterbody</u>

rank	*description*
0	Below water body water level
1	Mostly level with water body water level
2	Slightly above water body water level
3	< 1 m above water body water level
4	> 1 m above water body water level
5	No water body or much above water body water level

<u>Other surface water features</u>

Regular summer flooding	[it is likely this will not be known]
Regular winter flooding	[it is likely this will not be known]
Impeded drainage	[this would include water collecting areas such as pool systems on a slope; in lowland sites in topogenous stands by blockage of flow, *e.g.* sluice or dam]
Interceptor drains or ridges	[catchwater ditches, lagg zones, or elevated surfaces betw stand & apparent H2O source.]

Groundwater Features (if present)

<u>Groundwater outflow type</u>

rank	*description*
0	No known inputs or inputs trivial
1	Groundwater usually sub-surface in summer (includes marginal flushed areas that are summer dry)
2	Groundwater near or at surface in summer in topogenous areas (such as flat surfacs or shallow depressios) without an obvious summer surface outflow
3	Sloping seepage faces and topogenous hollows with an obvious surface water outflow in summer
4	Stand containing, or influenced by, strong springs and springheads
5	Stand containing, or influenced by, an active spring mound

<u>Proximity to groundwater outflow</u>

rank	*description*
0	None
1	> 100 m
2	30–100 m
3	10–30 m
4	3–10 m
5	Adjoining / within

<u>Level of surface below groundwater outflow level</u>

rank	*description*
0	No inflows or much above outflow
1	1–2 m above outflow
2	< 1 m above outflow
3	Slightly above outflow
4	More or less level with outflow (use should include, for example, spring mounds where the surface is kept wet by upflow)
5	Downslope of outflow

<u>Groundwater features</u>

Spring head
Spring mound
Soligenous slope
Intermittent soligenous slope
Runnels
Soakway
Water track

11.2 Annexe 2. Schematic drawings of topographical section profiles across the sites

See Annexe 3 for maps of site transect locations.

11.2.1 Wales

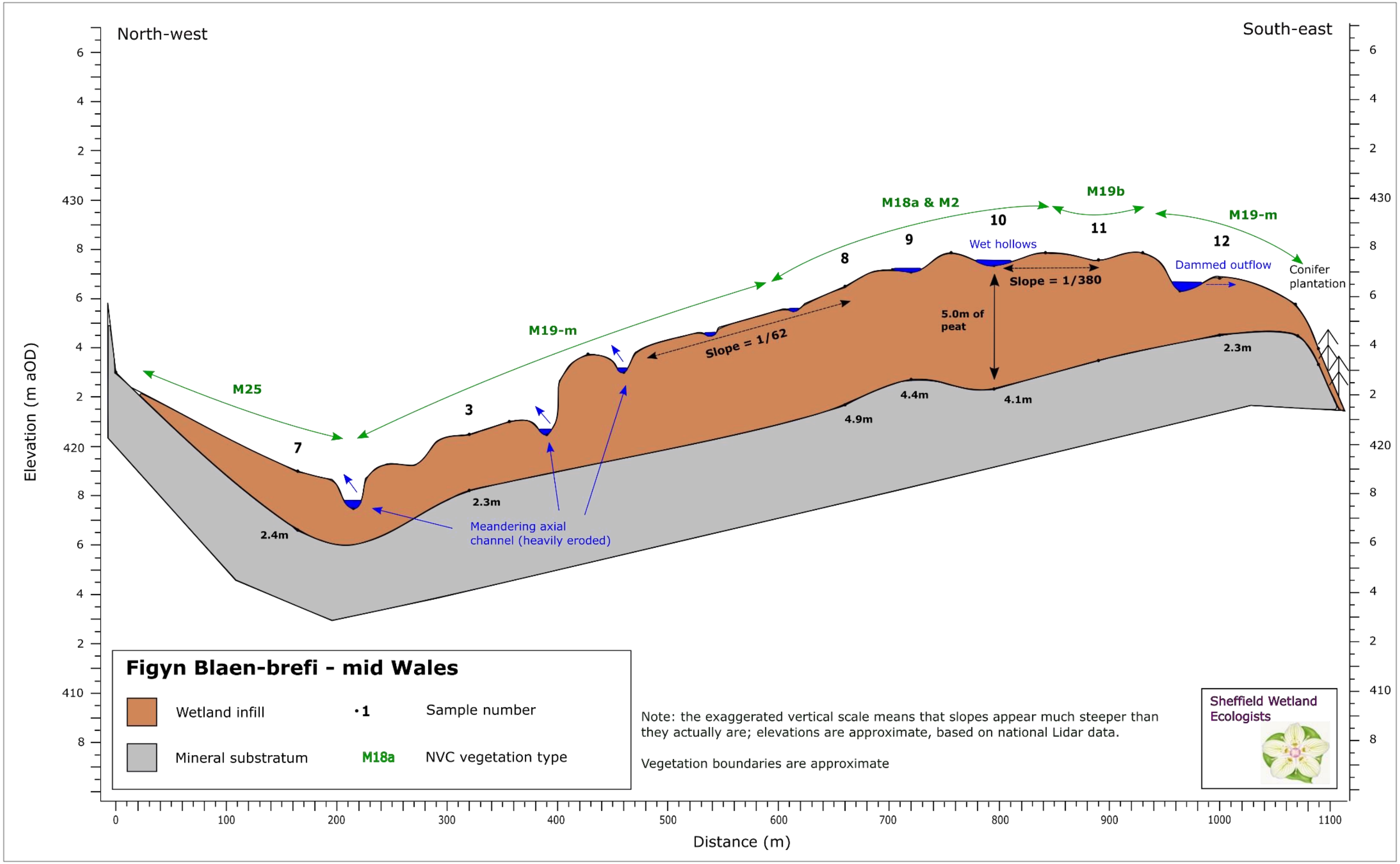

Figure A 1 Figyn Blaen-brefi NW–SE section.

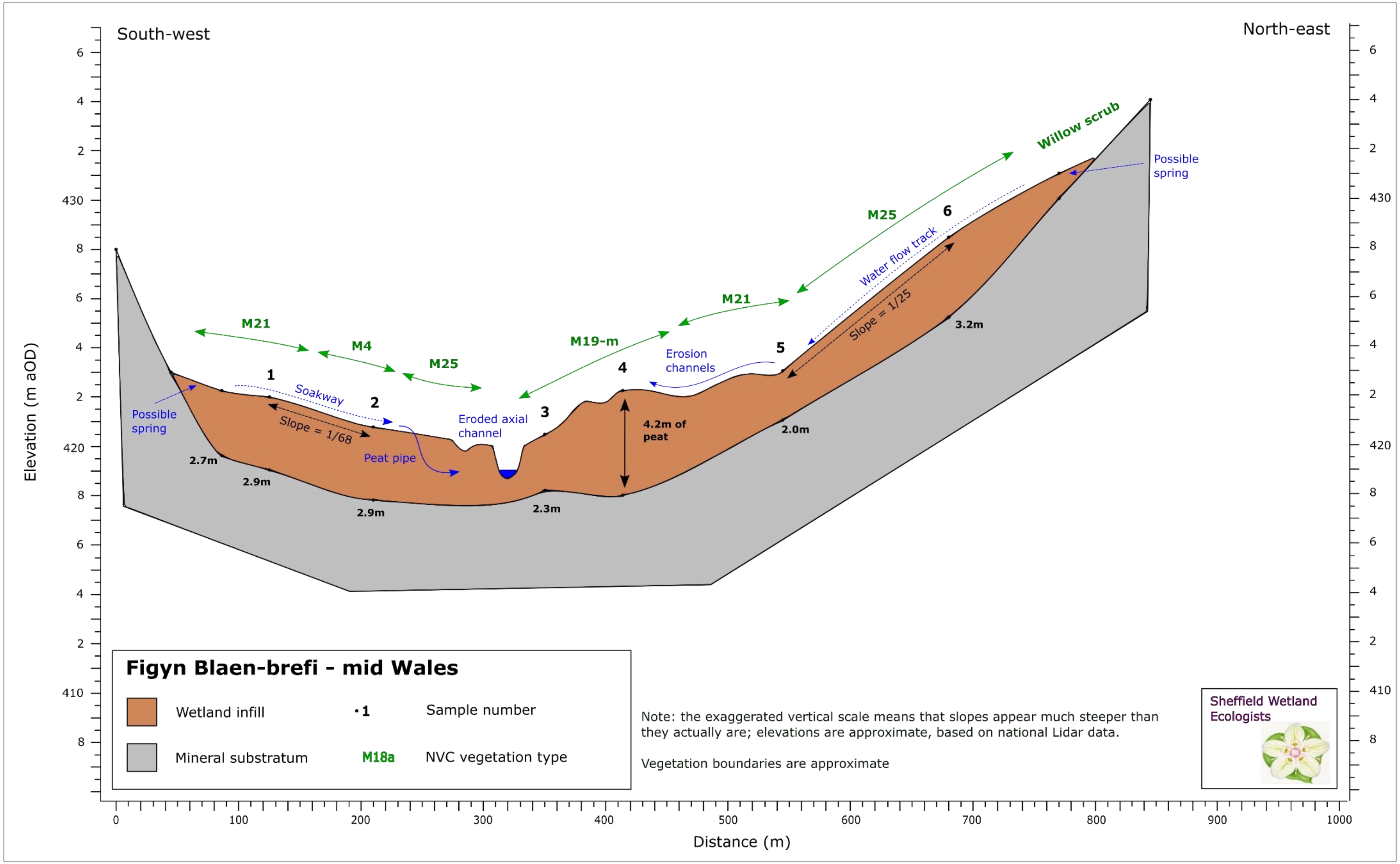

Figure A 2. Figyn Blaen-brefi SW–NE section.

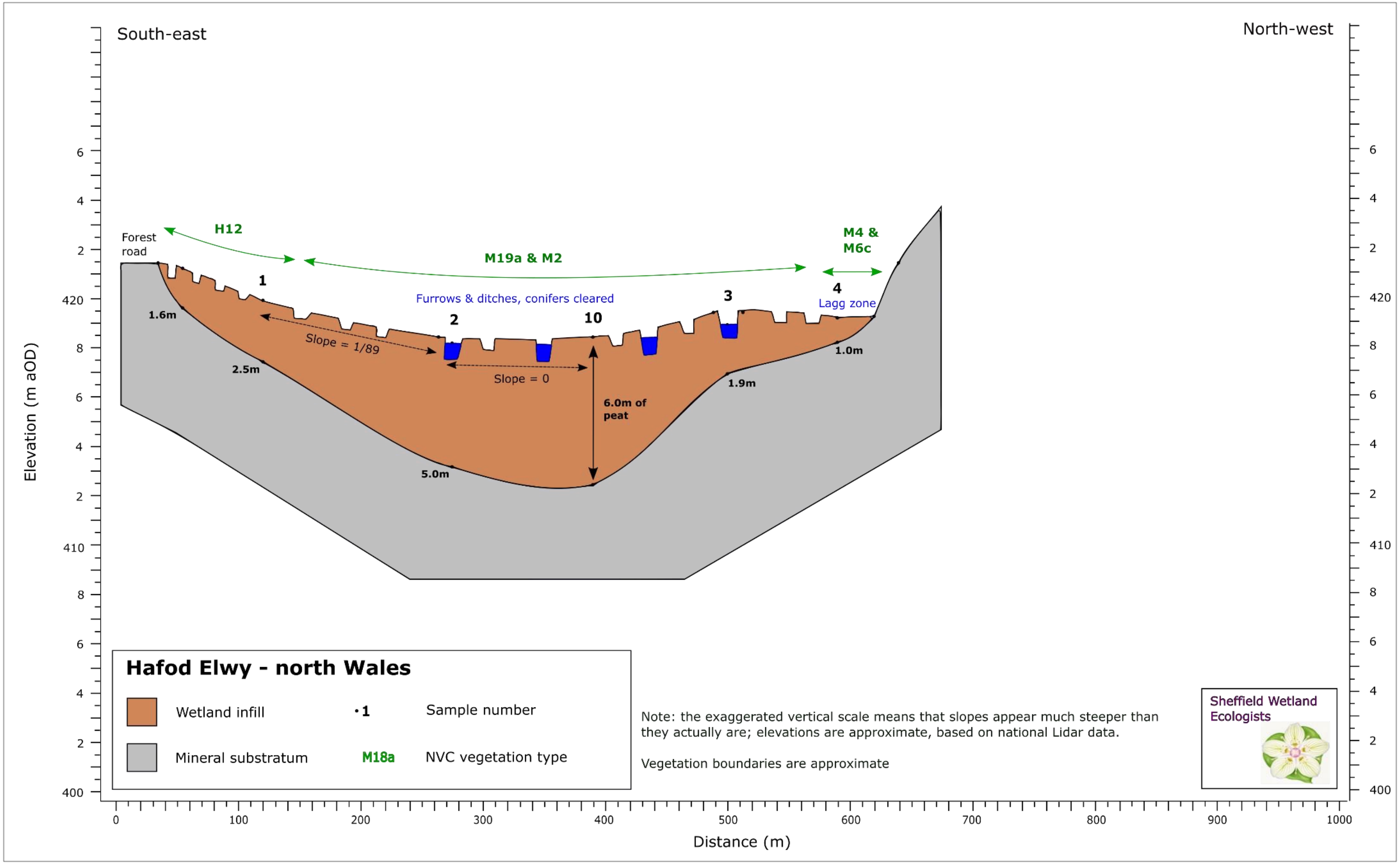

Figure A 3. Hafod Elwy SE–NW section.

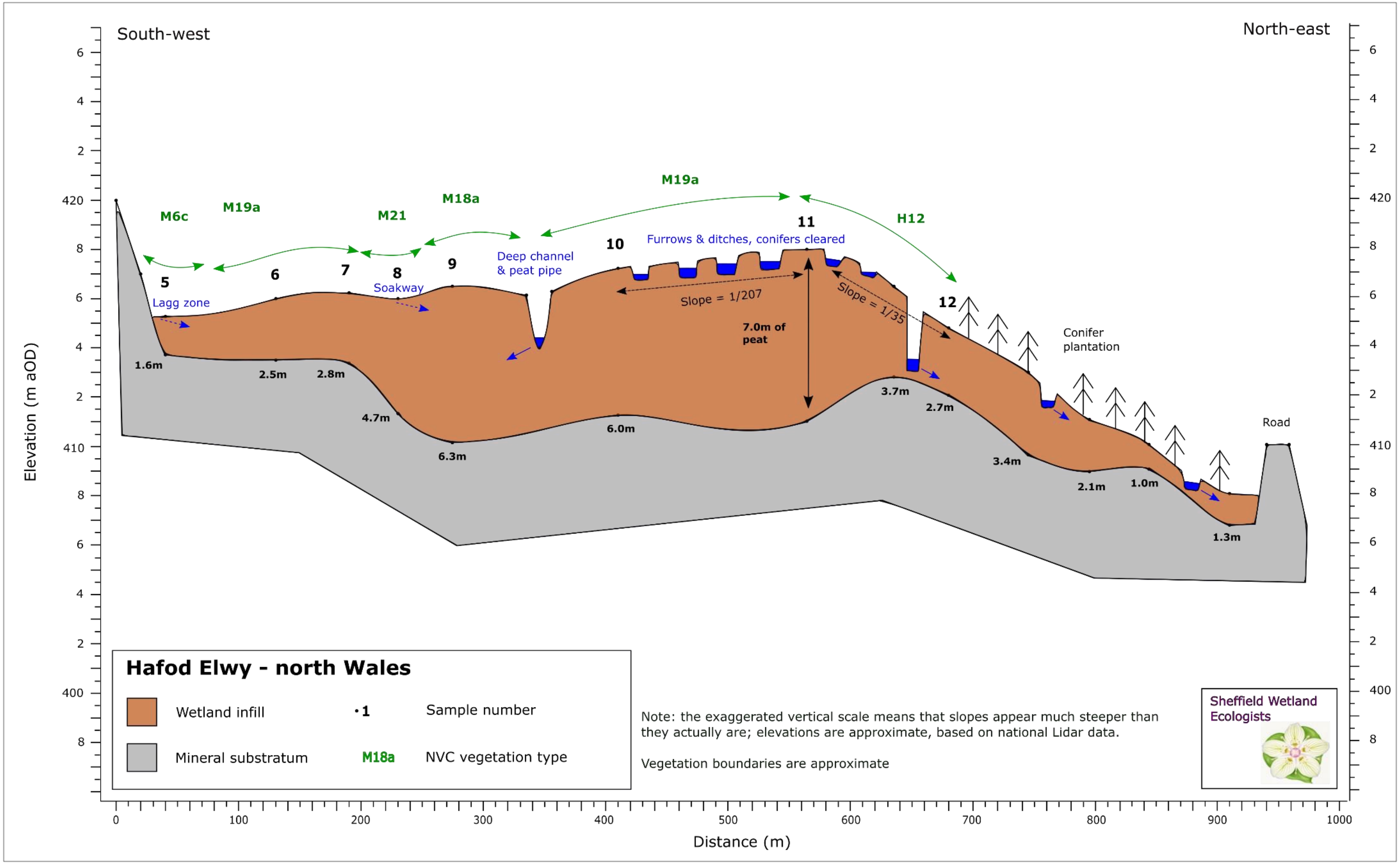

Figure A 4. Hafod Elwy SW–NE section.

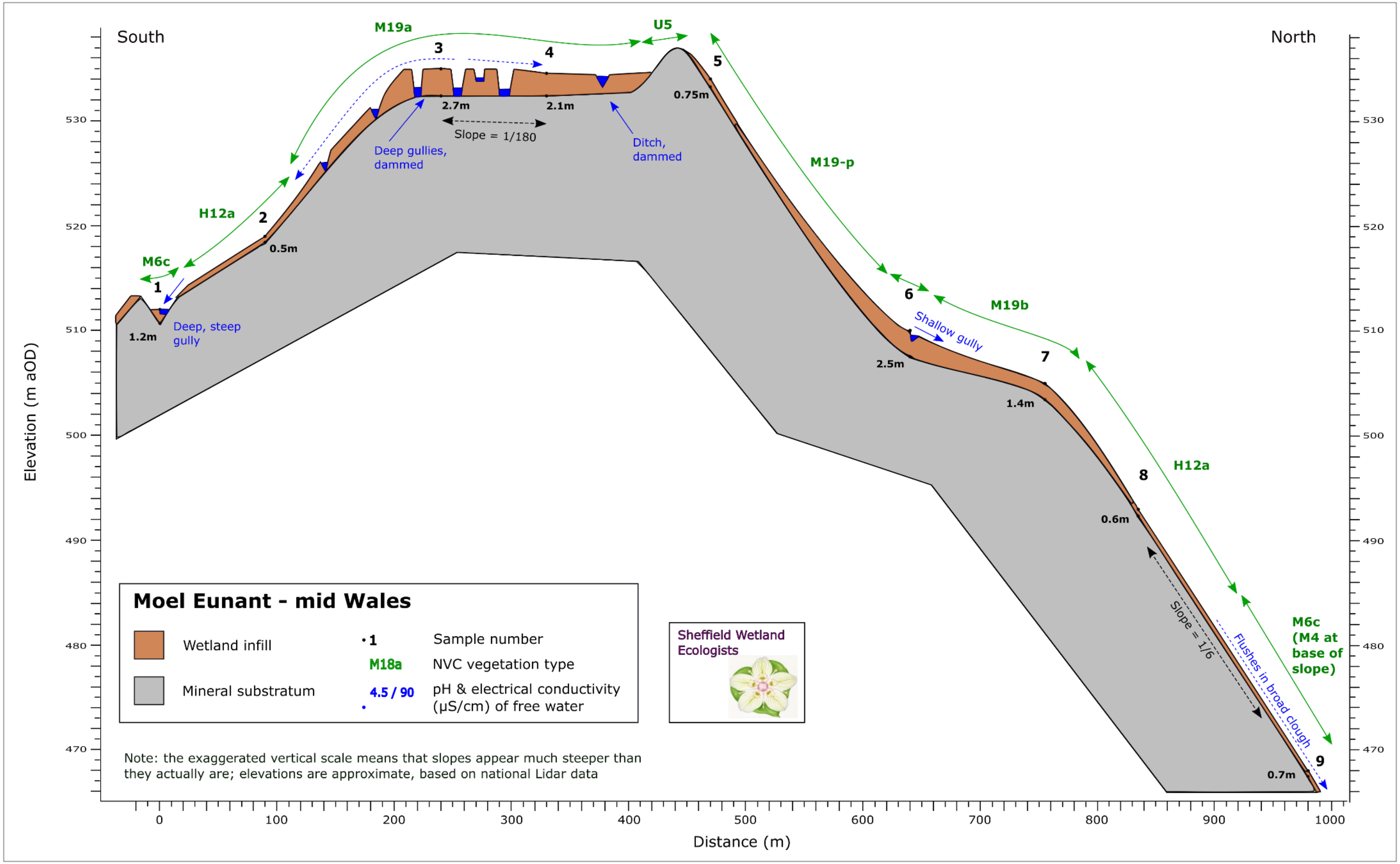

Figure A 5. Moel Eunant S–N section.

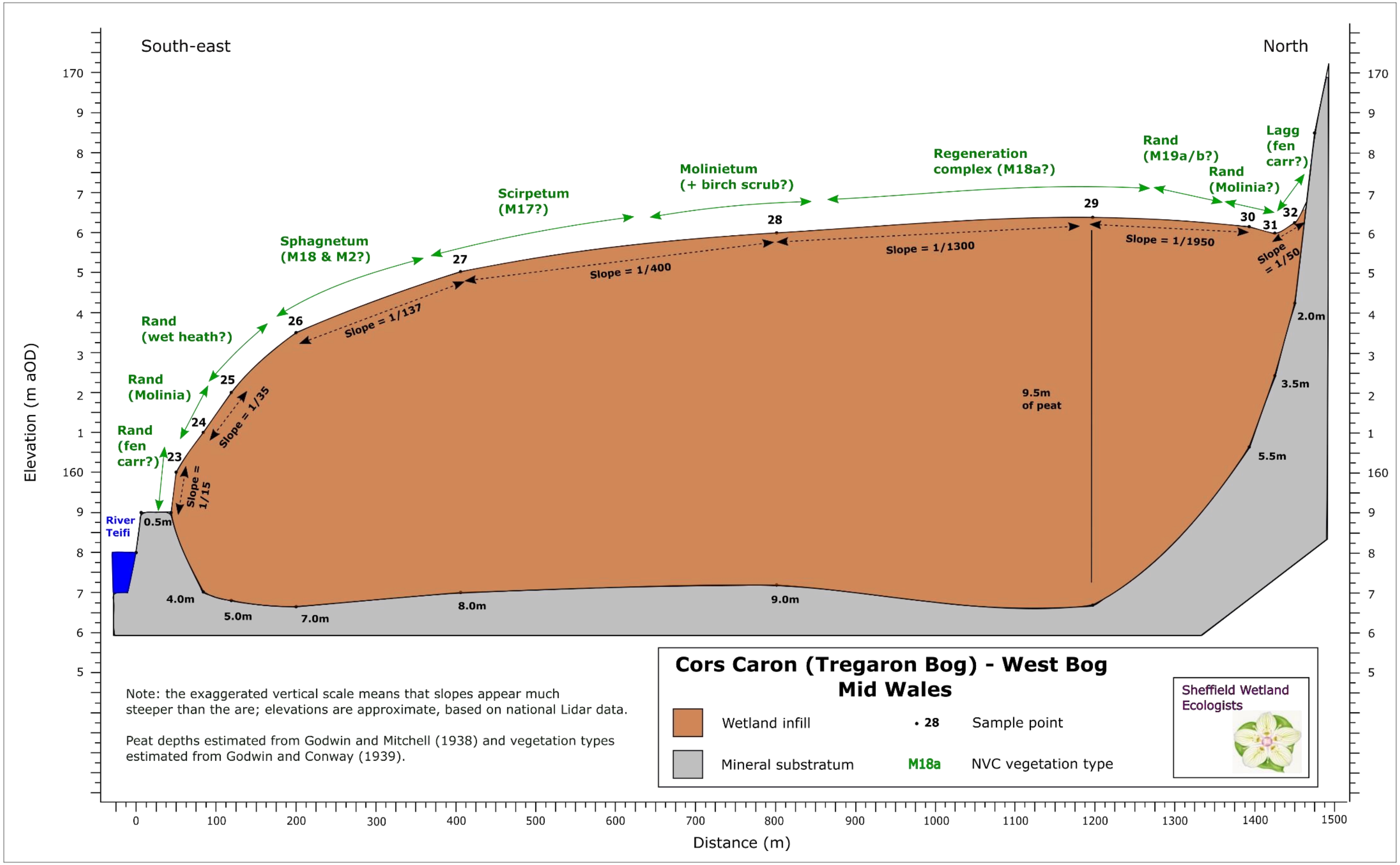

Figure A 6. Cors Caron (Tregaron Bog) – West Bog, SE–N section.

11.2.2 South Pennines

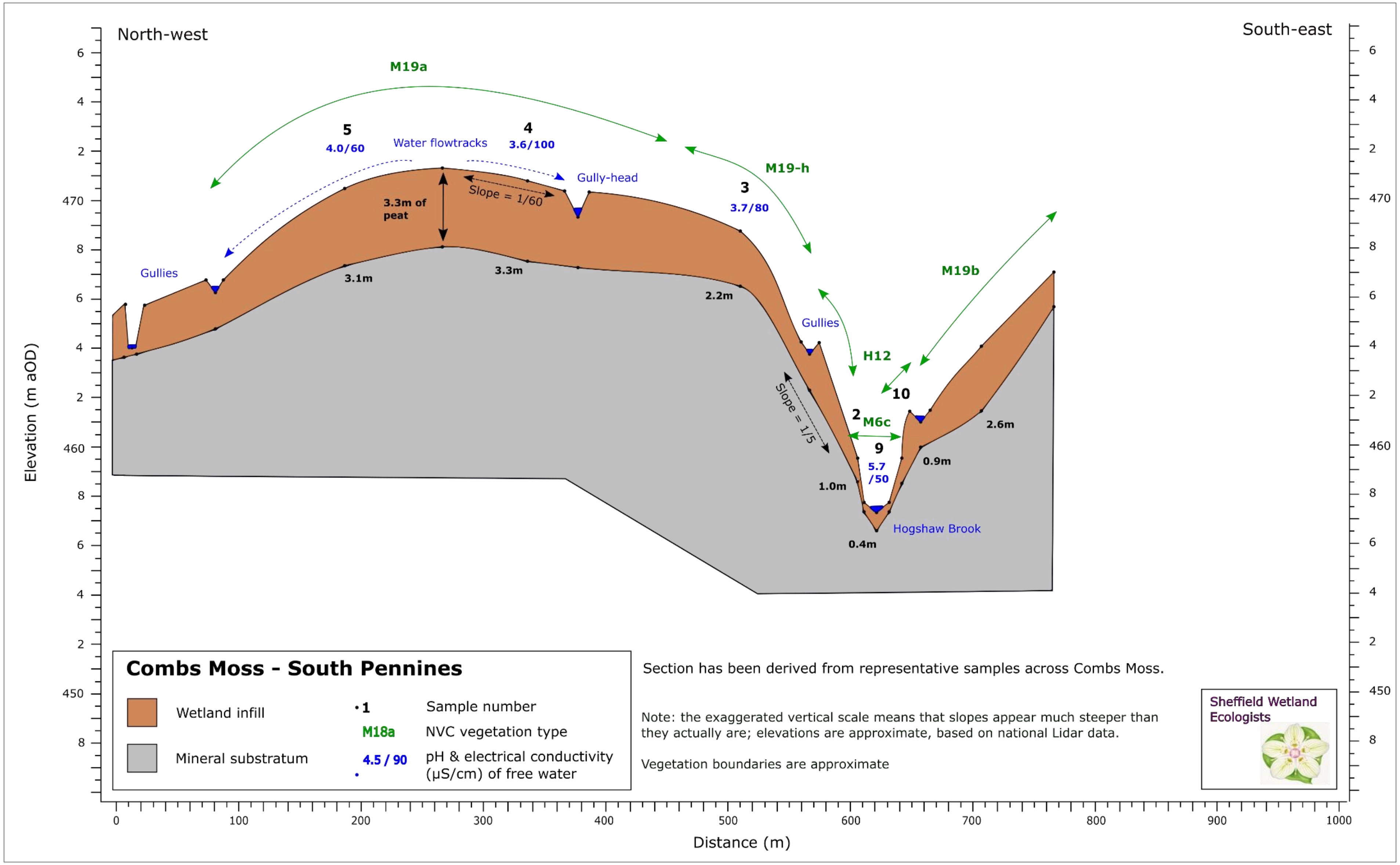

Figure A 7. Combs Moss NW–SE section.

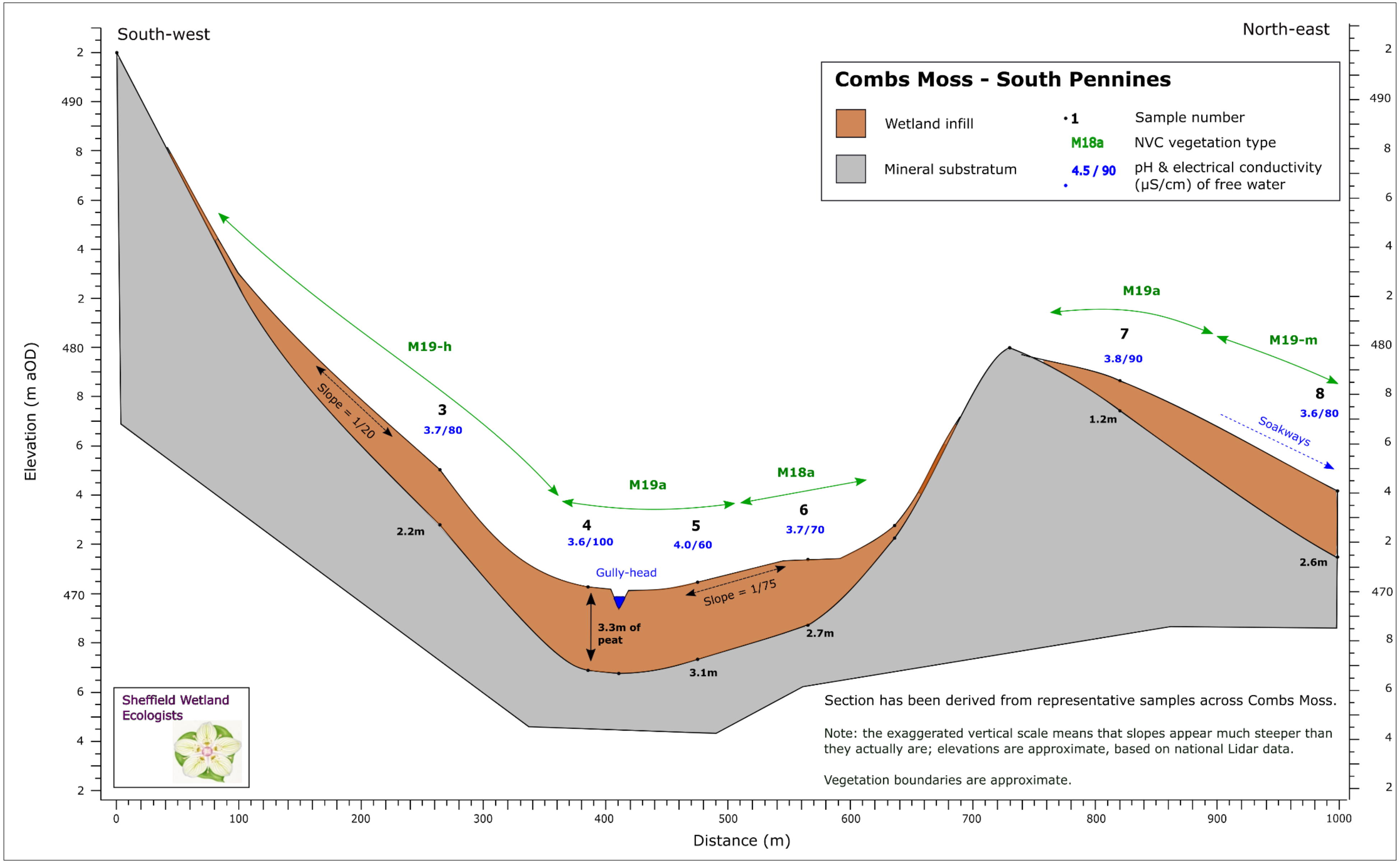

Figure A 8. Combs Moss SW–NE section.

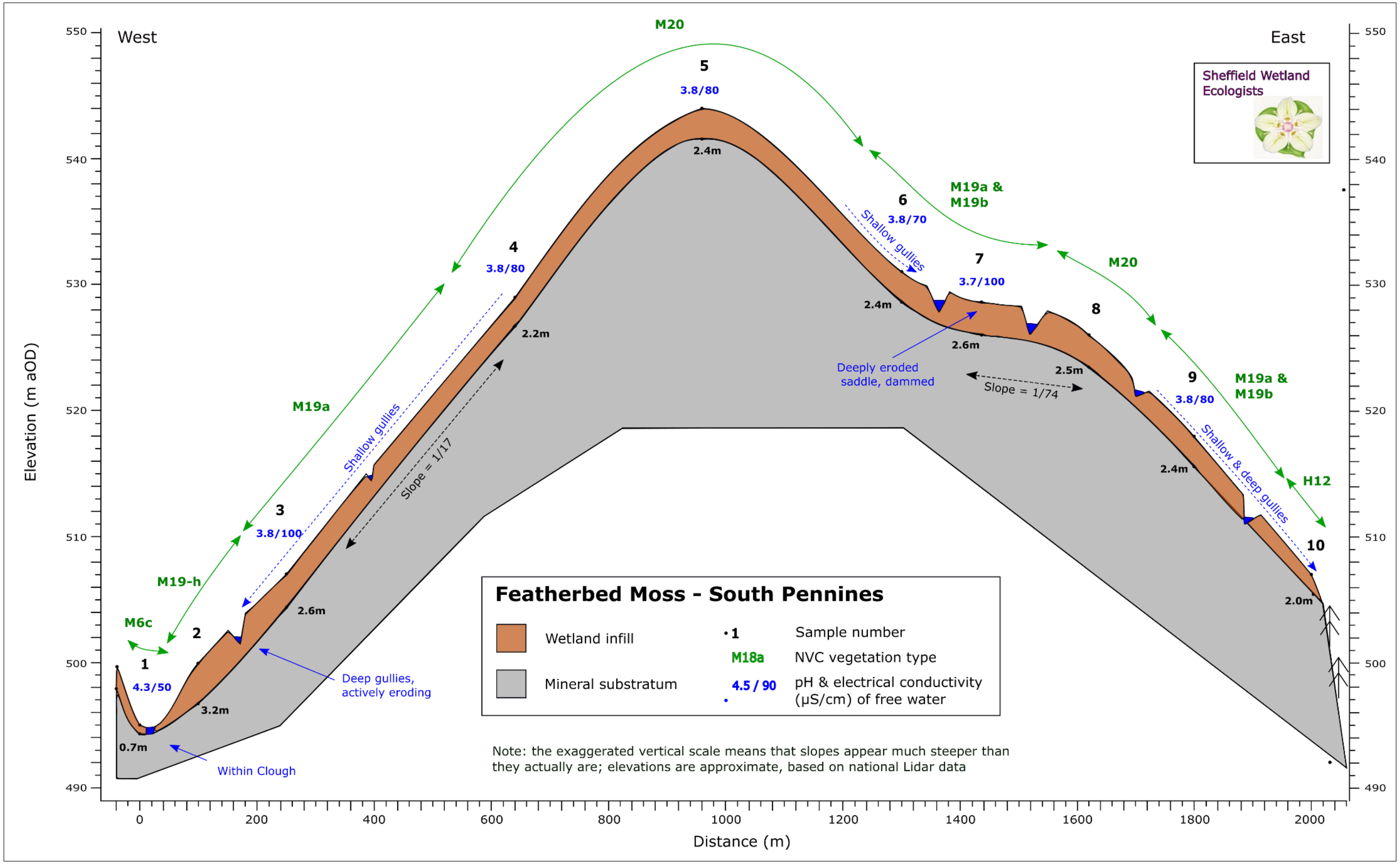

Figure A 9. Featherbed Moss W–E section.

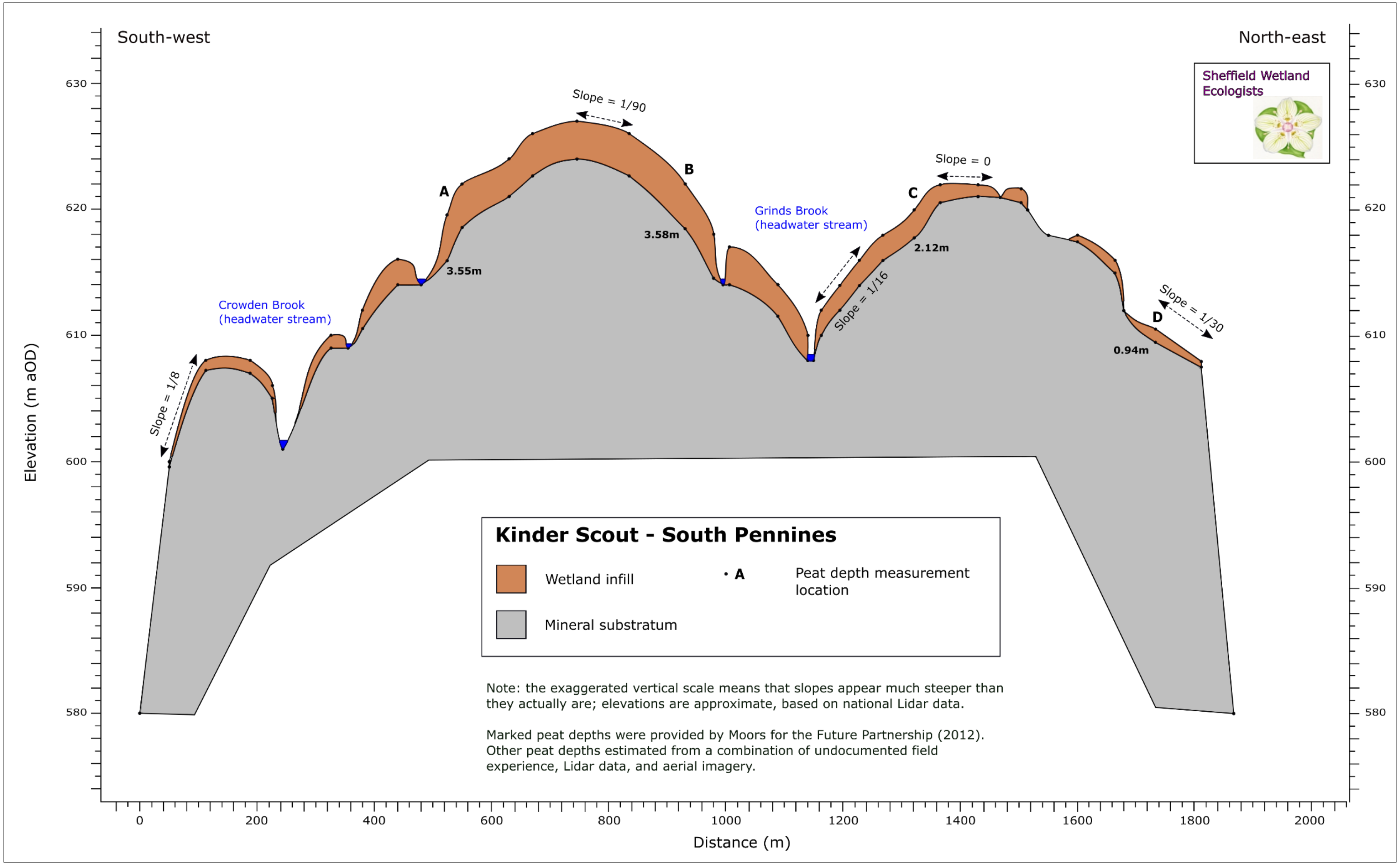

Figure A 10. Kinder Scout SW–NE section.

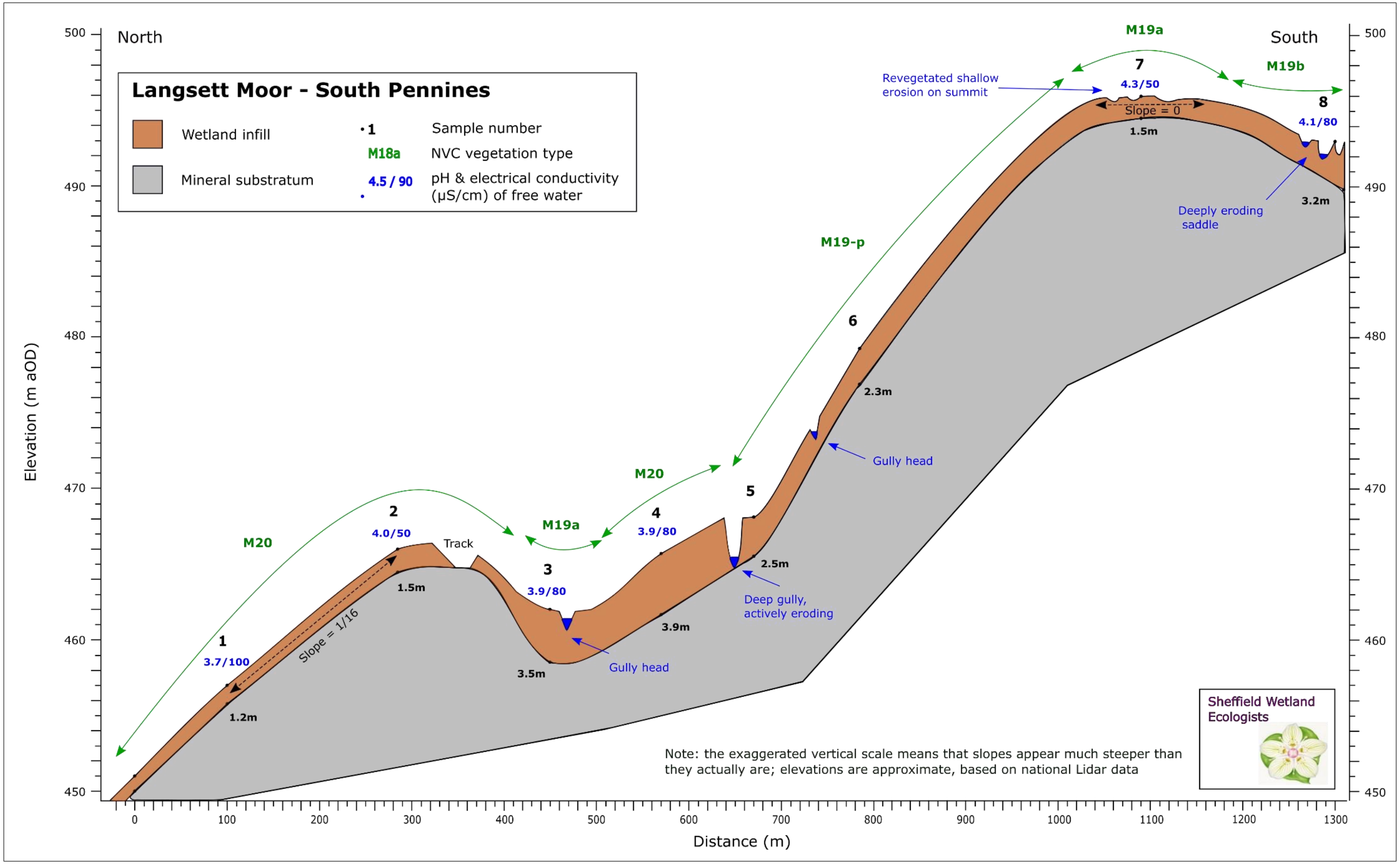

Figure A 11. Langsett Moors N–S section.

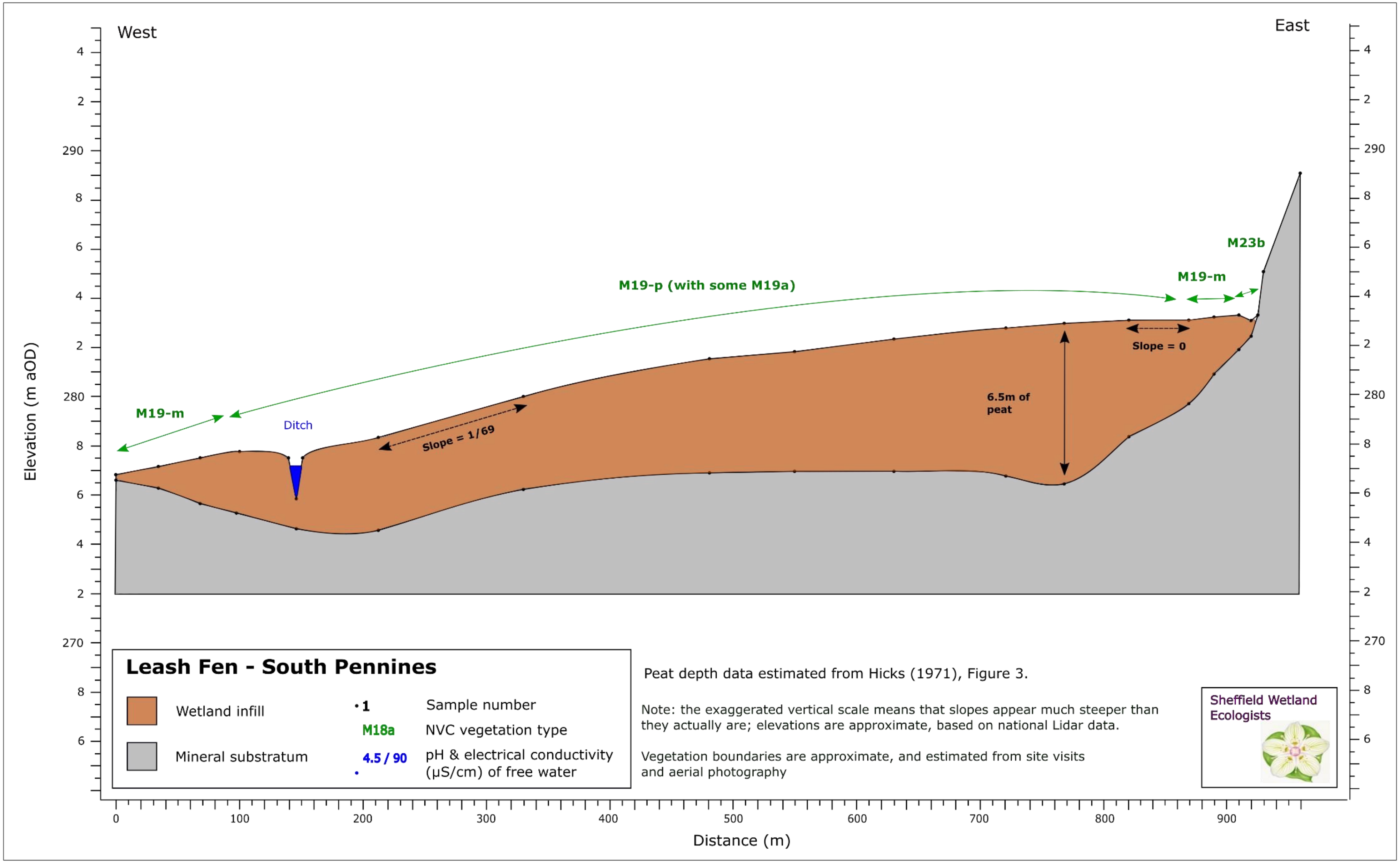

Figure A 12. Leash Fen W–E section.

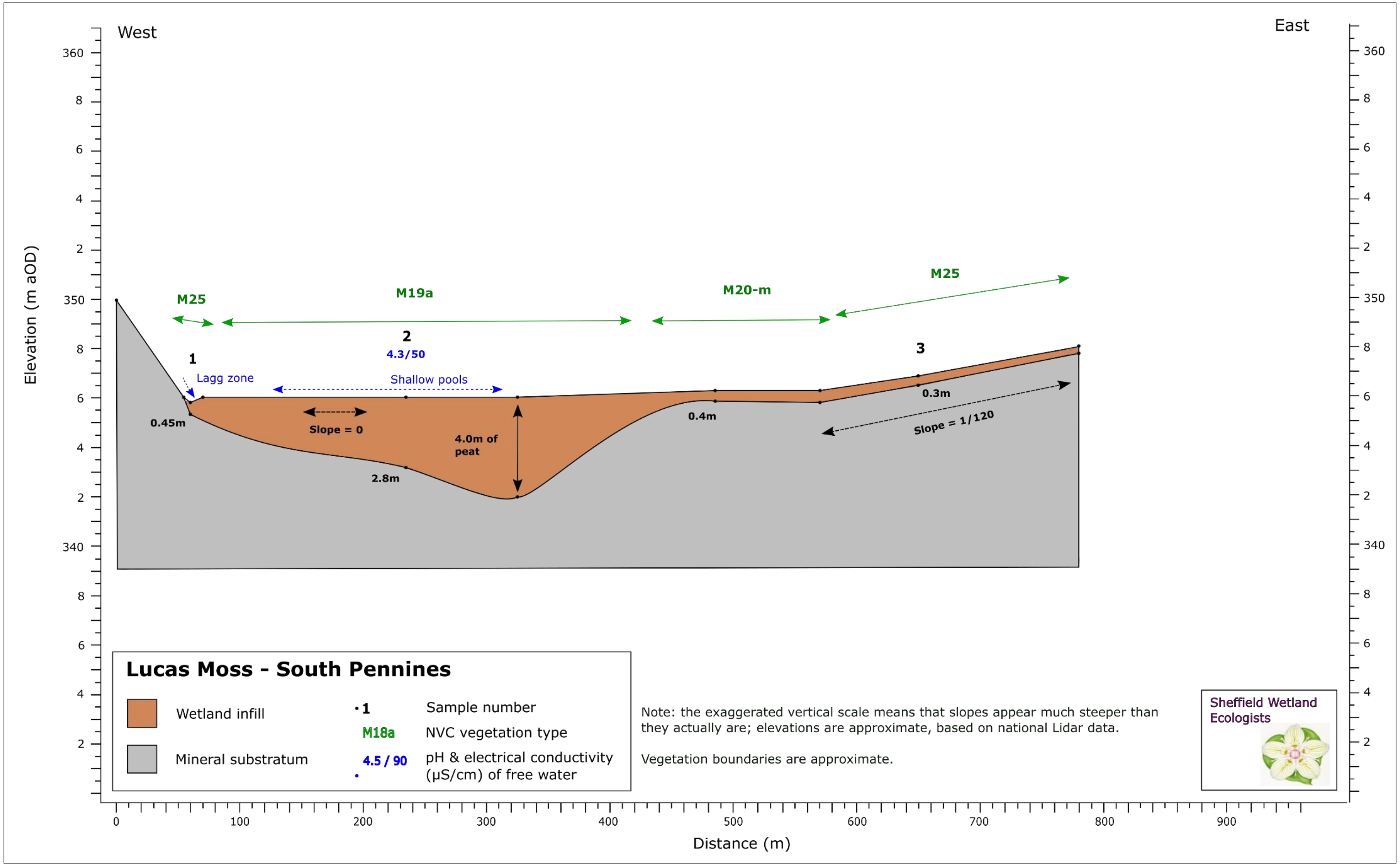

Figure A 13. Lucas Moss W–E section.

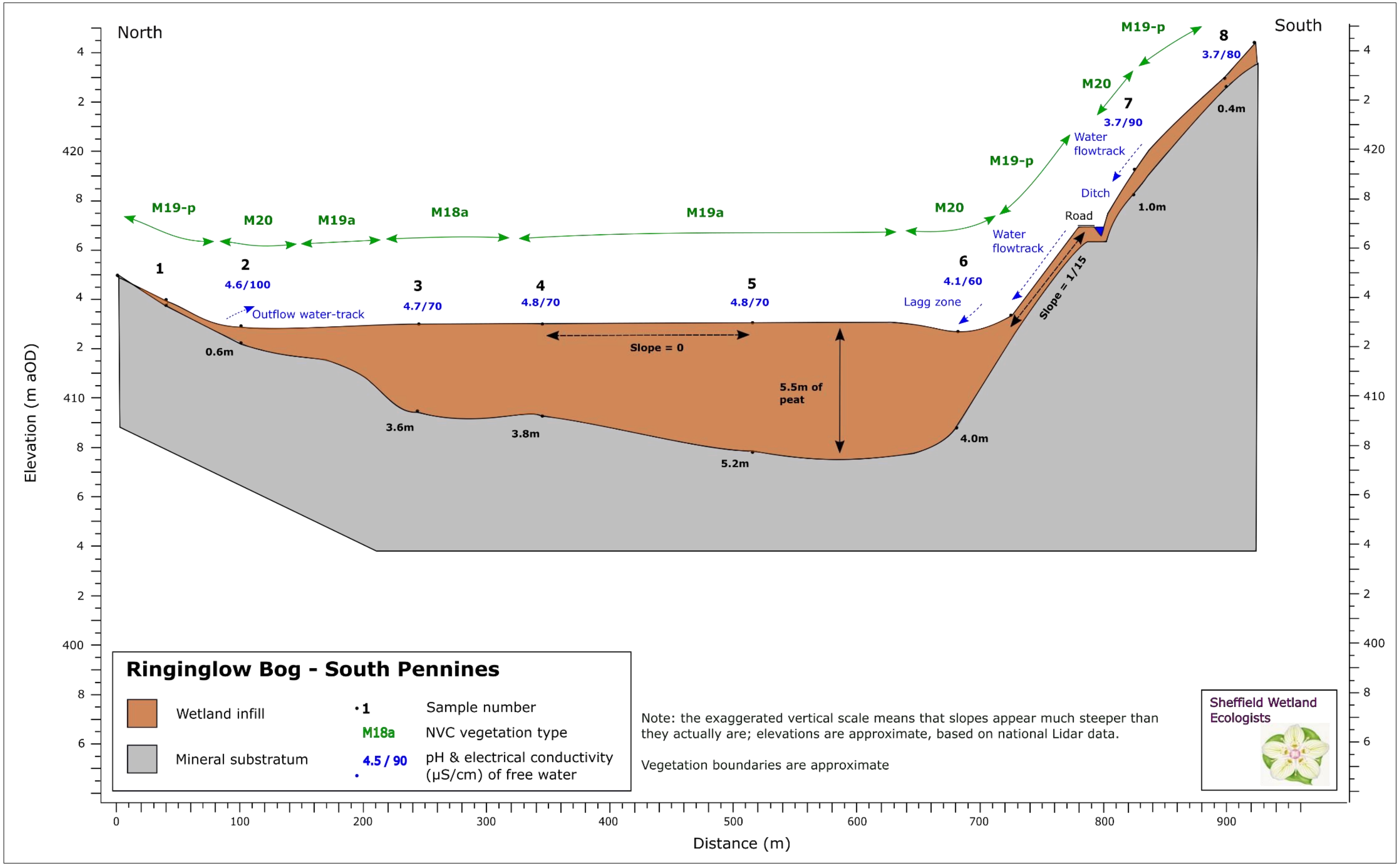

Figure A 14. Ringinglow Bog N–S section.

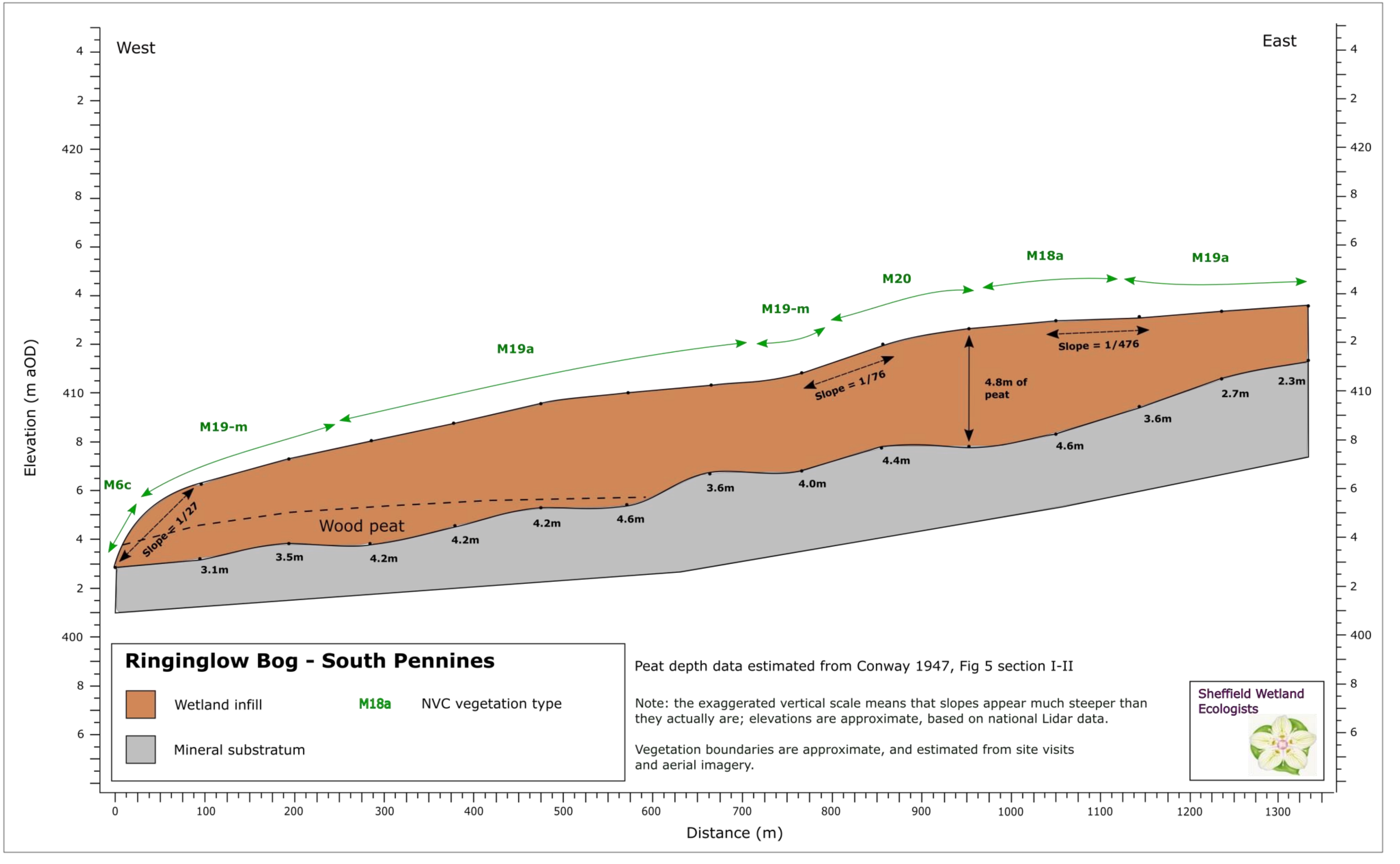

Figure A. 15. Ringinglow Bog W–E section.

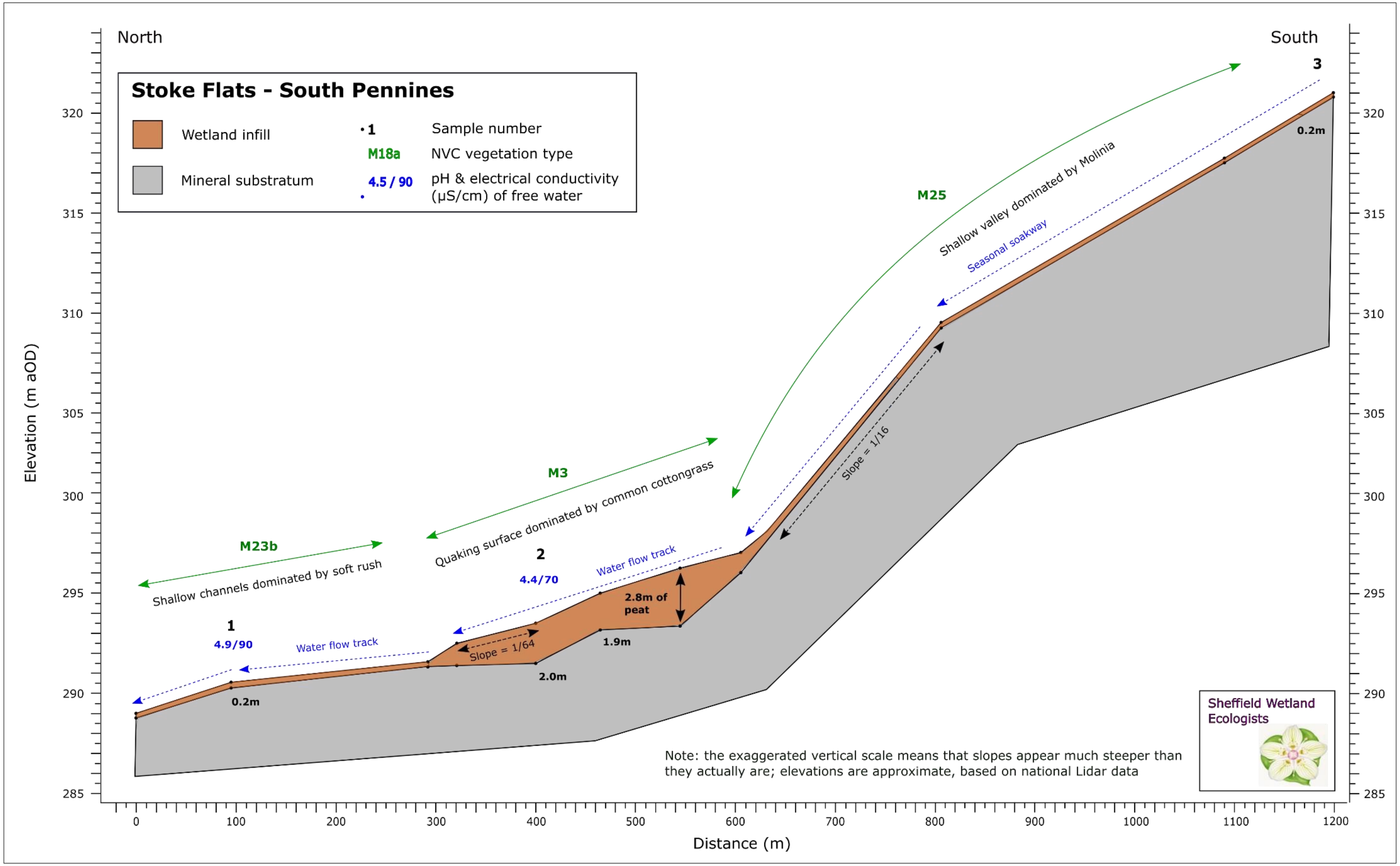

Figure A 16. Stoke Flats N–S section.

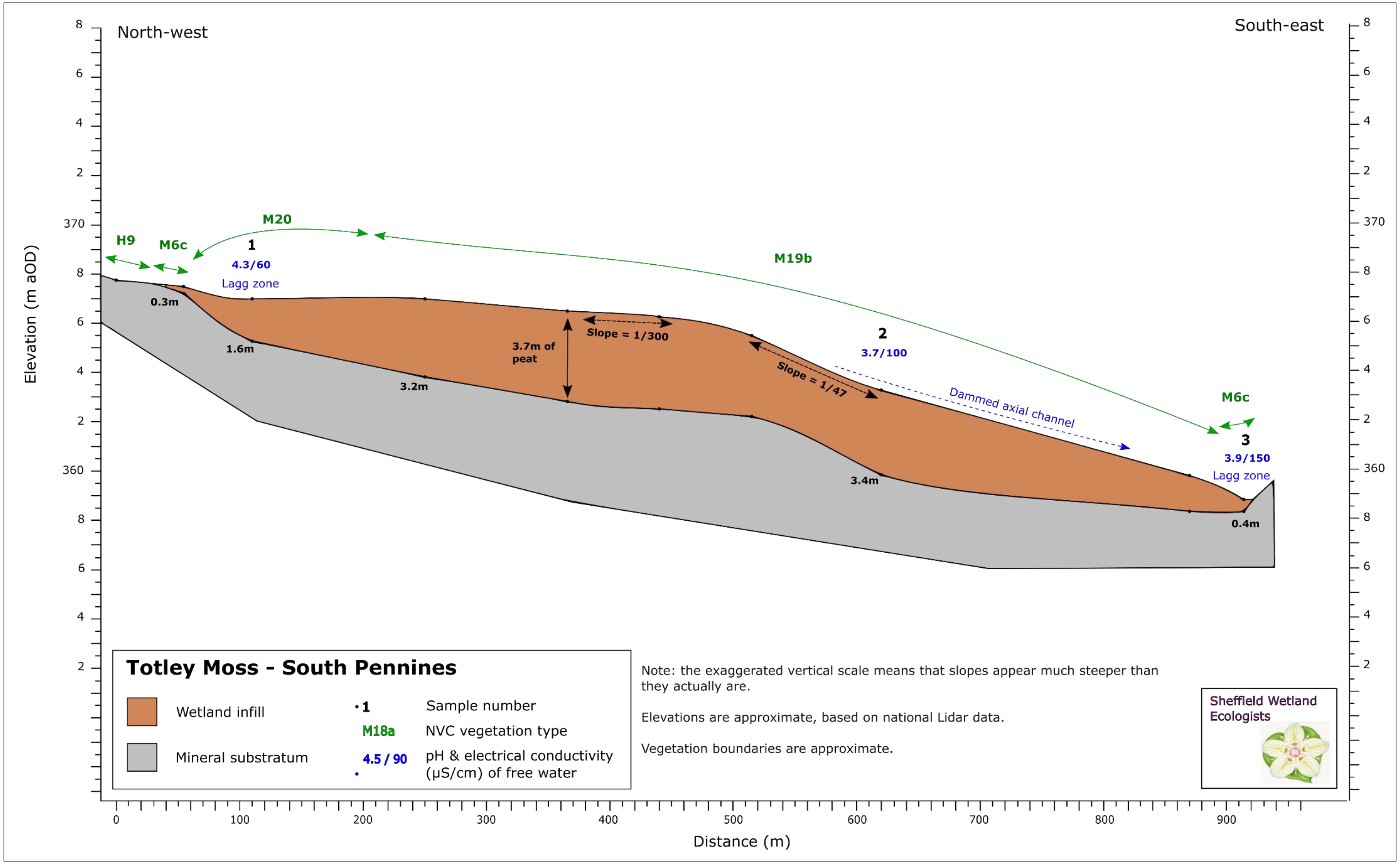

Figure A 17. Totley Moss NW–SE section.

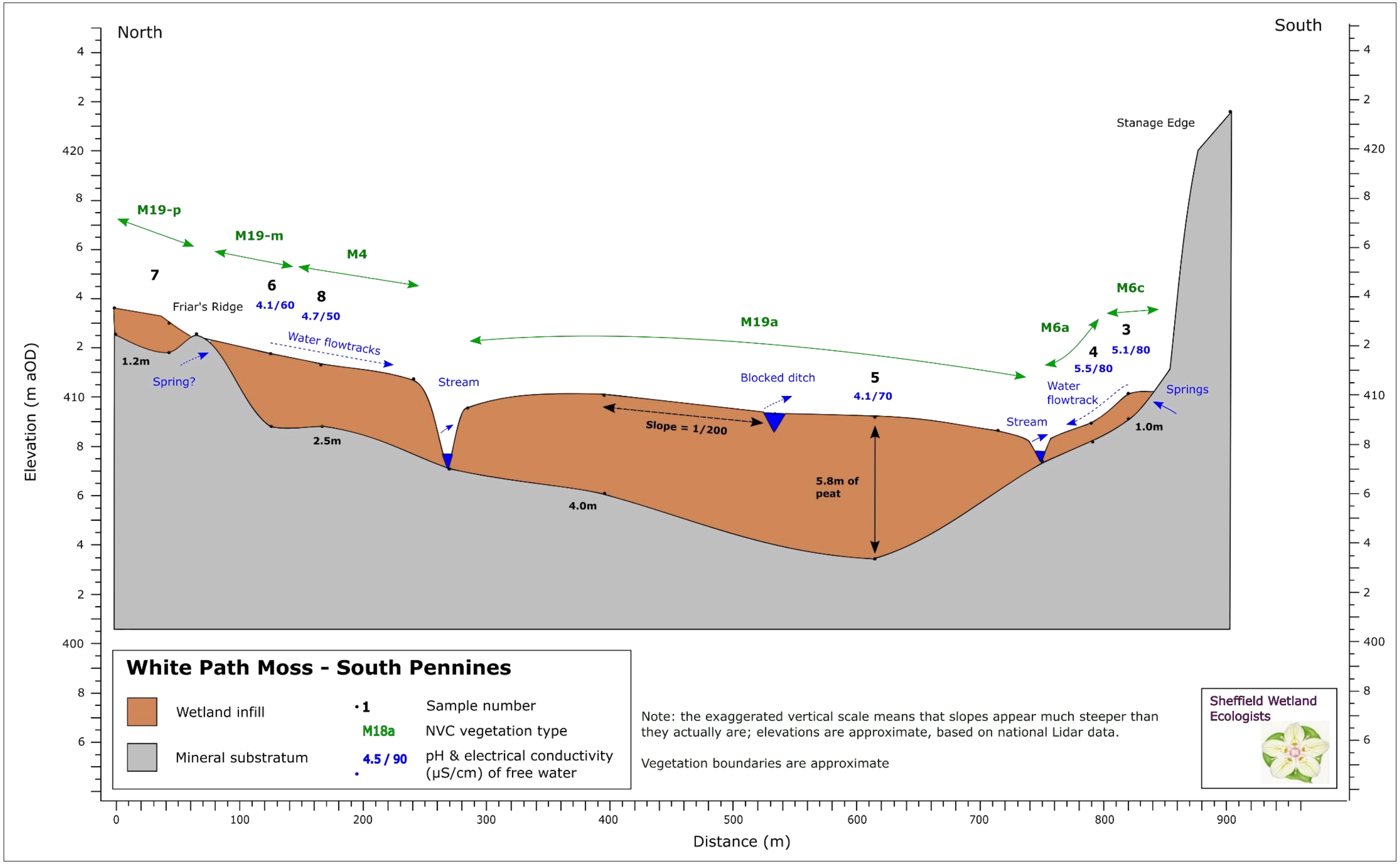

Figure A 18. White Path Moss N–S section.

11.2.3 Forest of Bowland

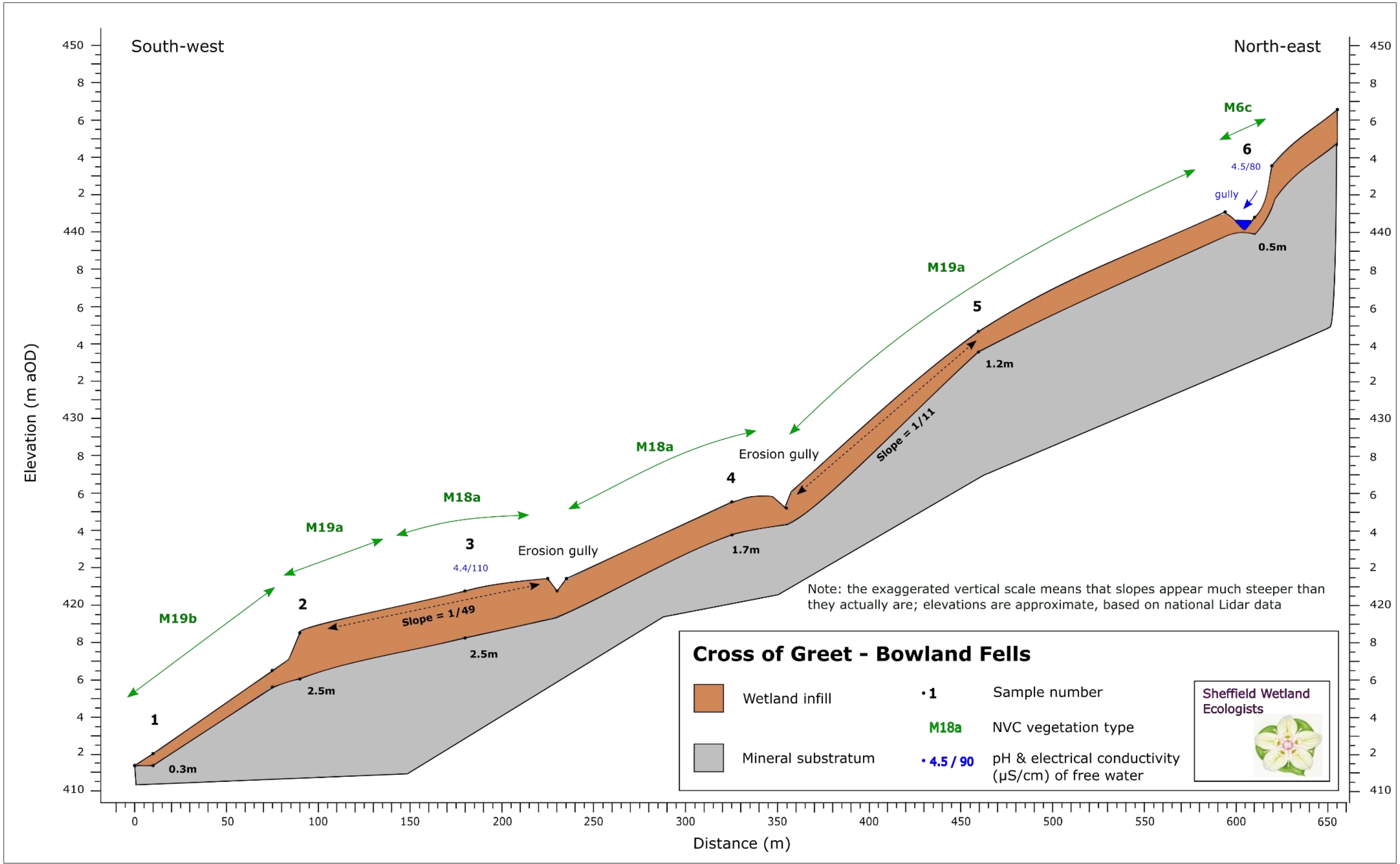

Figure A 19. Cross of Greet SW–NE section.

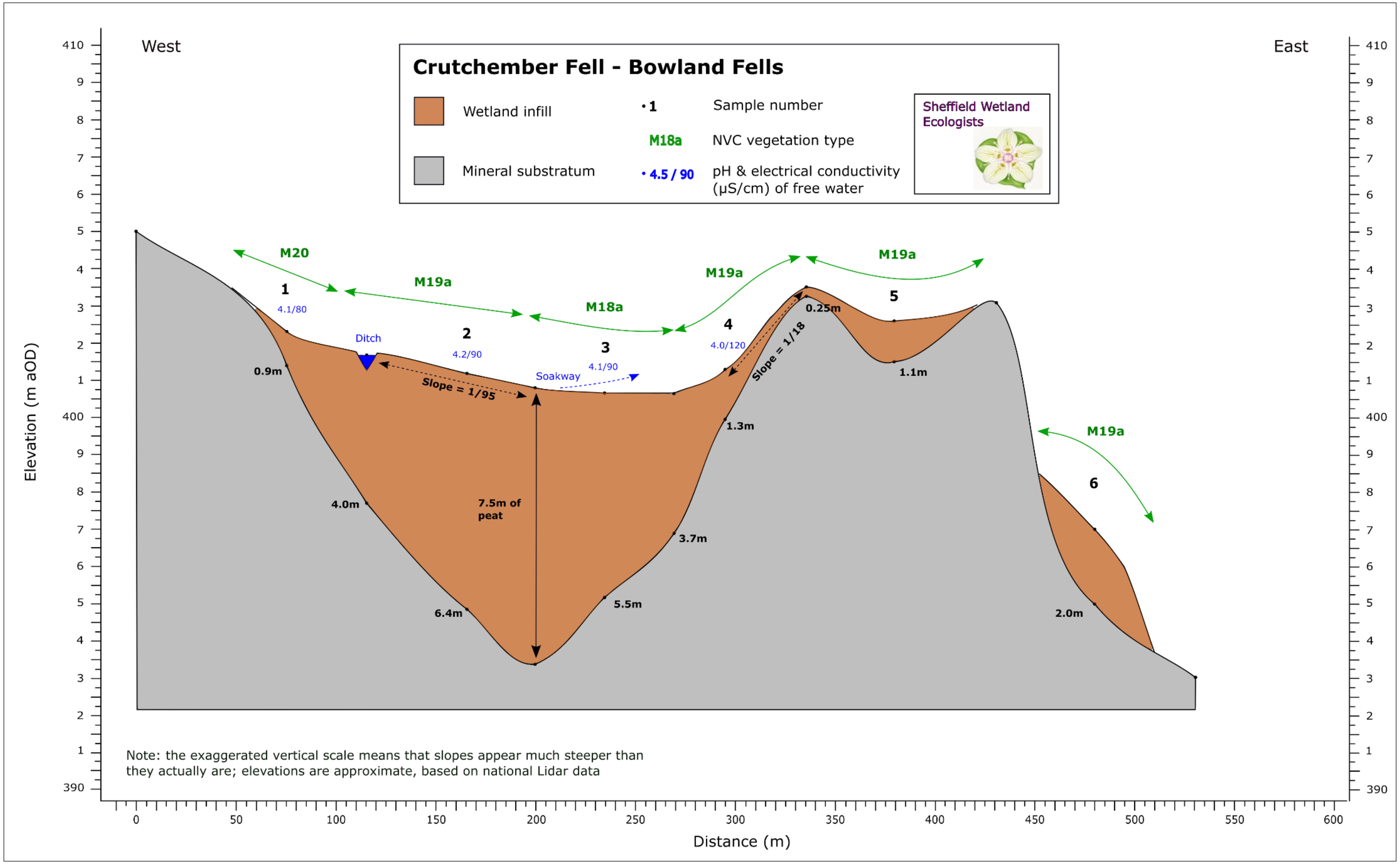

Figure A 20. Crutchember Fell W–E section.

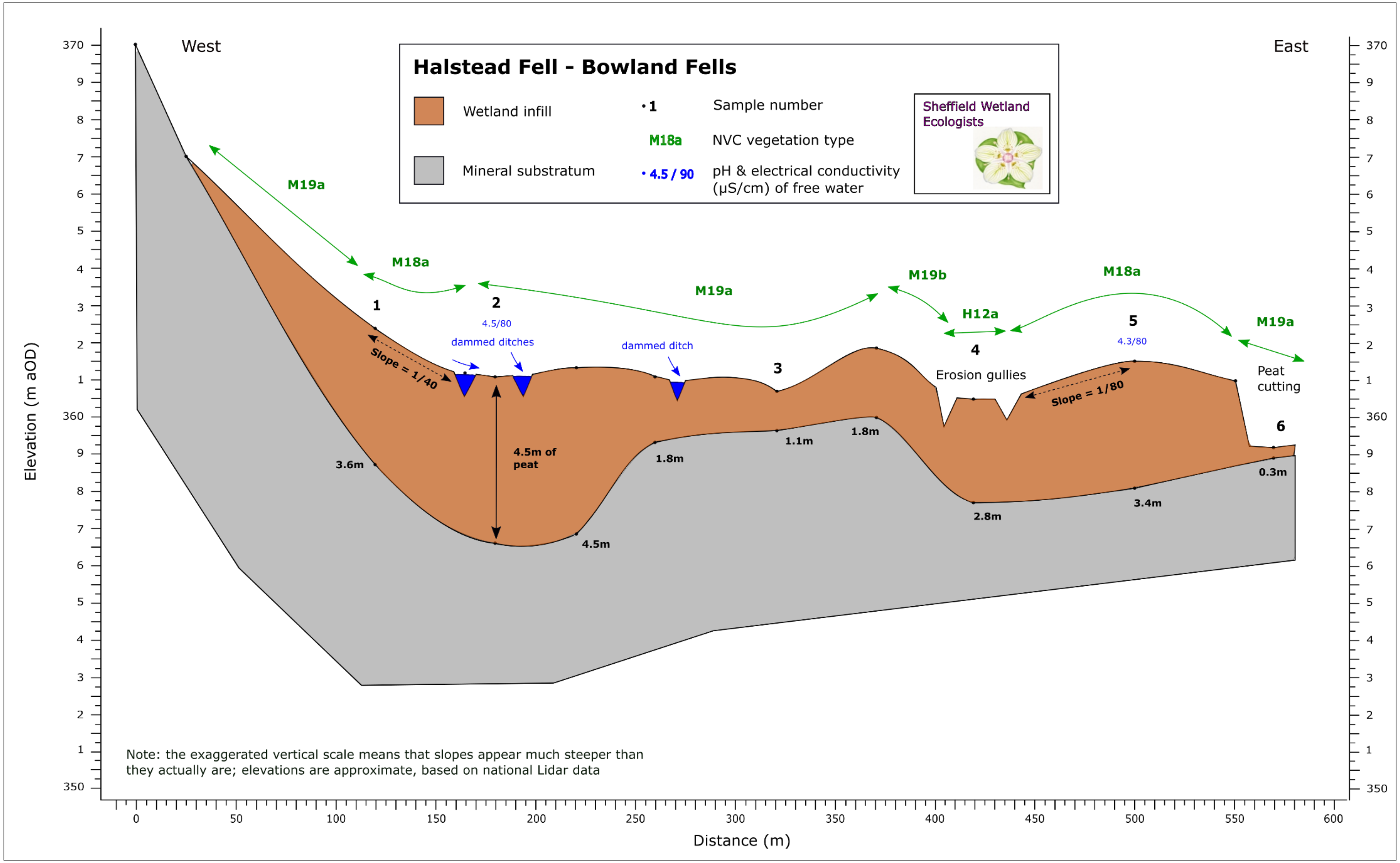

Figure A 21. Halstead Fell W–E section.

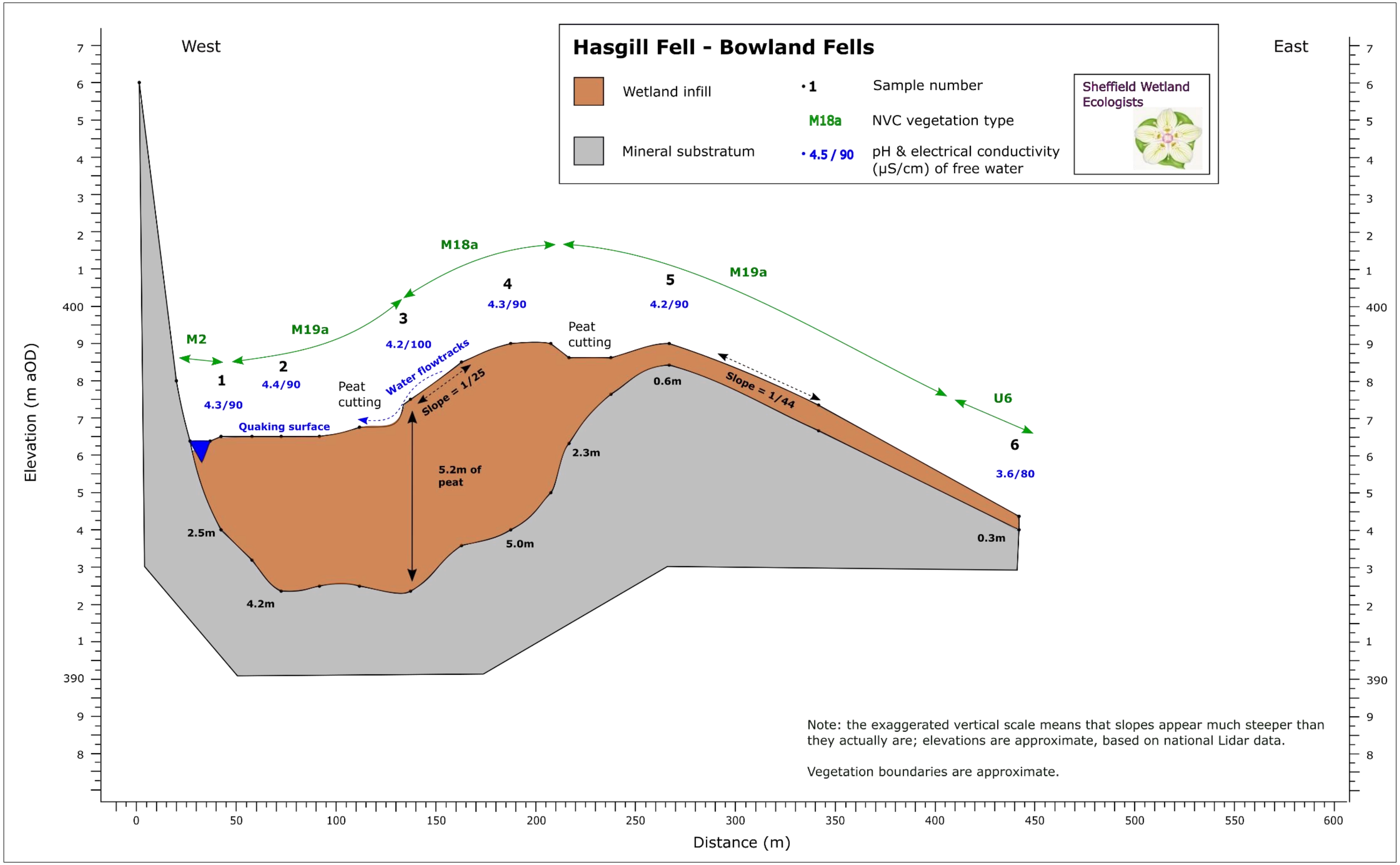

Figure A 22. Hasgill Fell W–E section.

11.2.4 Greater Manchester, North Yorkshire, North Pennines & south Cumbria

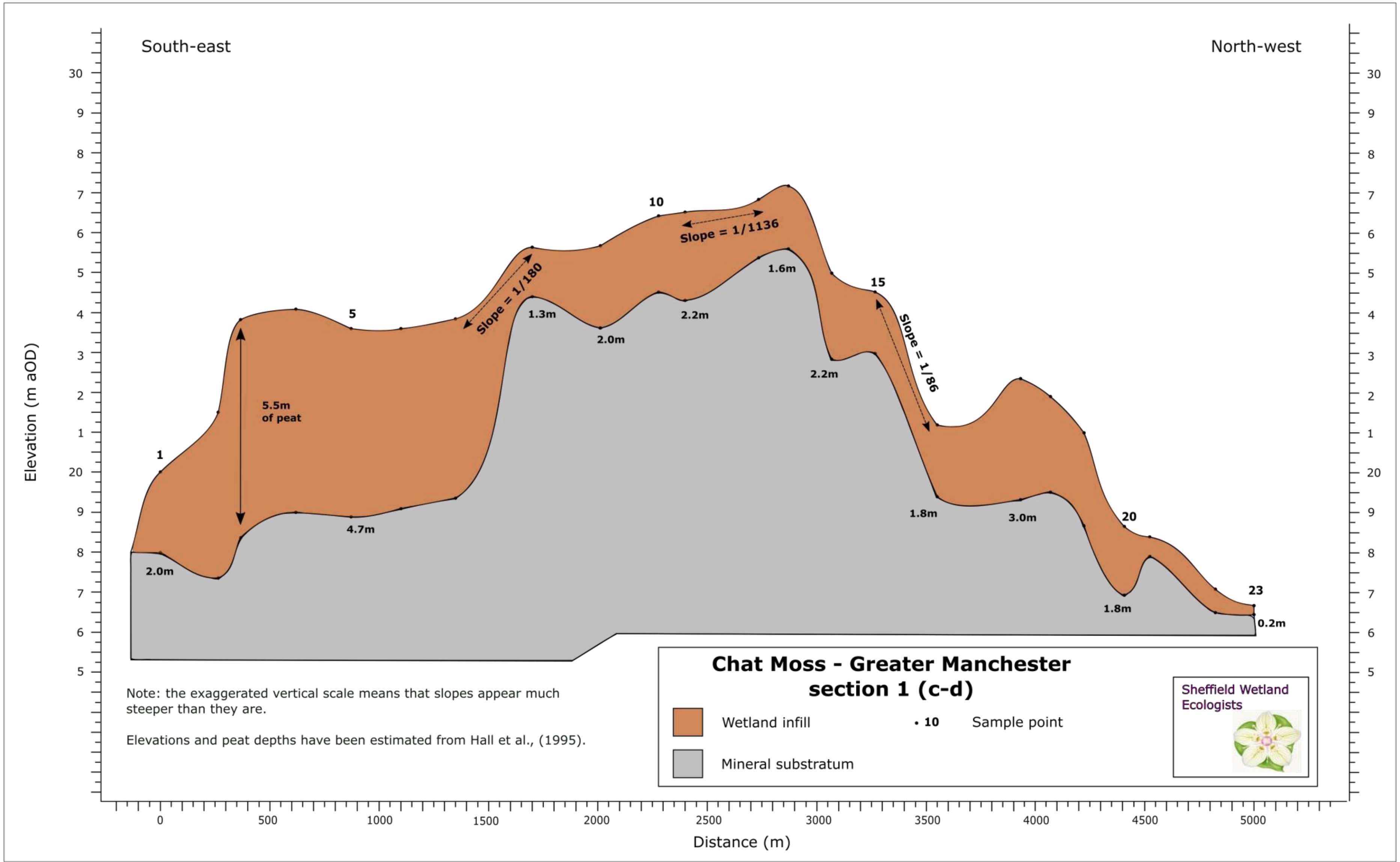

Figure A. 23. Chat Moss SE–NW section.

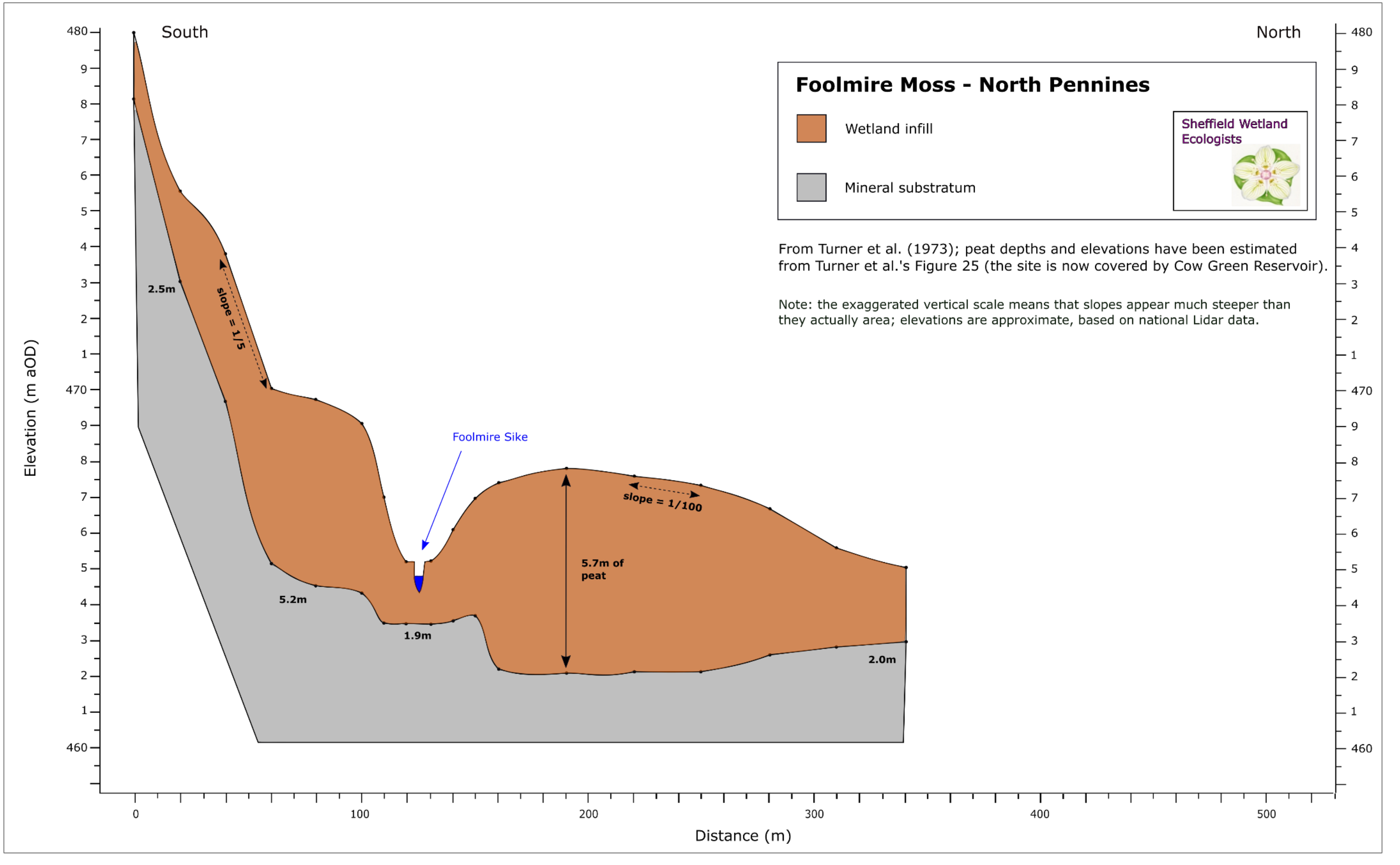

Figure A 24. Foolmire Moss S–N section.

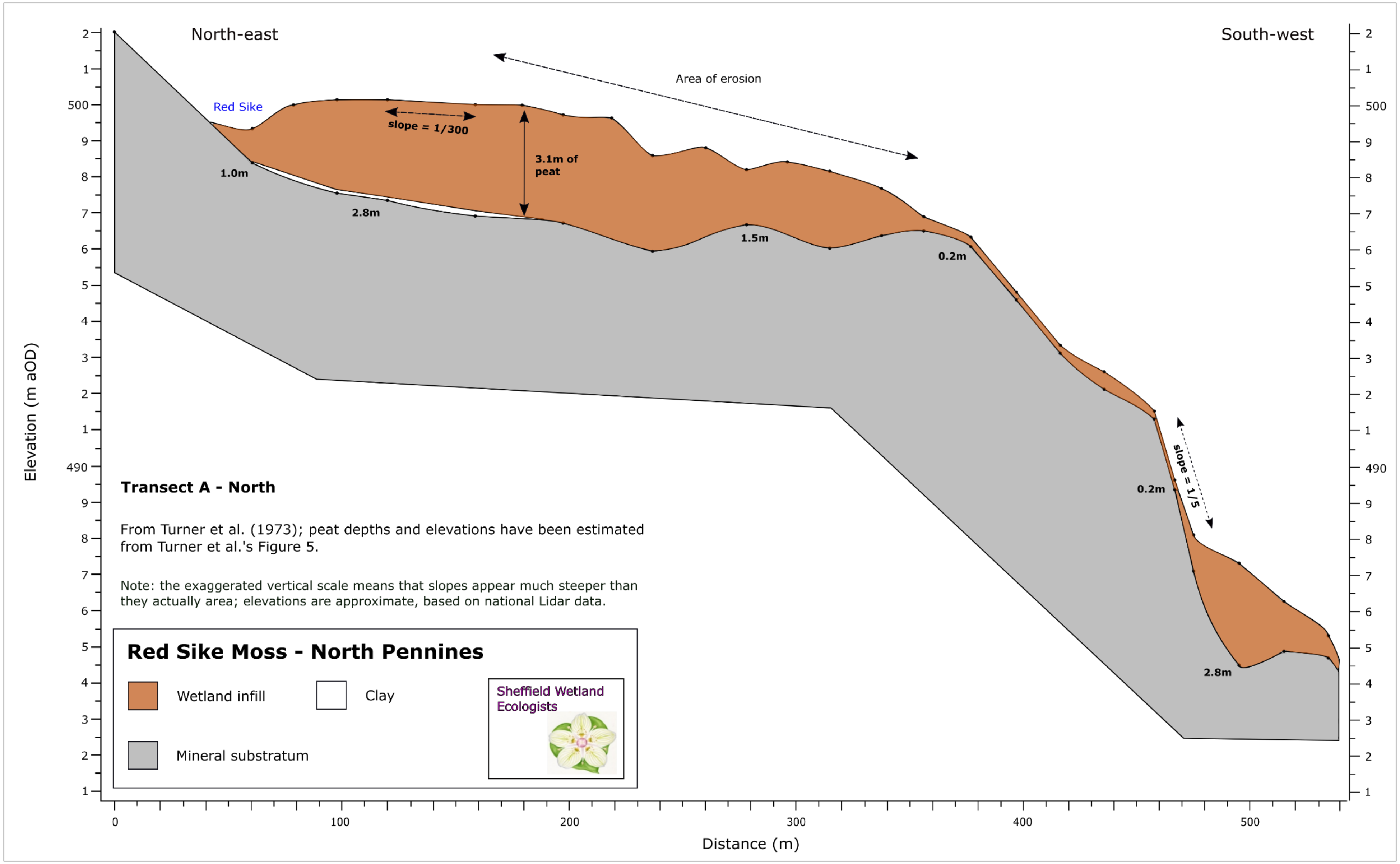

Figure A 25. Red Sike Moss Transect A, NE–SW section (part 1).

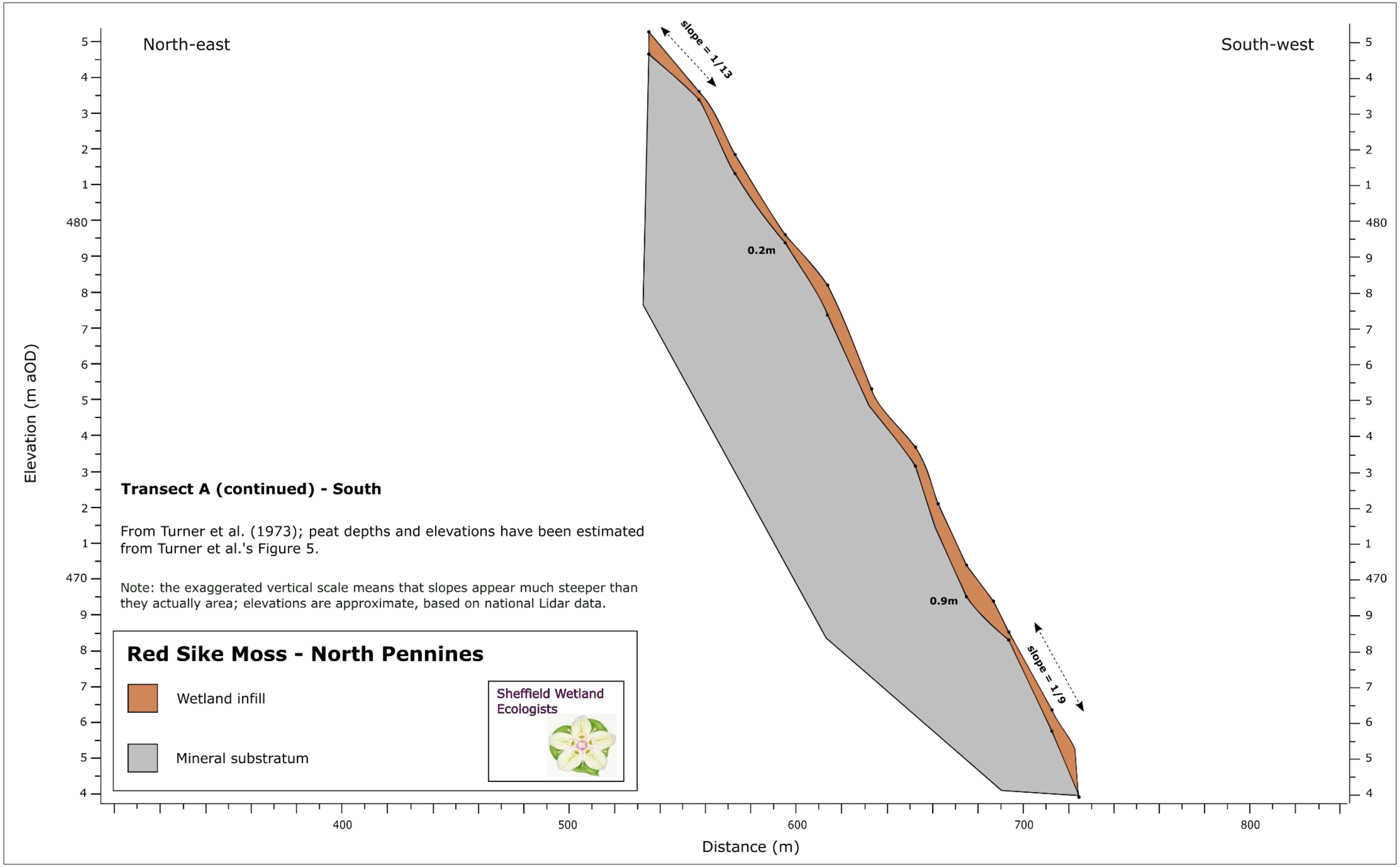

Figure A 26. Red Sike Moss Transect A, NE–SW section (part 2).

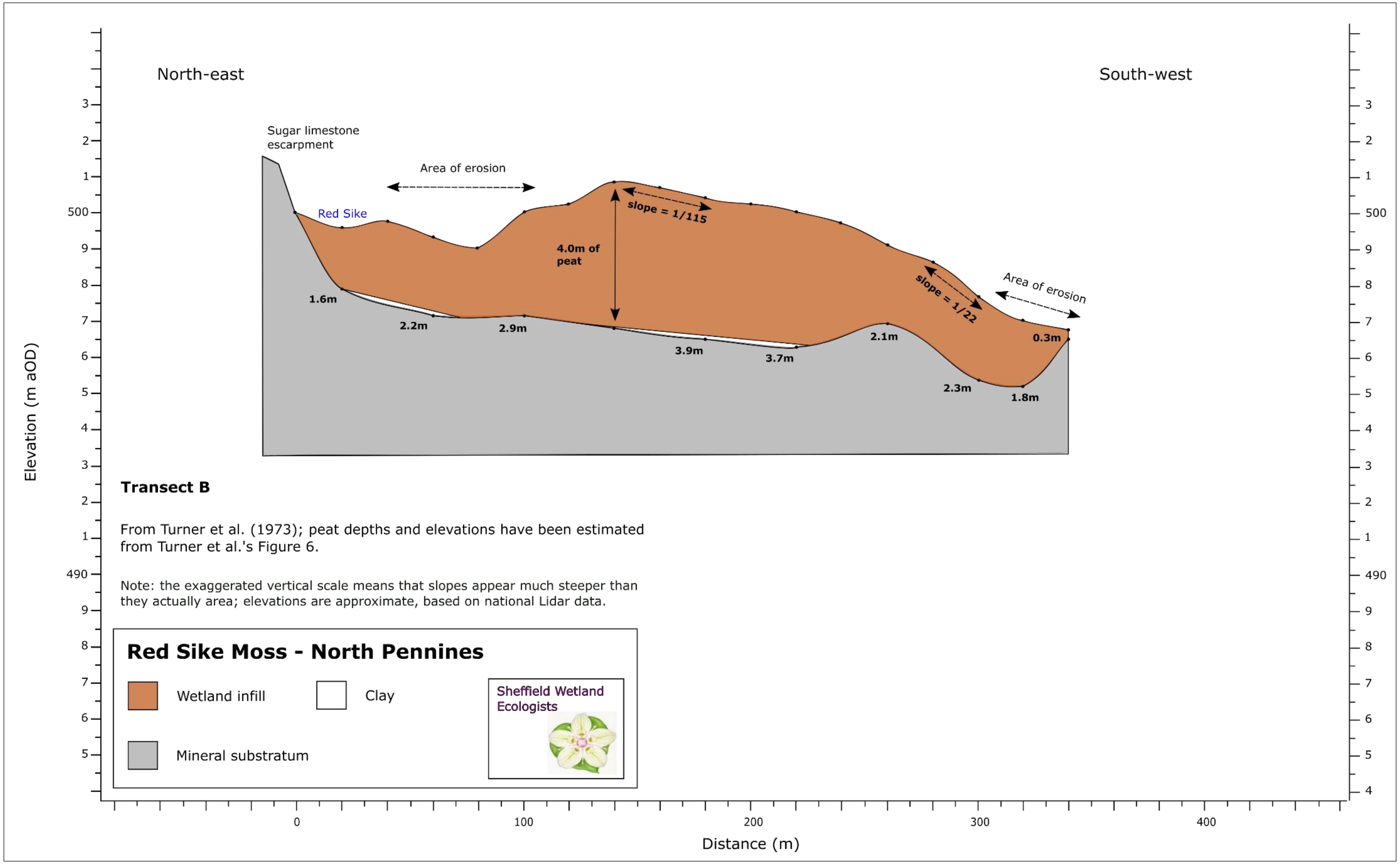

Figure A 27. Red Sike Moss Transect B, NE–SW section.

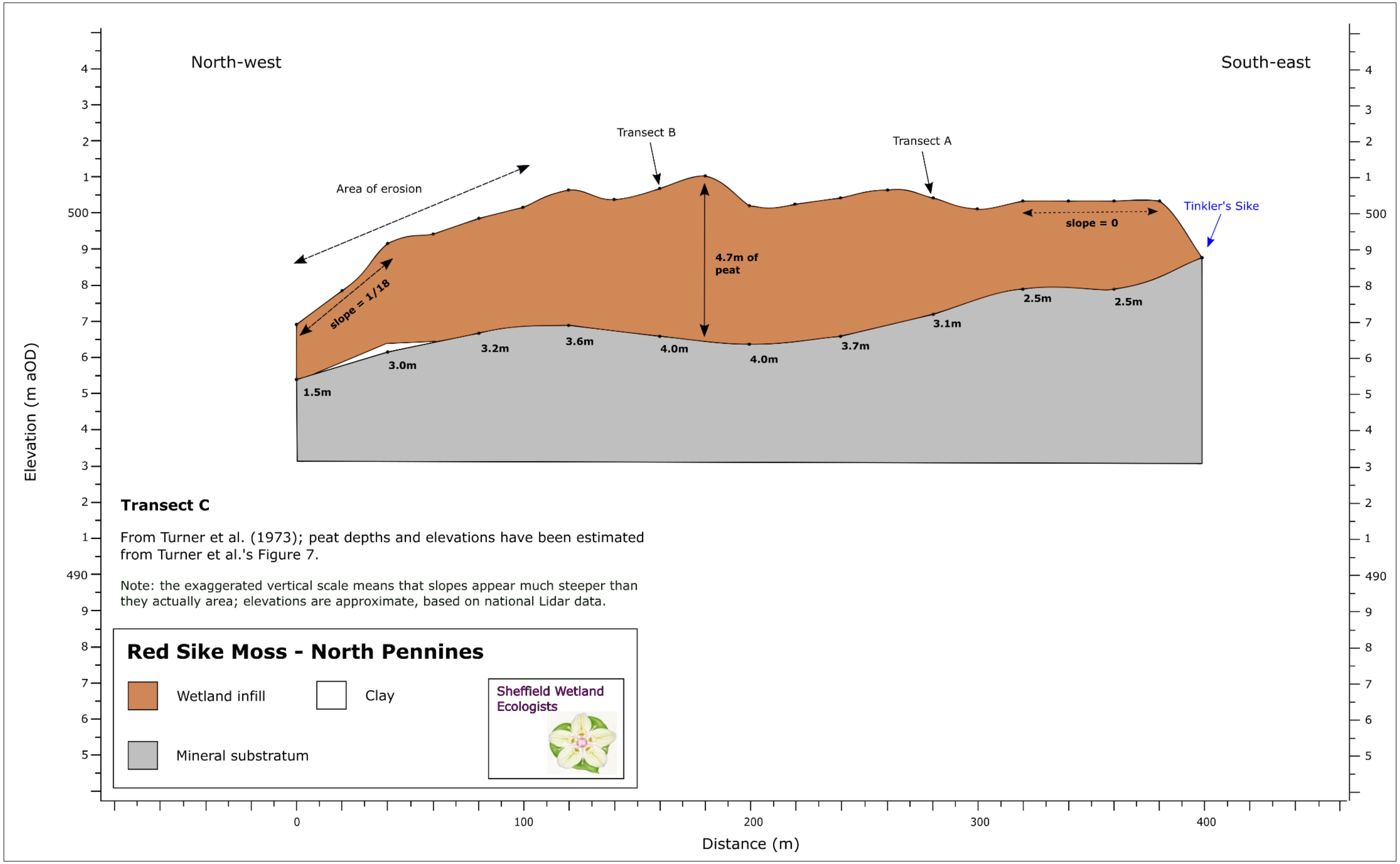

Figure A 28. Red Sike Moss Transect C, NW–SE section.

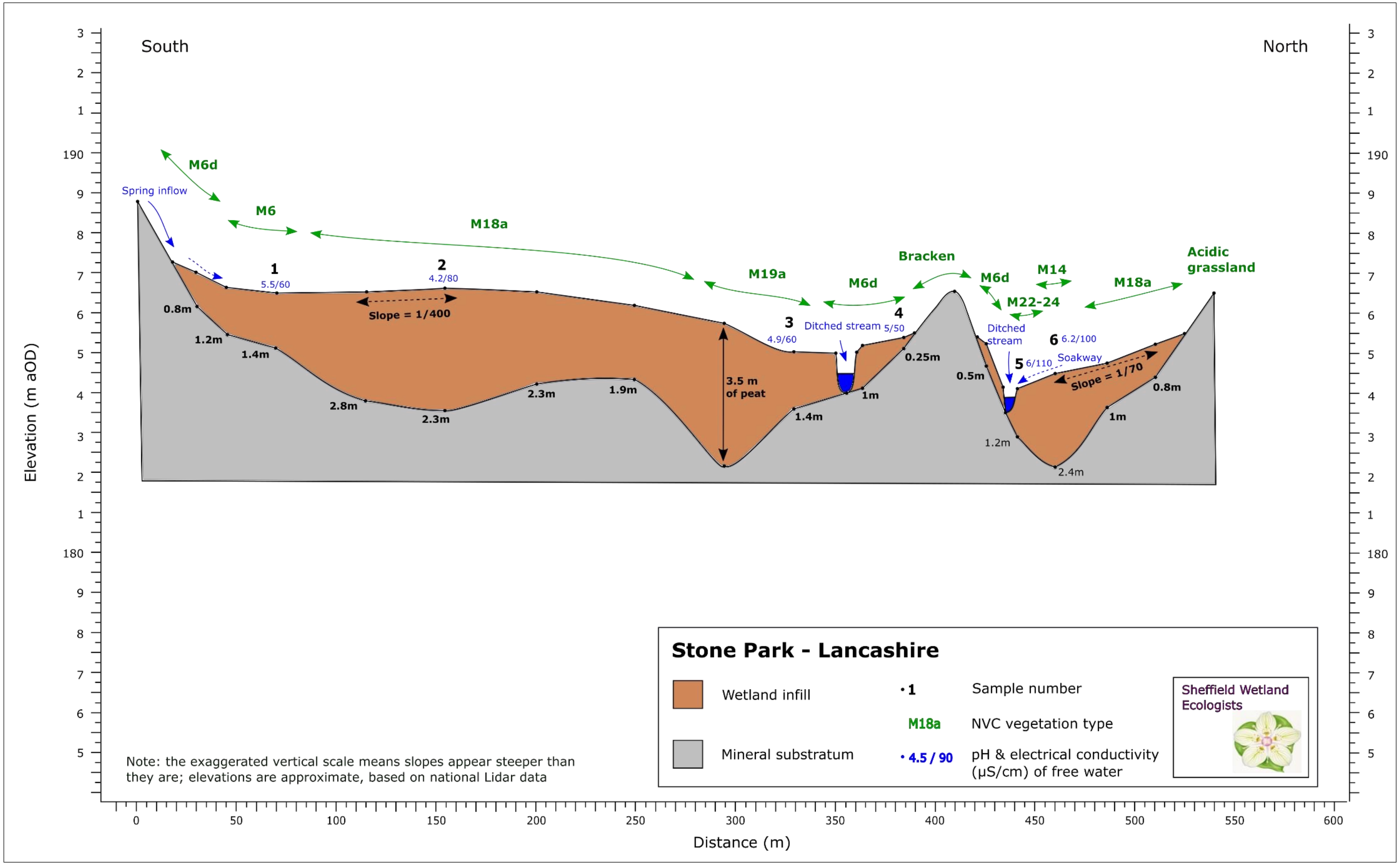

Figure A 29. Stone Park S–N section.

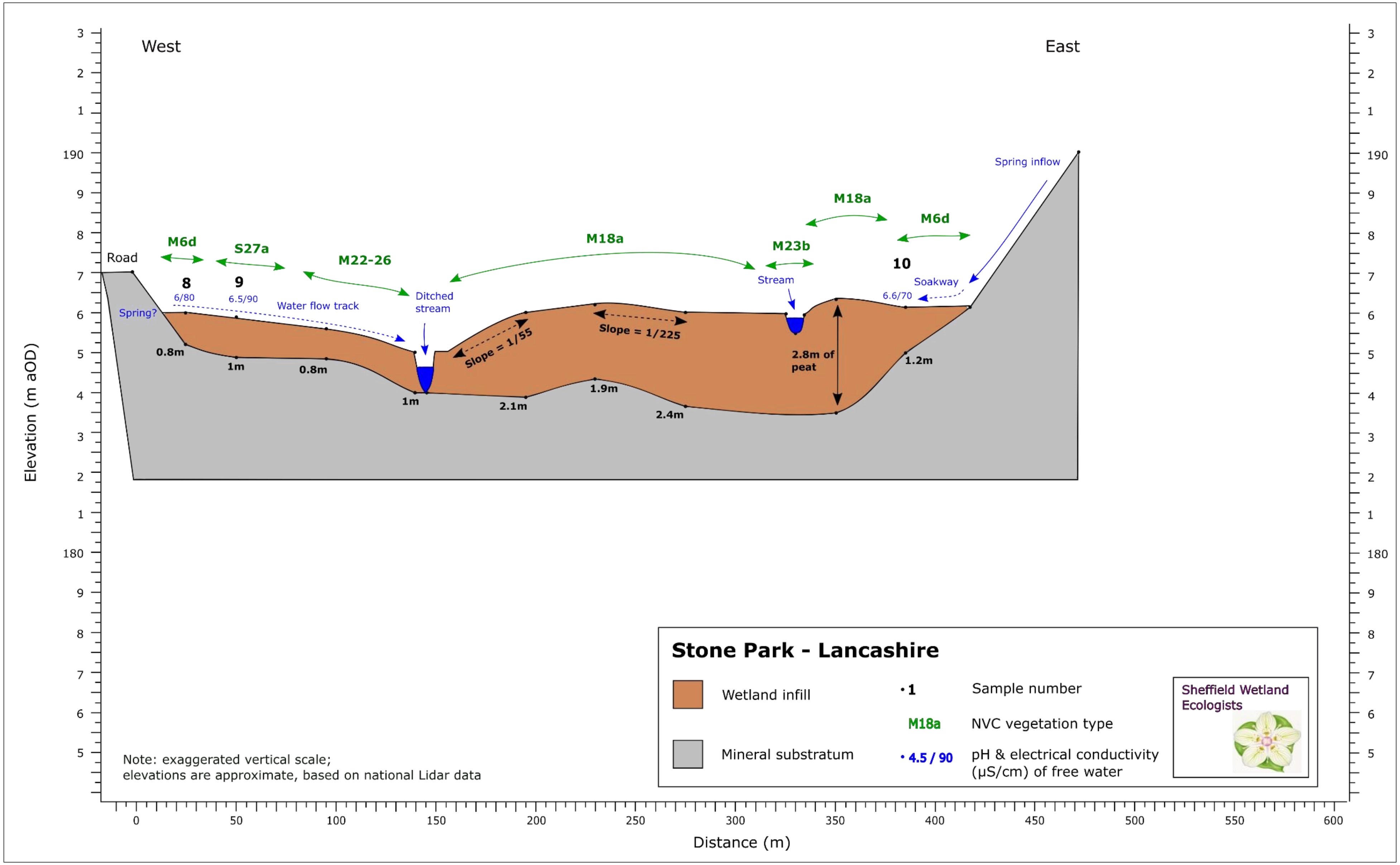

Figure A 30. Stone Park W–E section.

11.2.5 Cumbria and Northumberland (including the Border Mires)

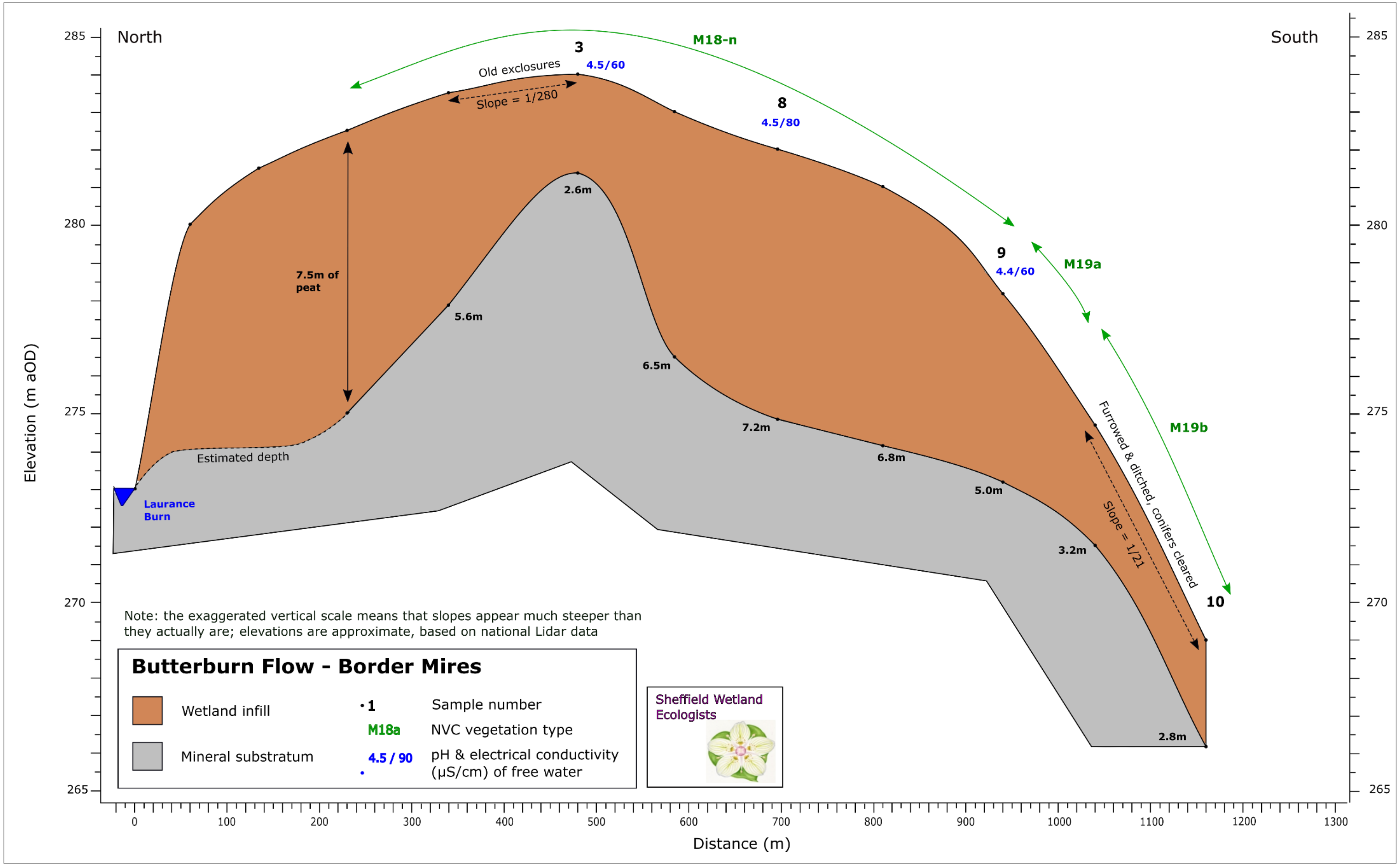

Figure A 31. Butterburn Flow N–S section.

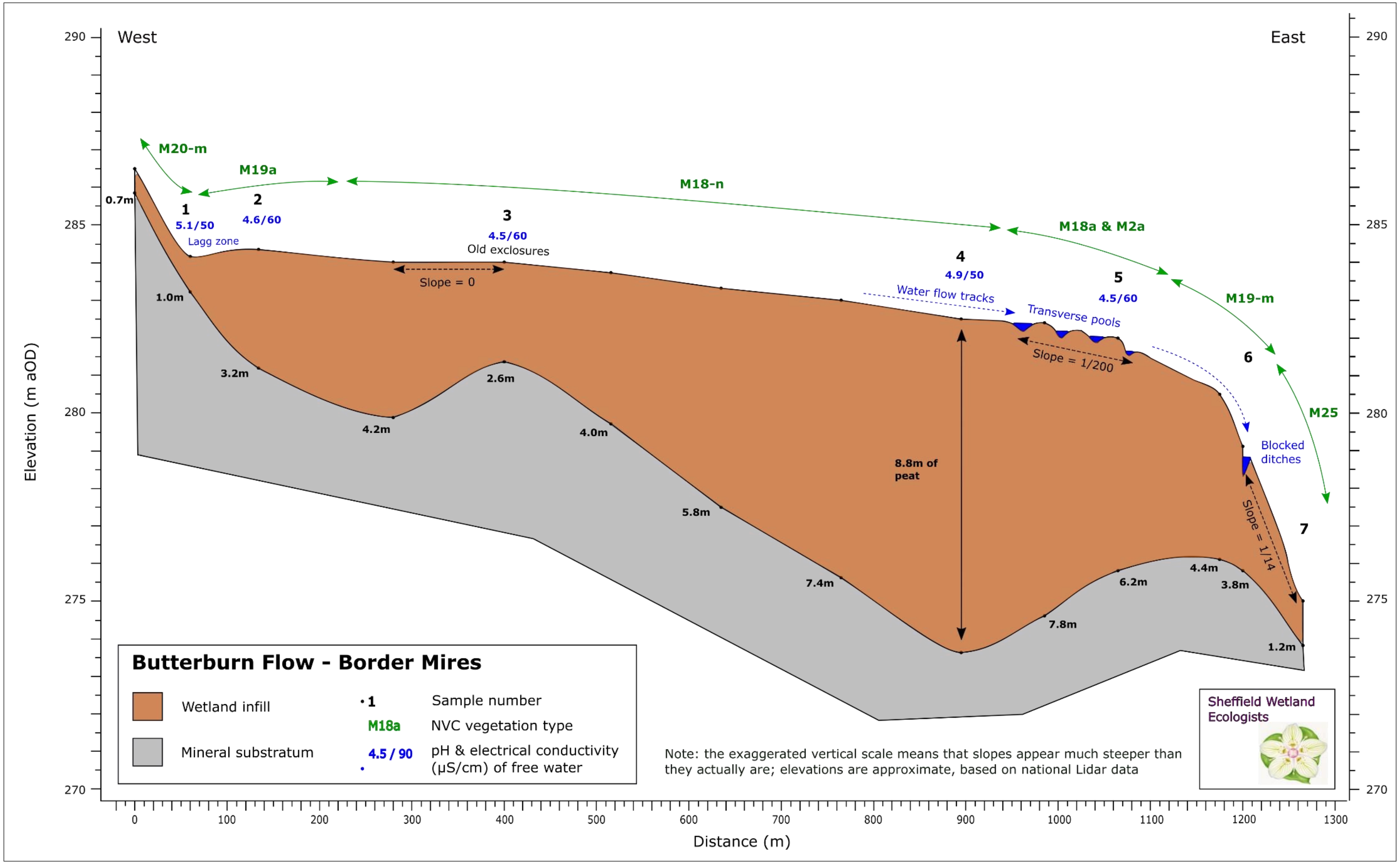

Figure A 32. Butterburn Flow W–E section.

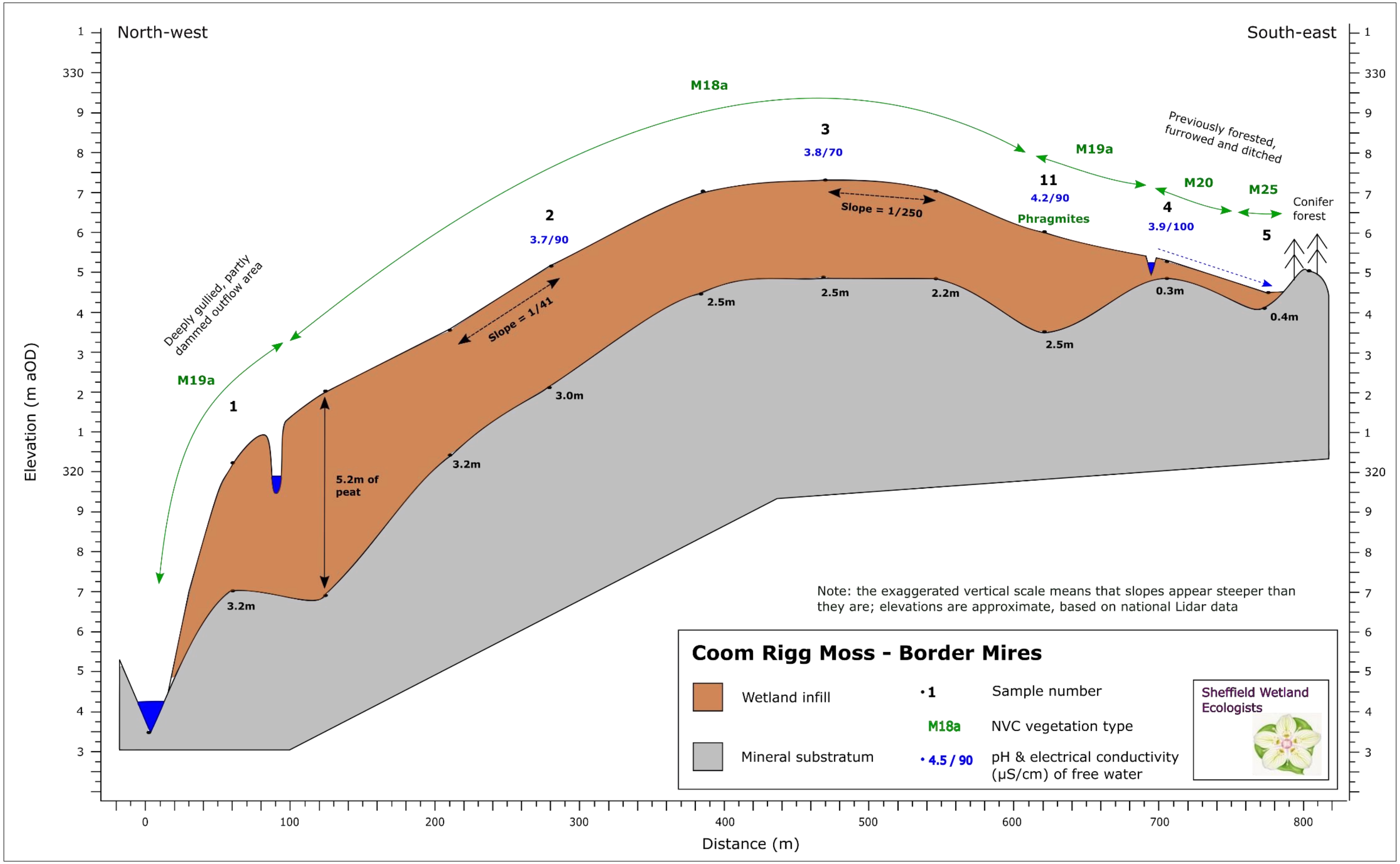

Figure A 33. Coom Rigg Moss NW–SE section.

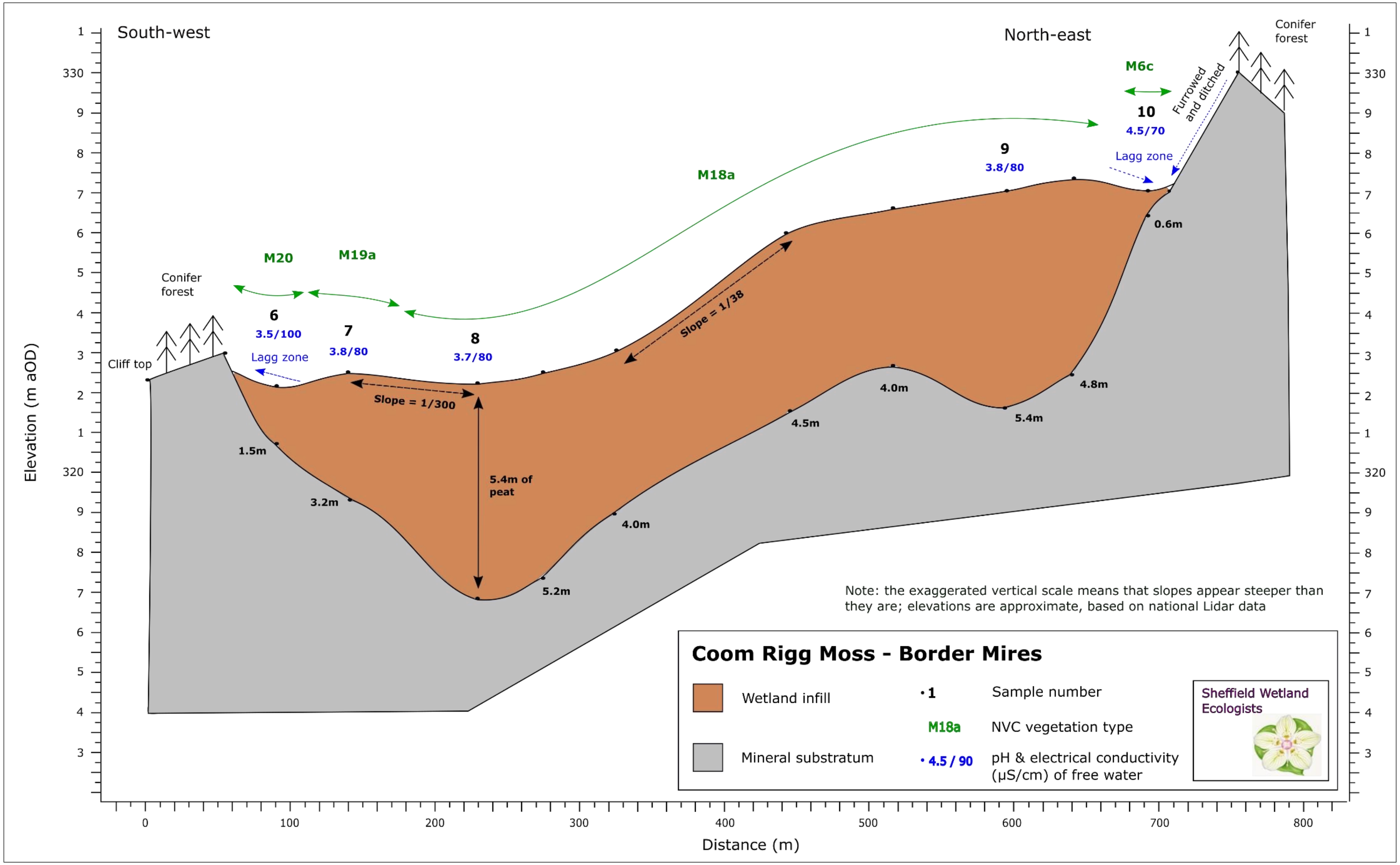

Figure A 34. Coom Rigg Moss SW–NE section.

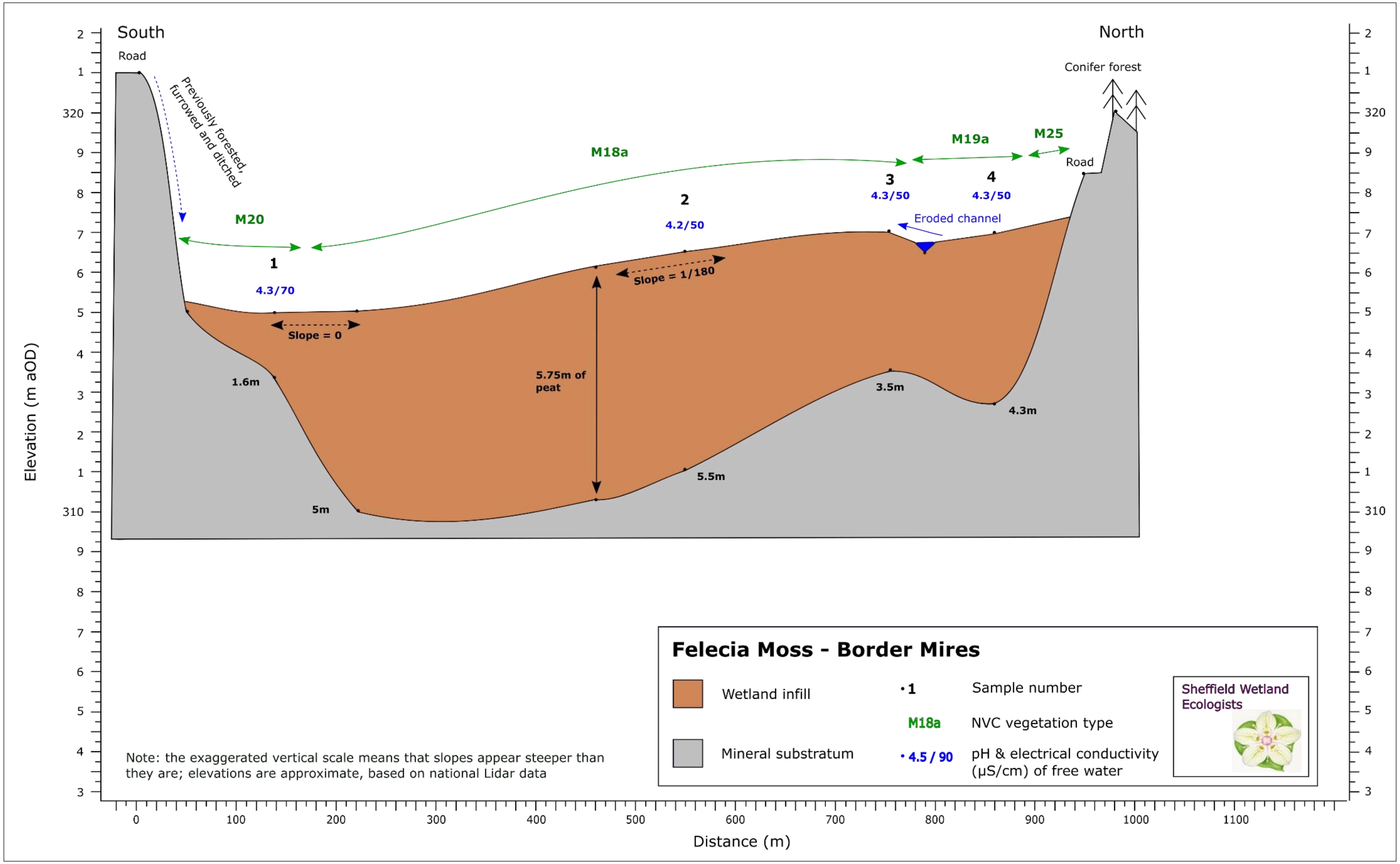

Figure A 35. Felecia Moss S–N section.

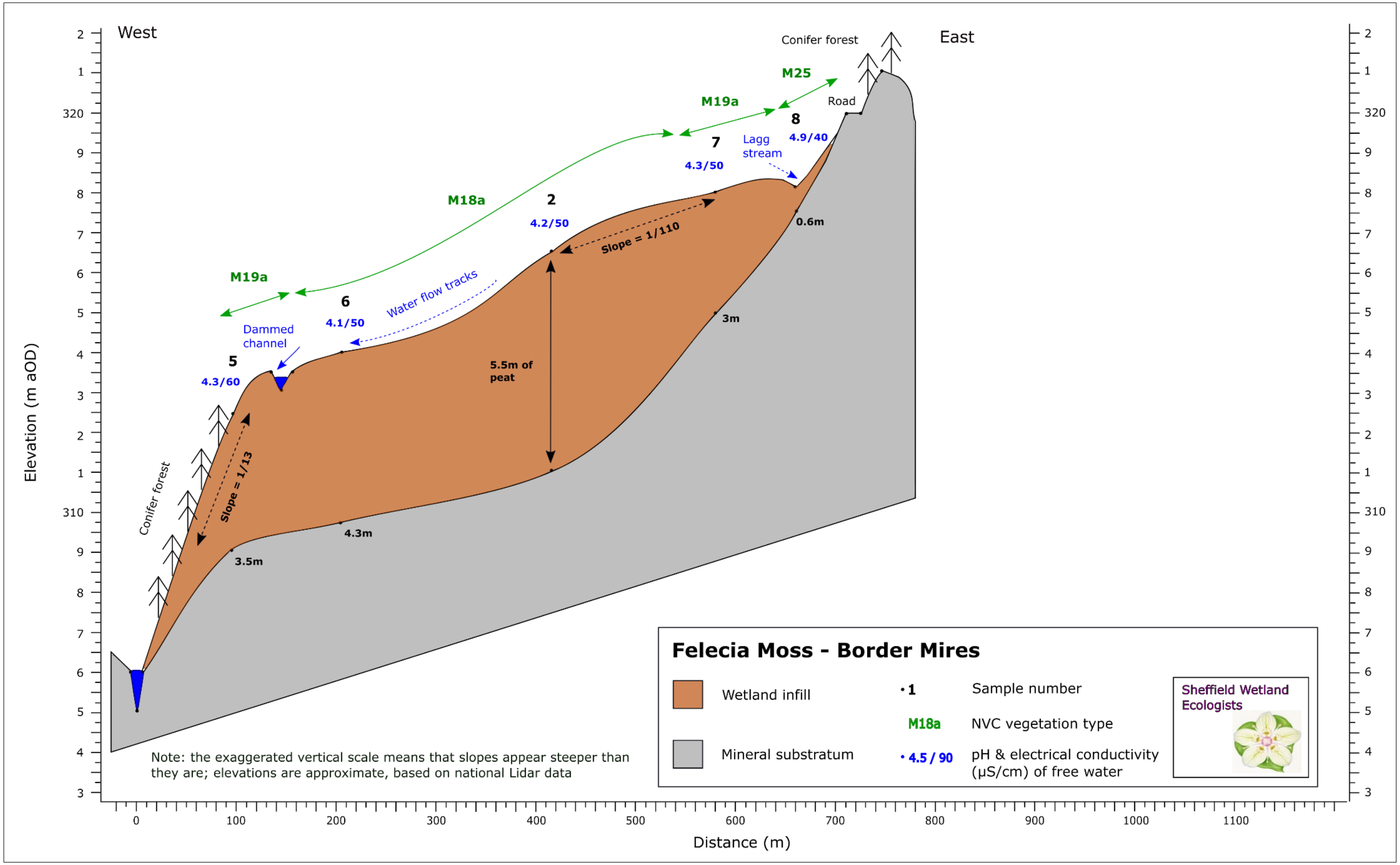

Figure A 36. Felecia Moss W–E section.

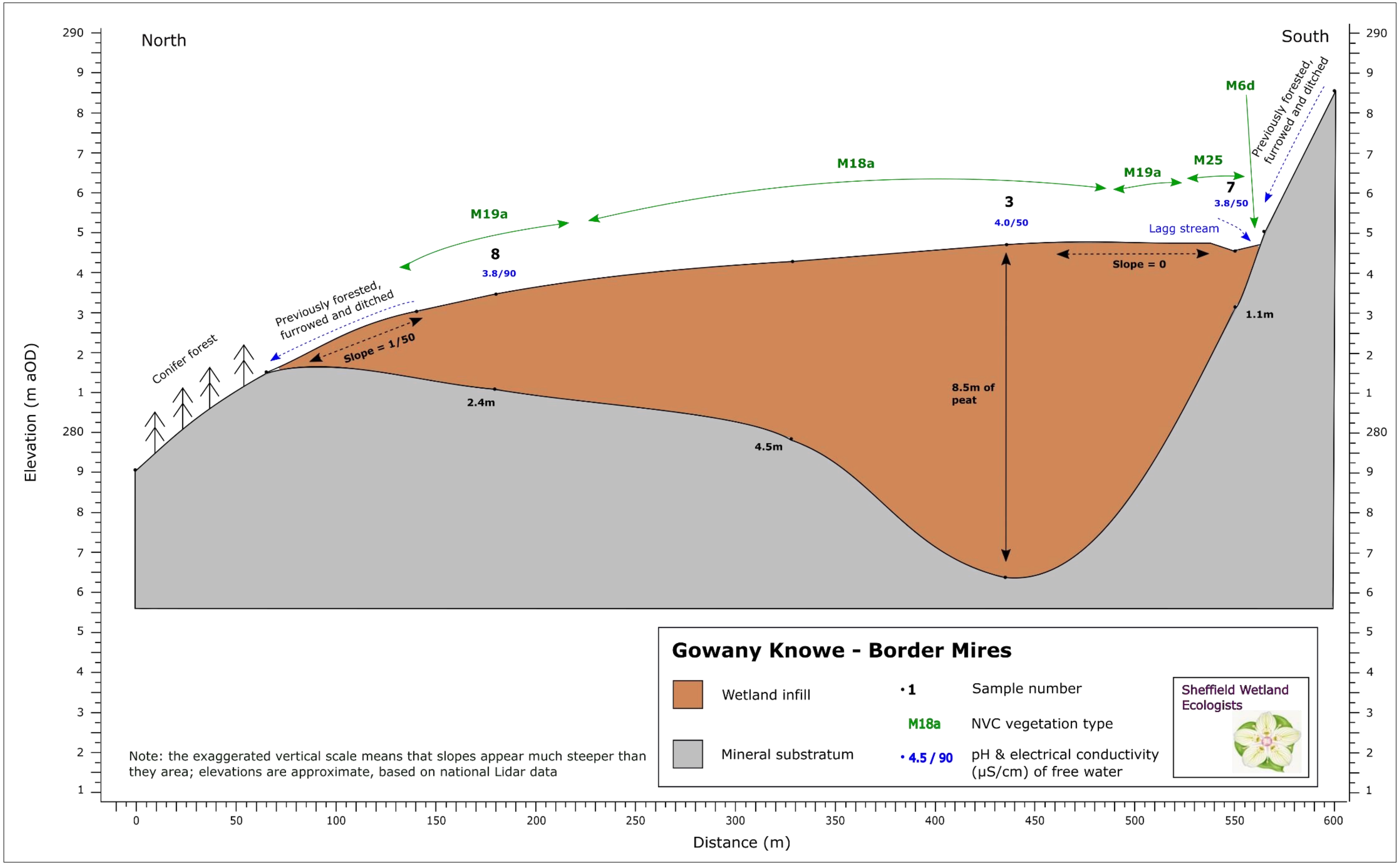

Figure A 37. Gowany Knowe N–S section.

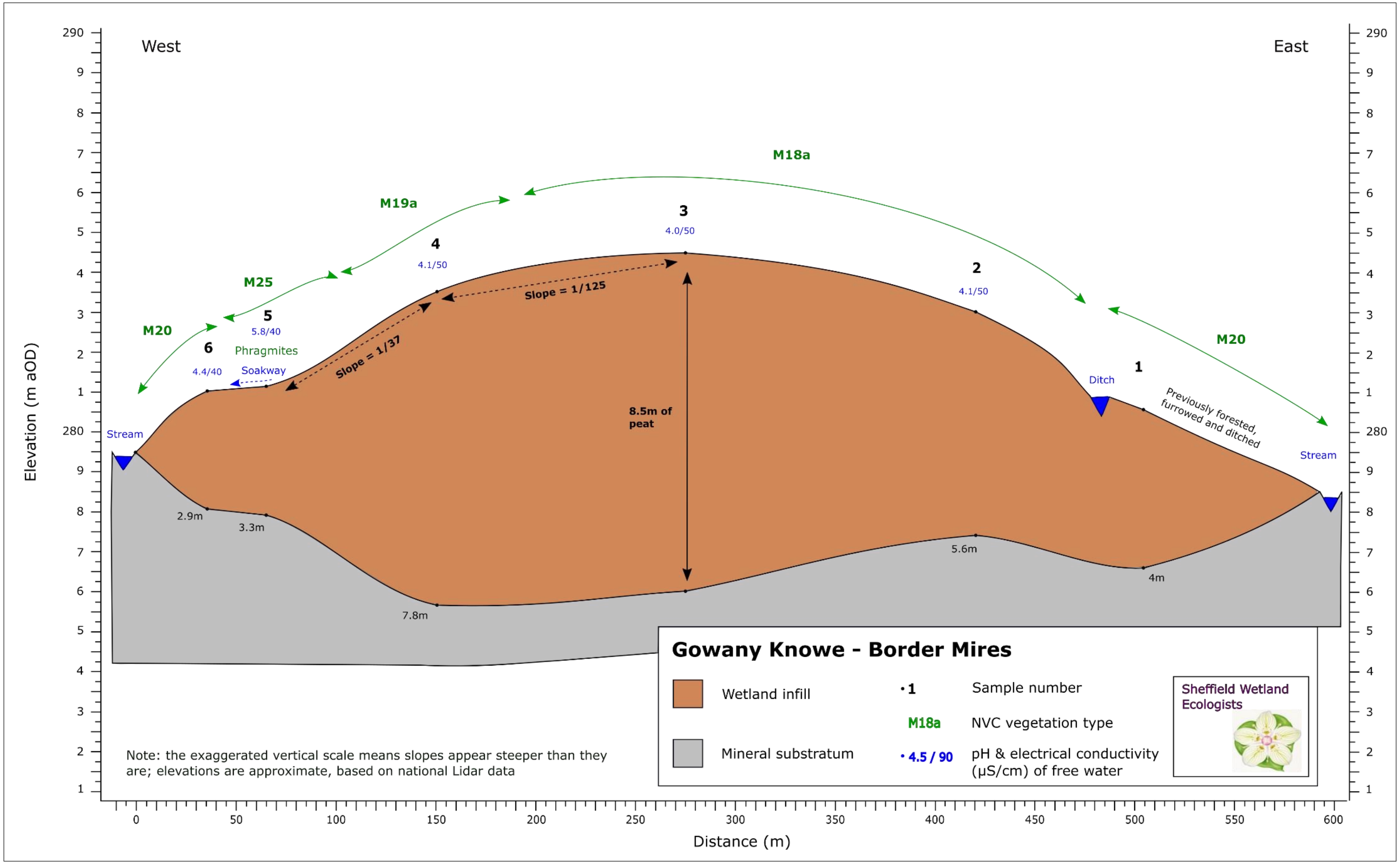

Figure A 38. Gowany Knowe W–E section.

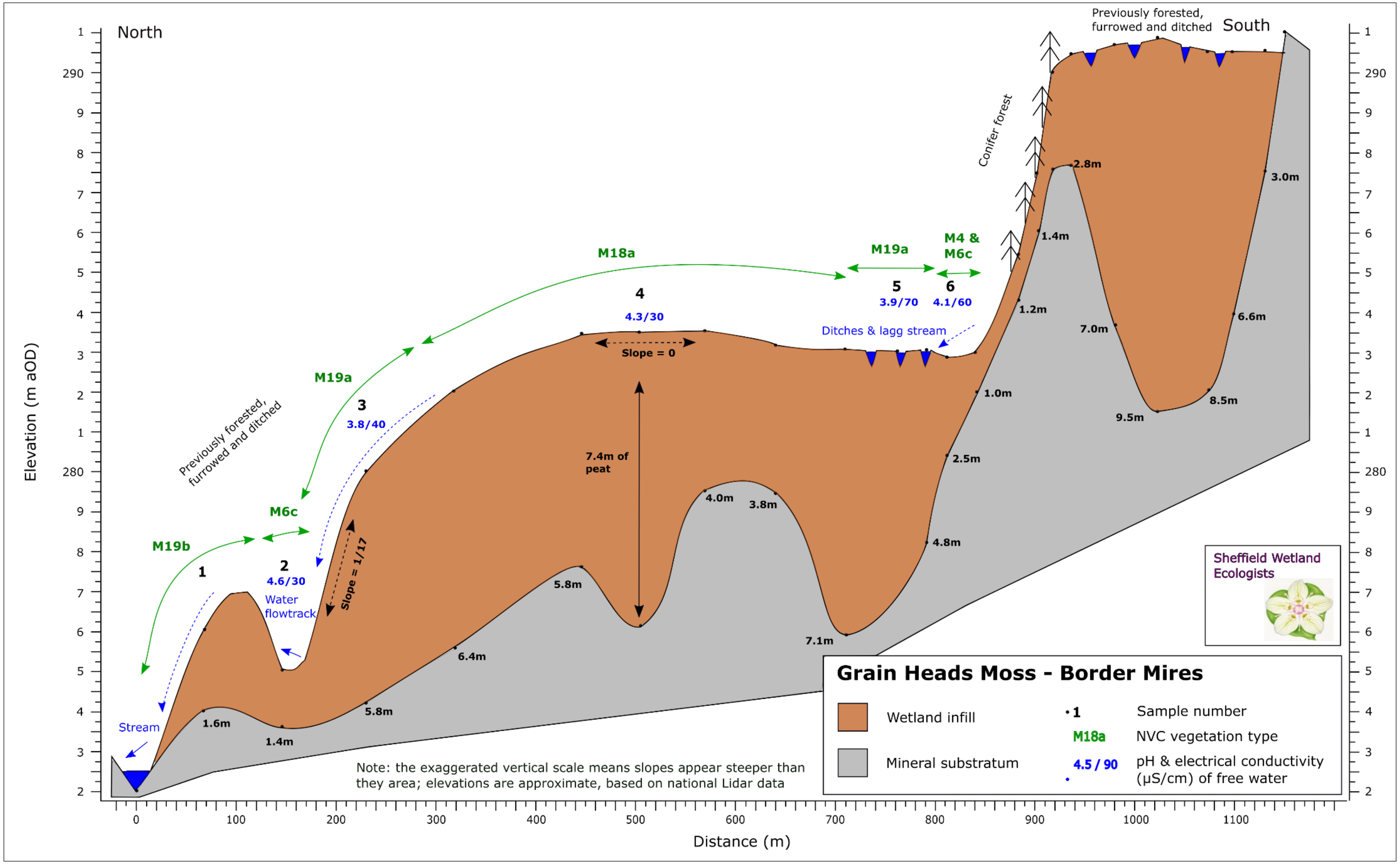

Figure A 39. Grain Heads Moss N–S section.

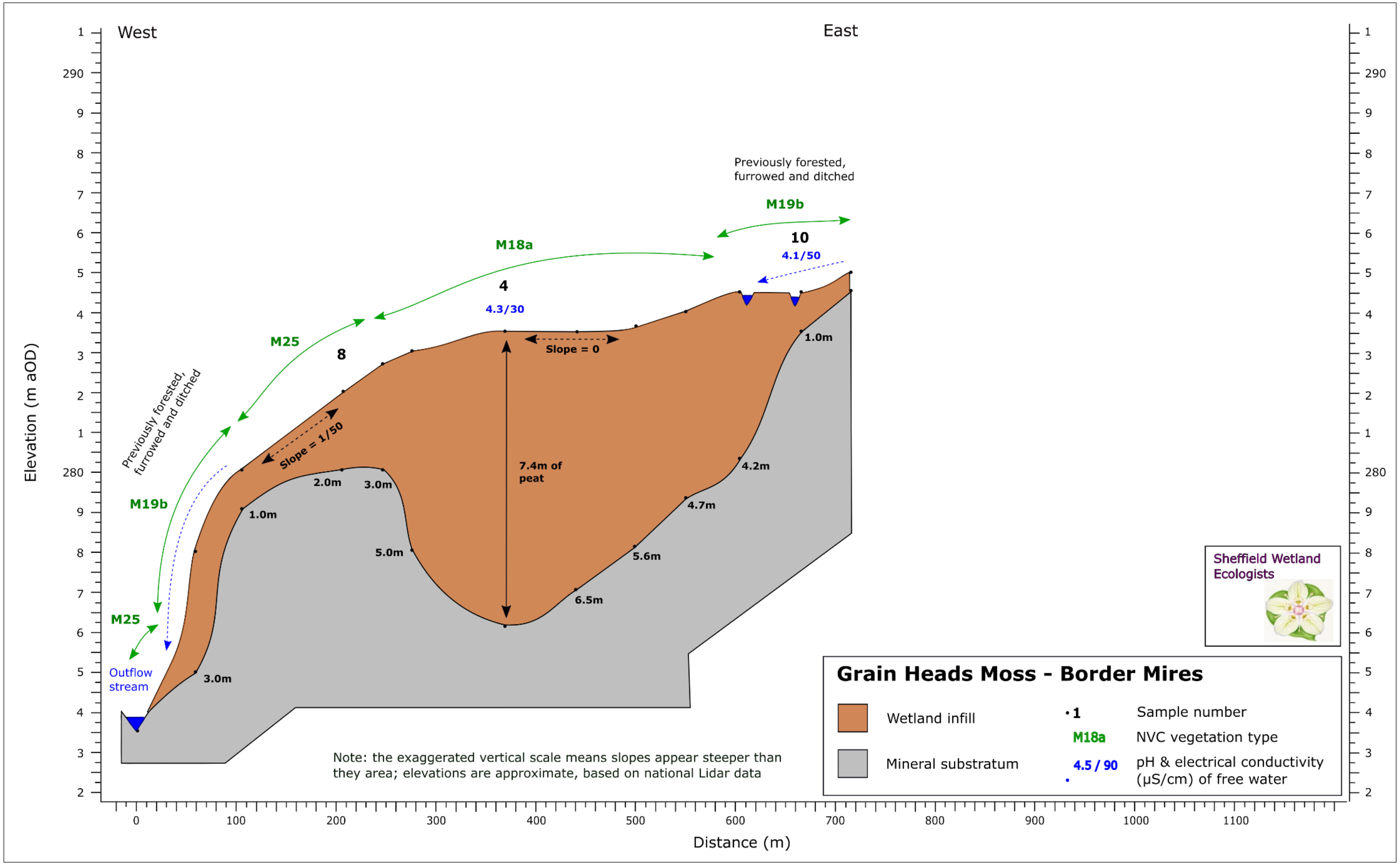

Figure A 40. Grain Heads Moss W–E section.

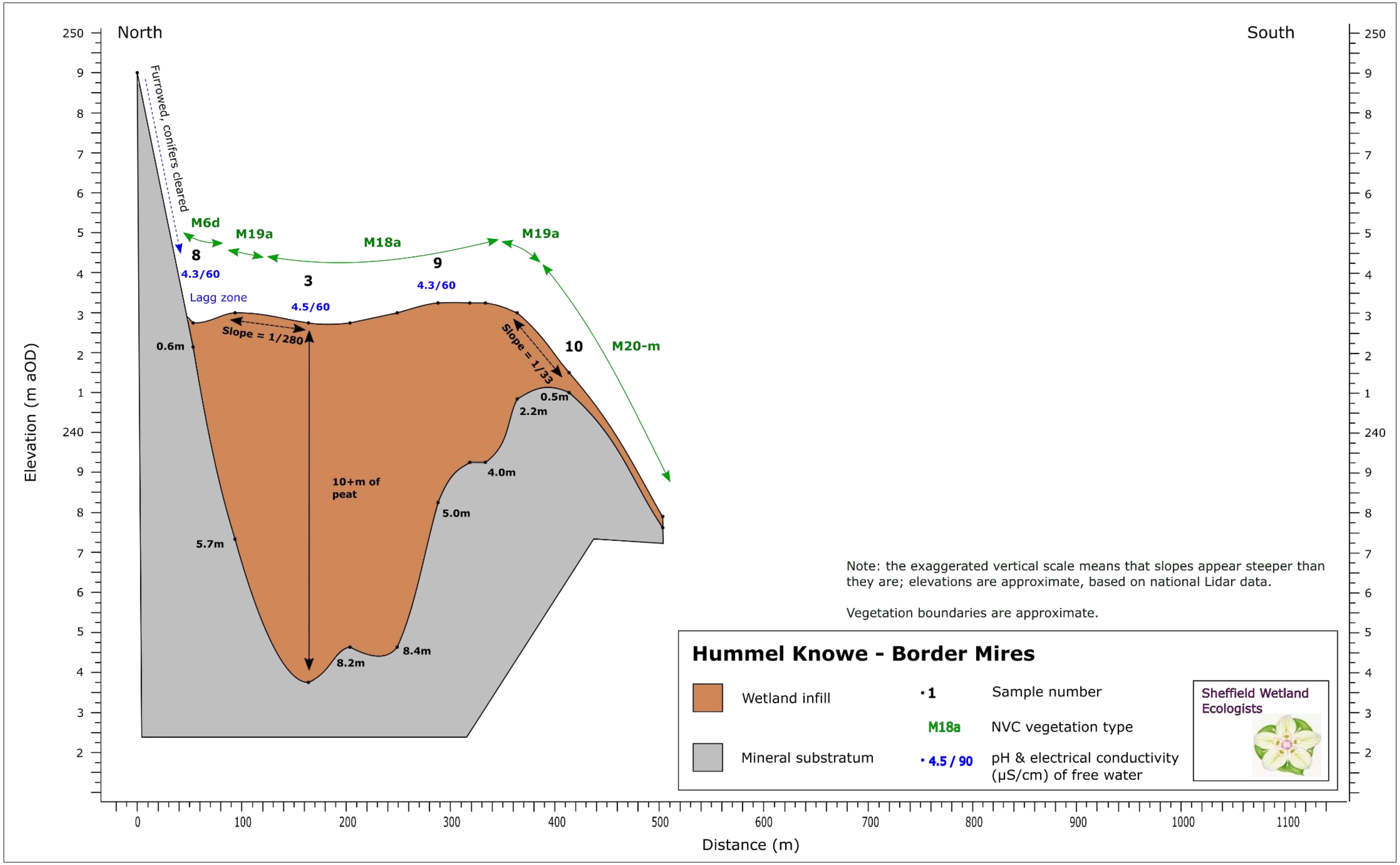

Figure A 41. Hummel Knowe N–S section.

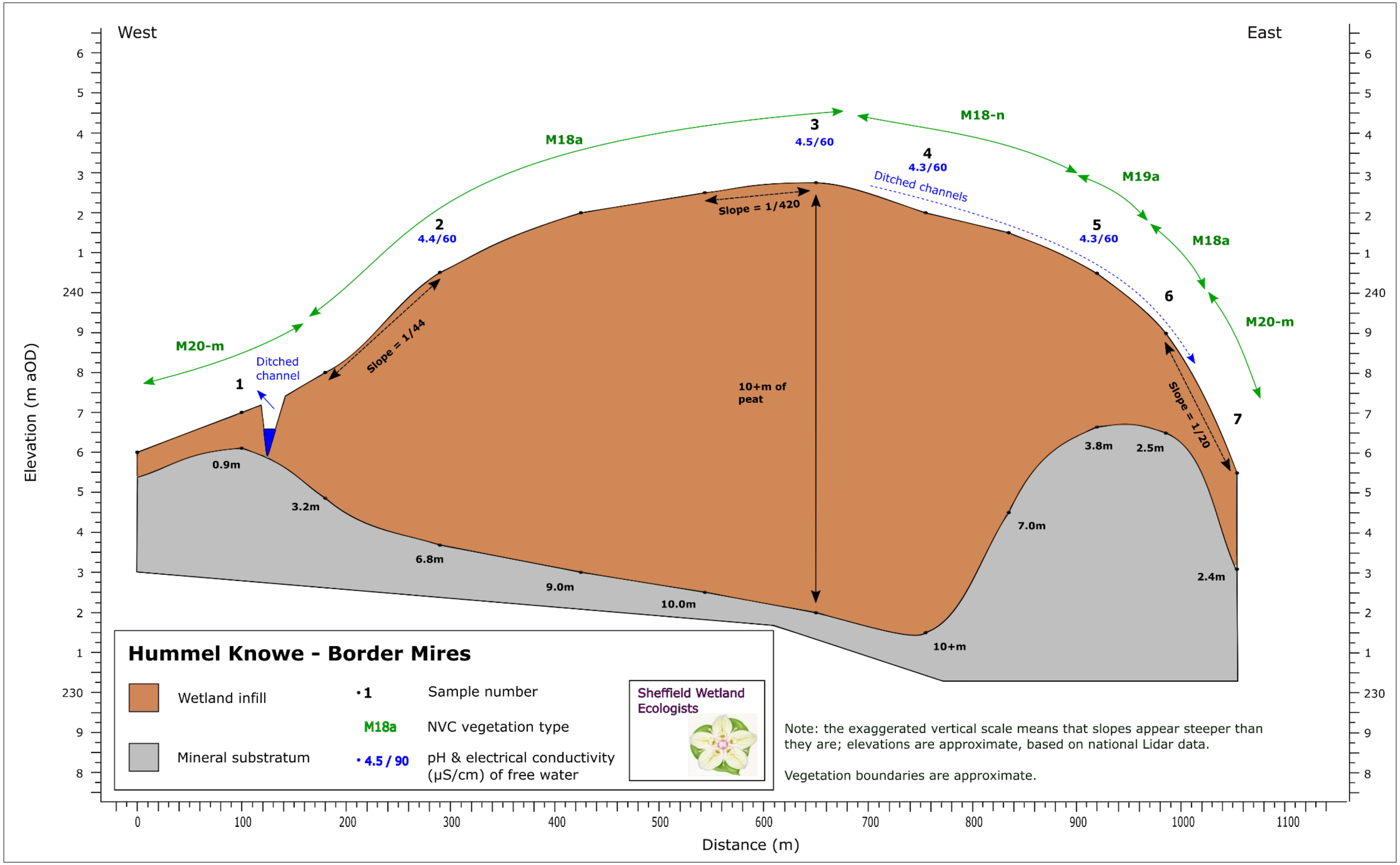

Figure A 42. Hummel Knowe W–E section.

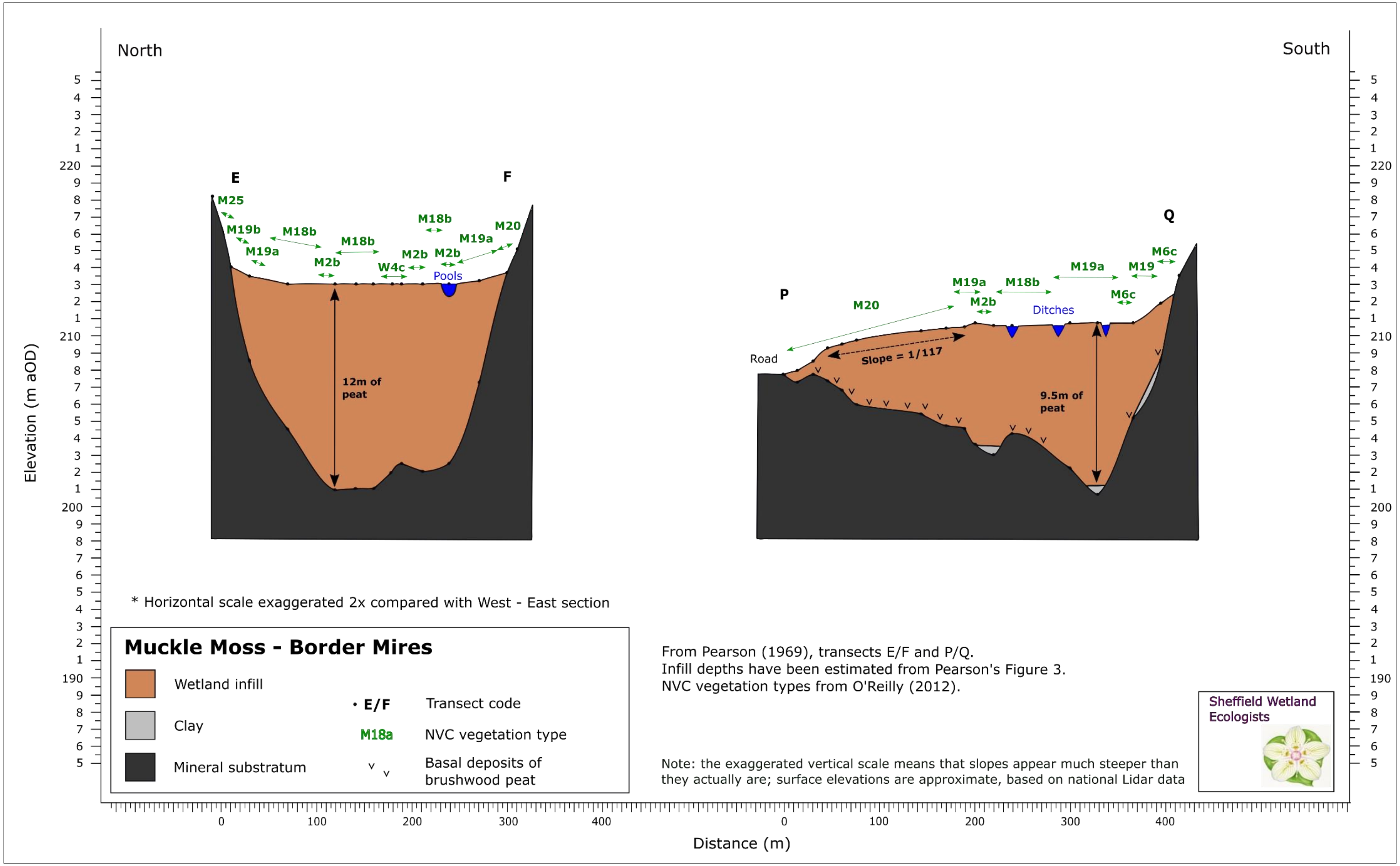

Figure A 43. Muckle Moss N–S section.

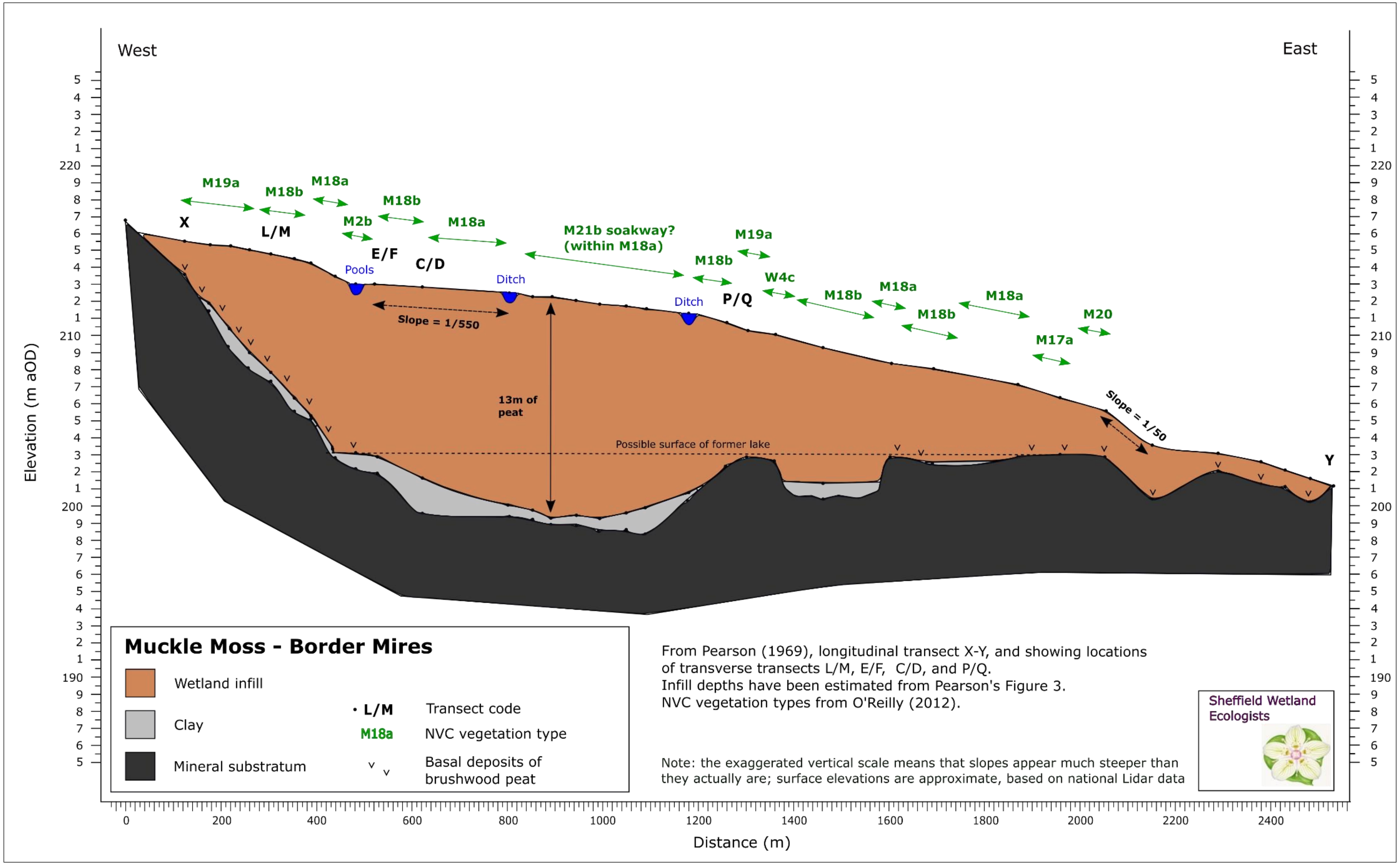

Figure A 44. Muckle Moss W–E section.

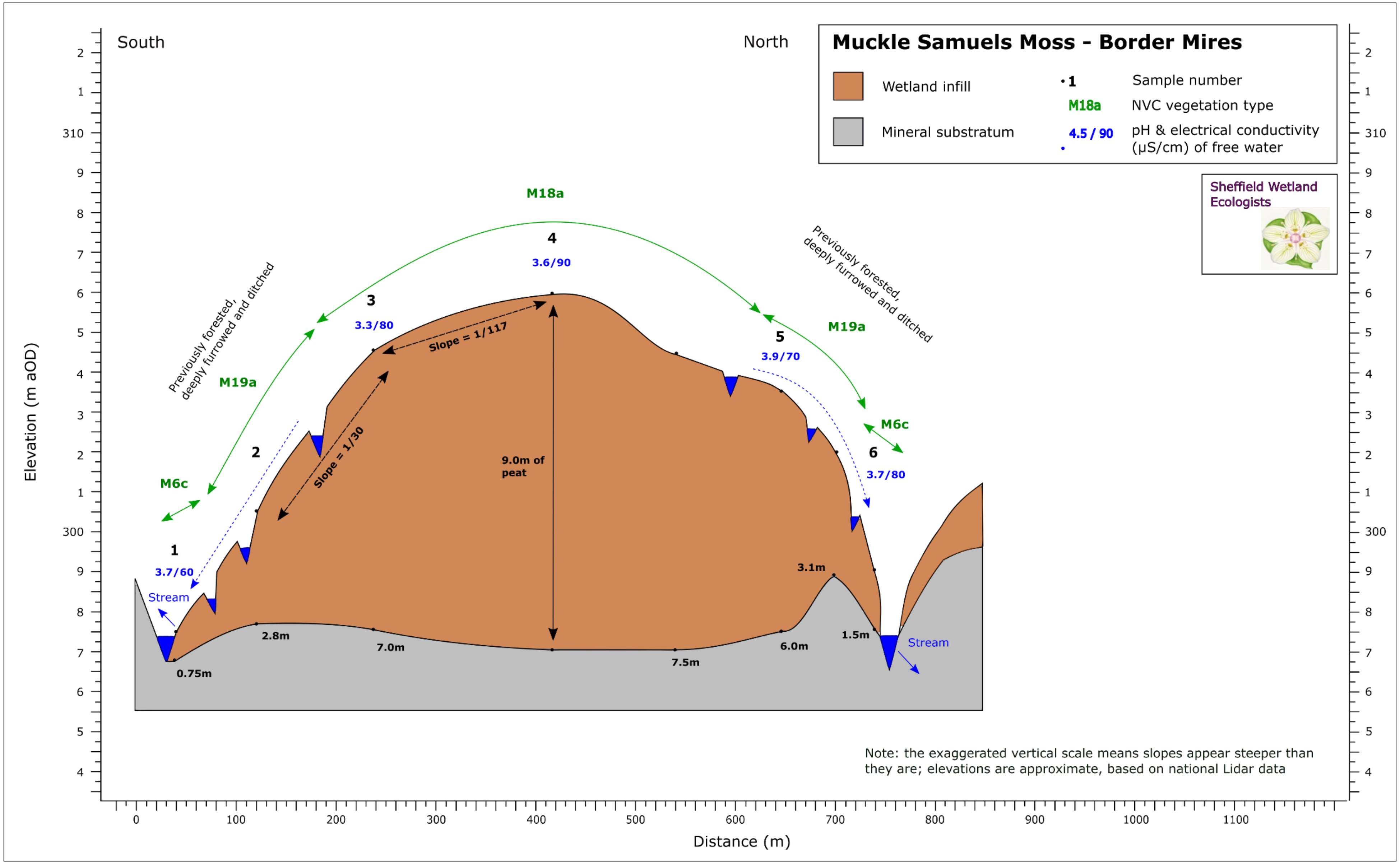

Figure A 45. Muckle Samuels Moss S–N section.

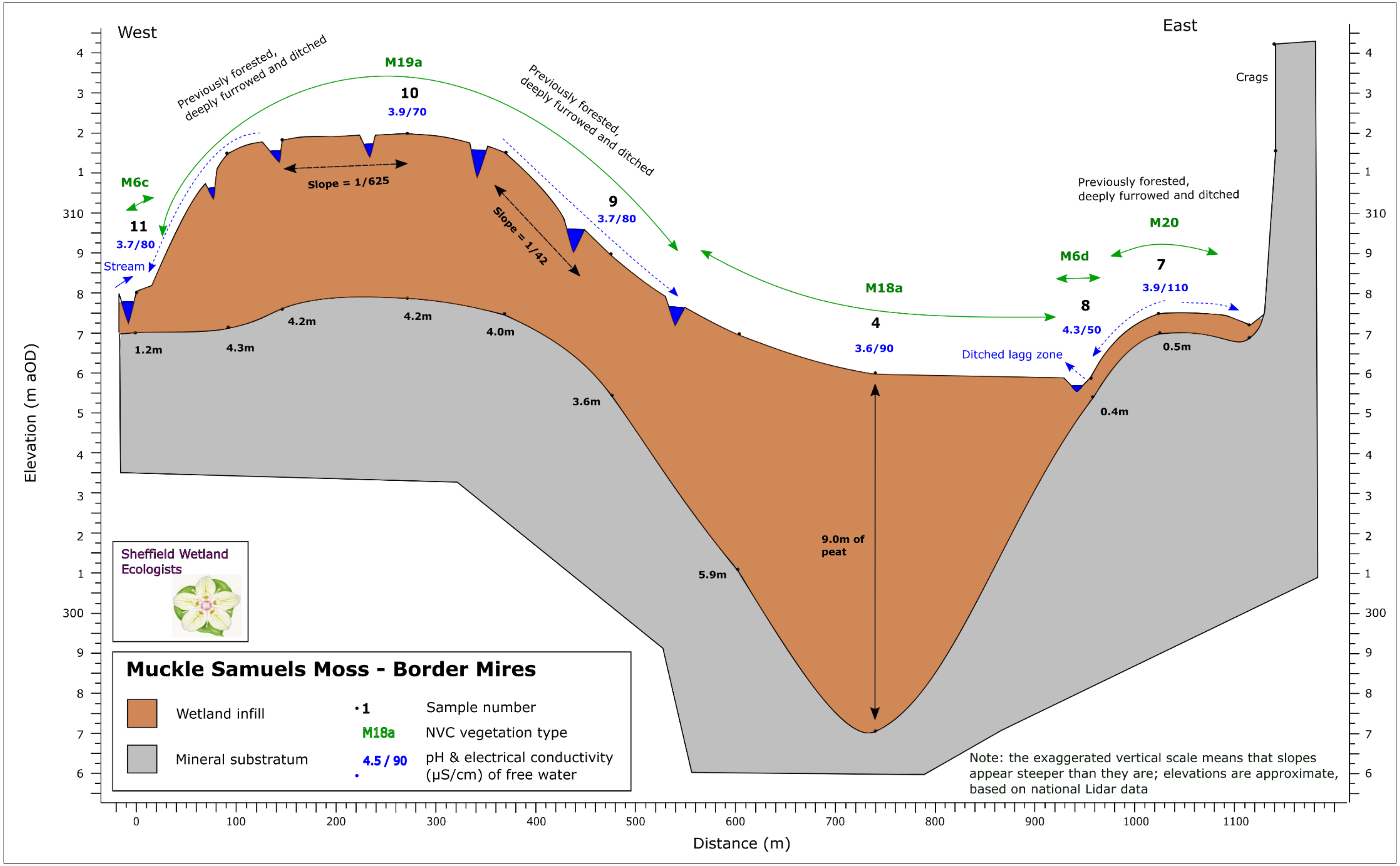

Figure A 46. Muckel Samuels Moss W–E section.

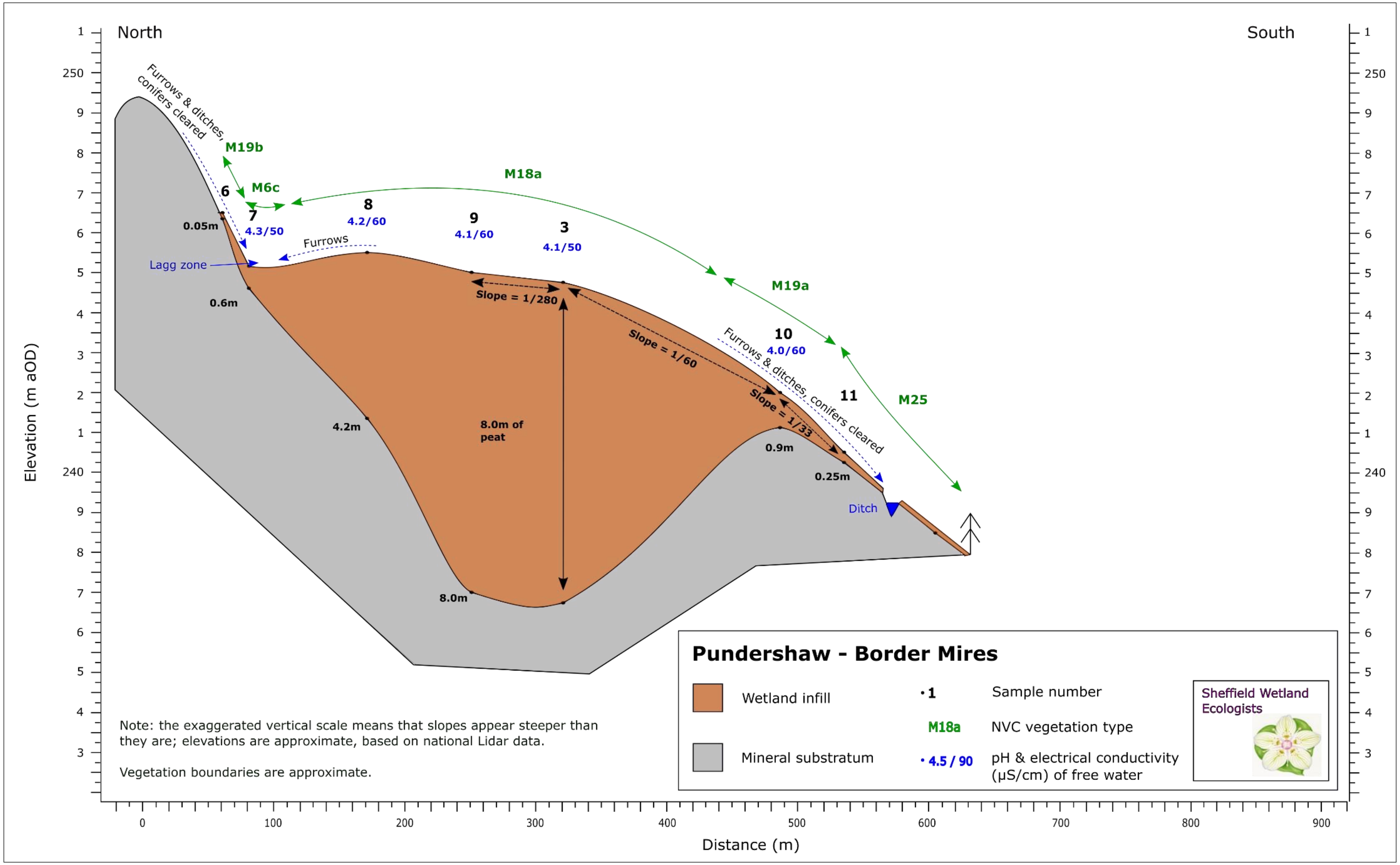

Figure A 47. Pundershaw N–S section.

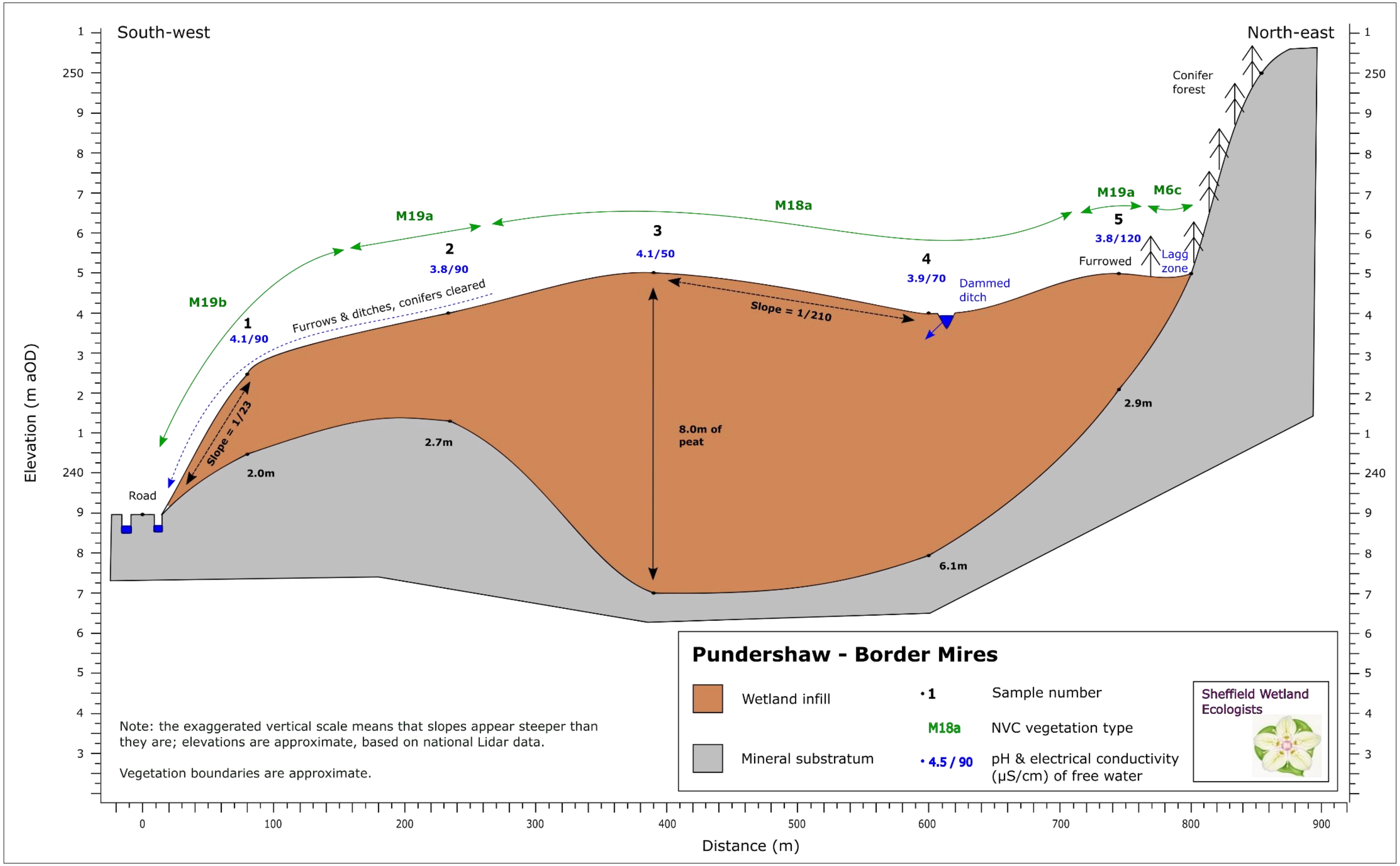

Figure A 48. Pundershaw SW–NE section.

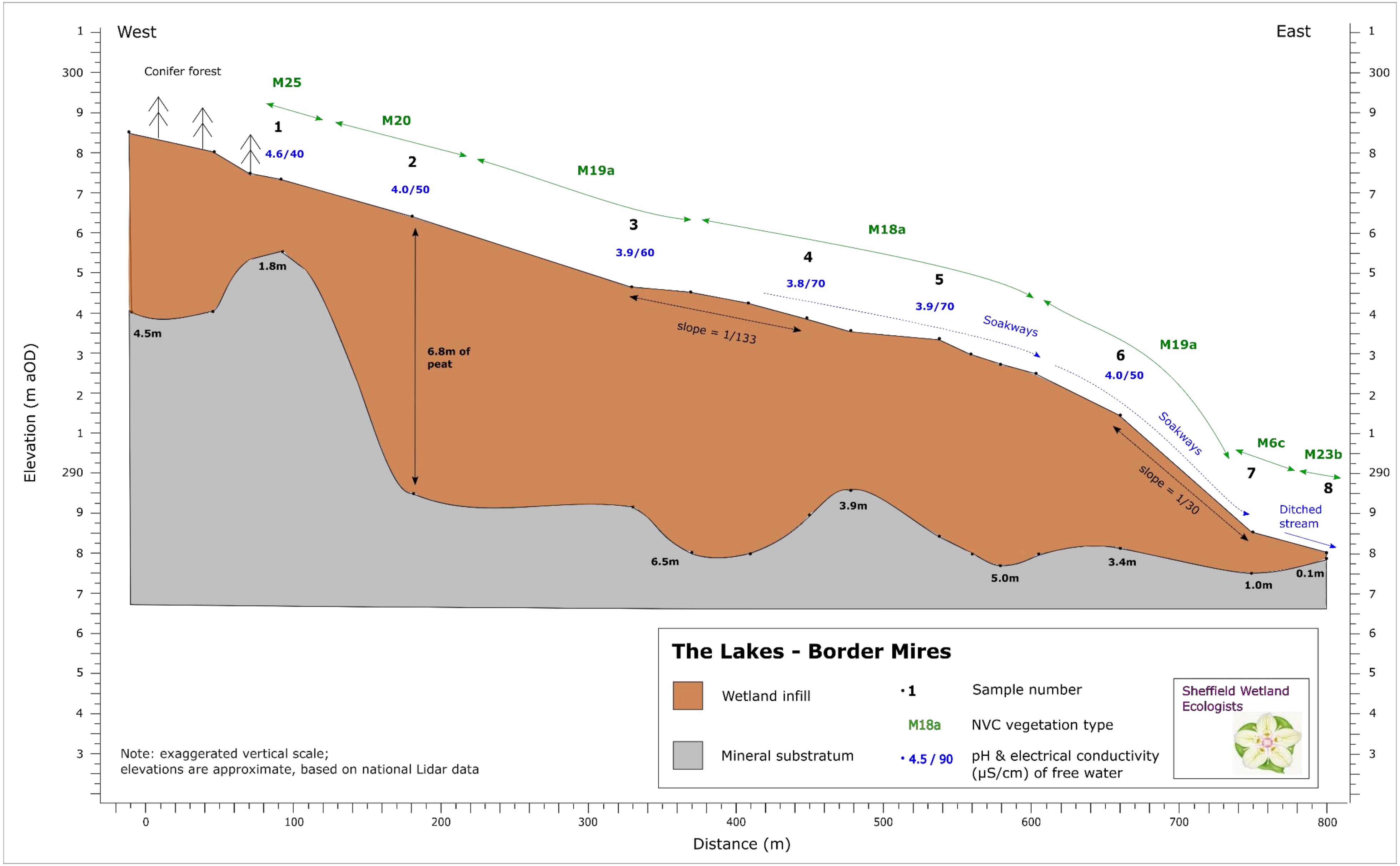

Figure A 49. The Lakes W–E section.

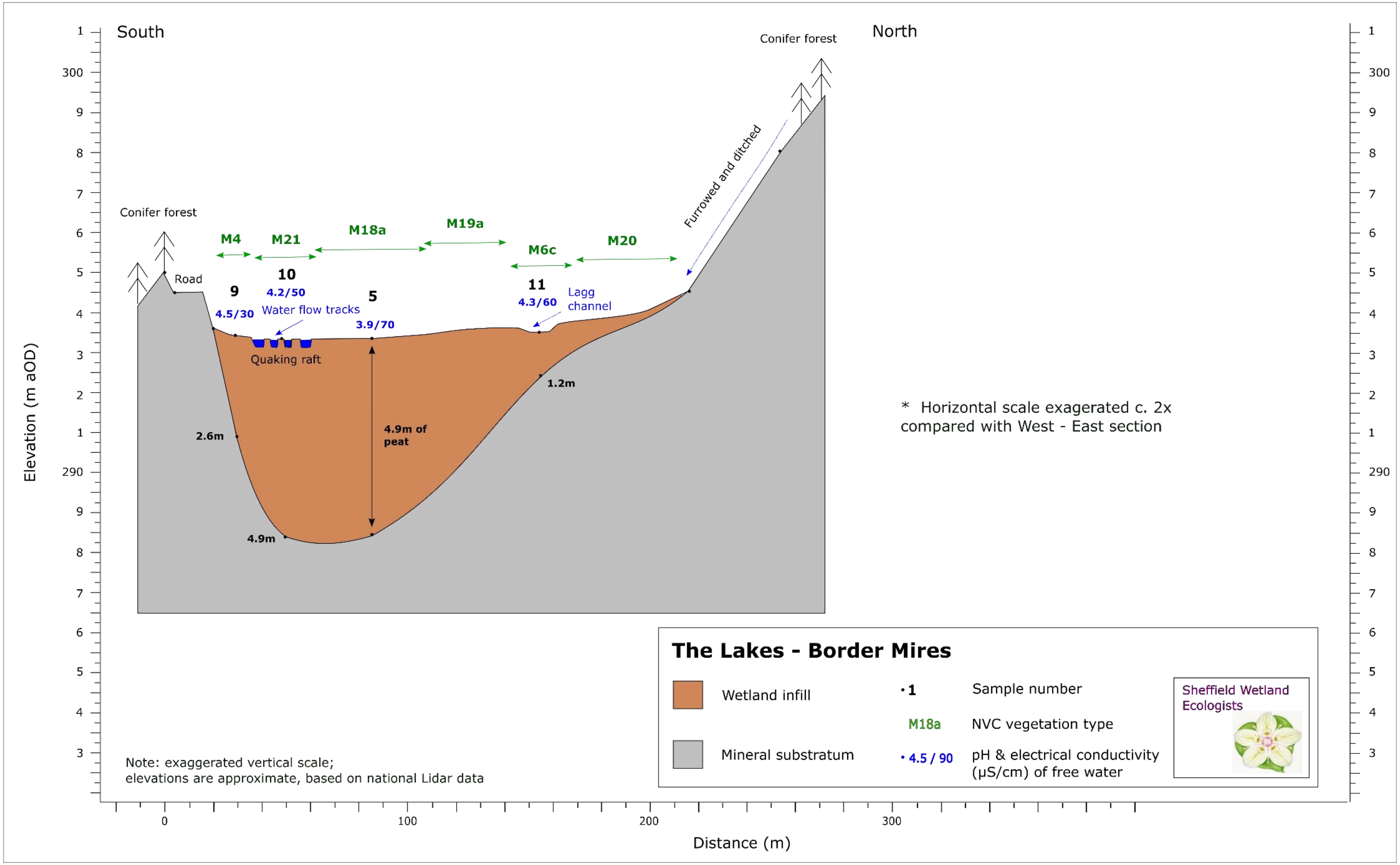

Figure A 50. The Lakes S–N section.

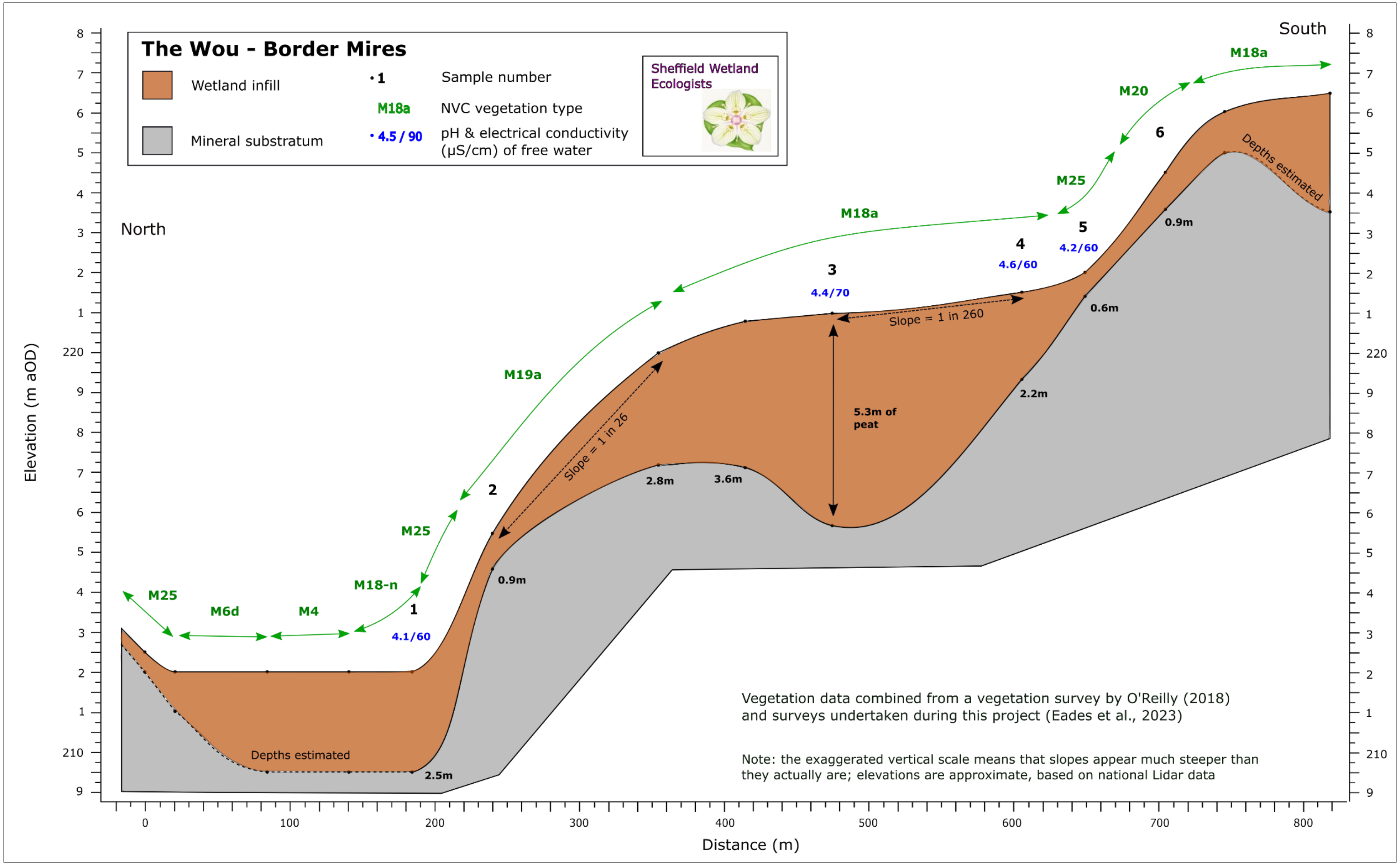

Figure A 51. The Wou N–S section.

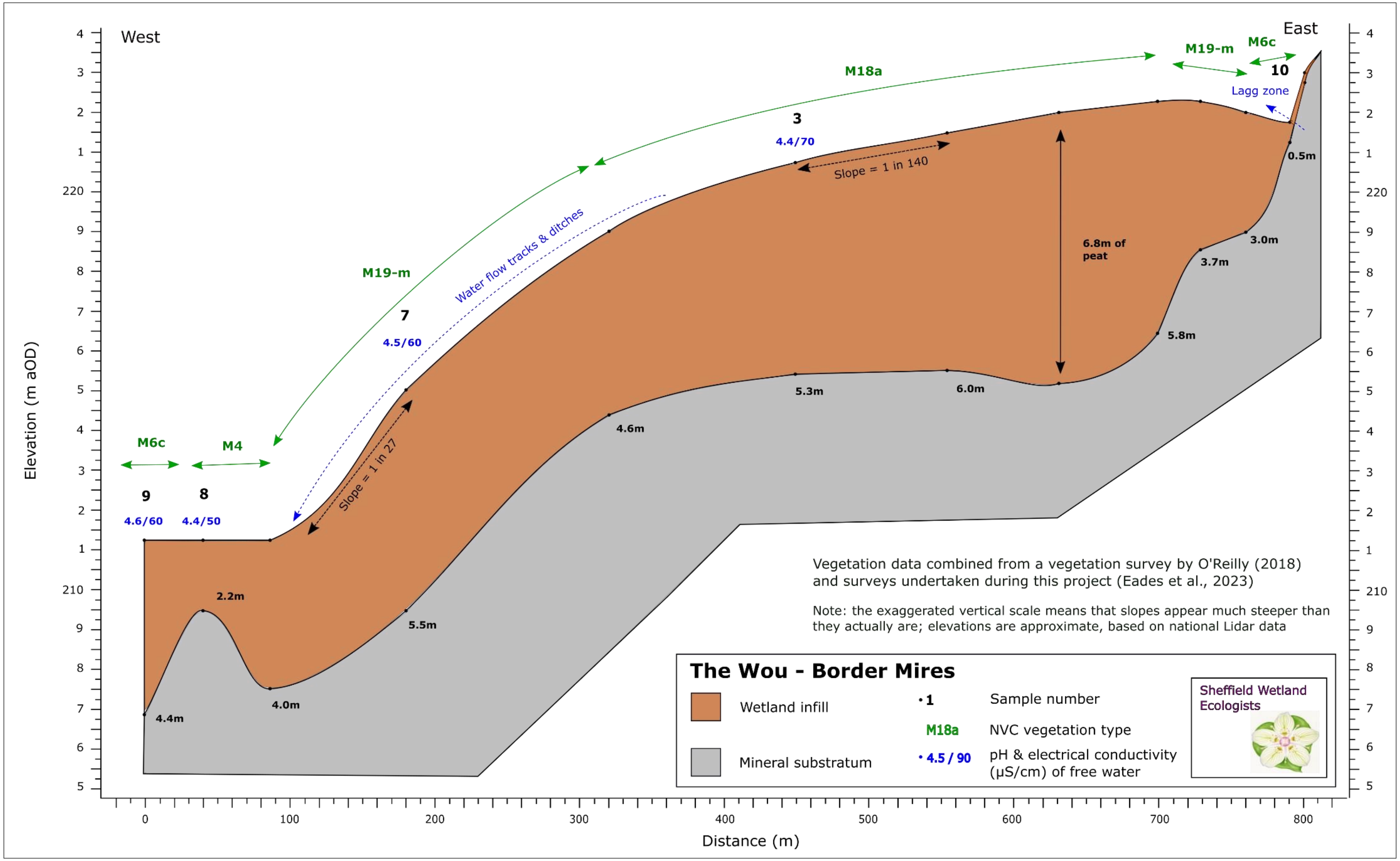

Figure A 52. The Wou W–E section.

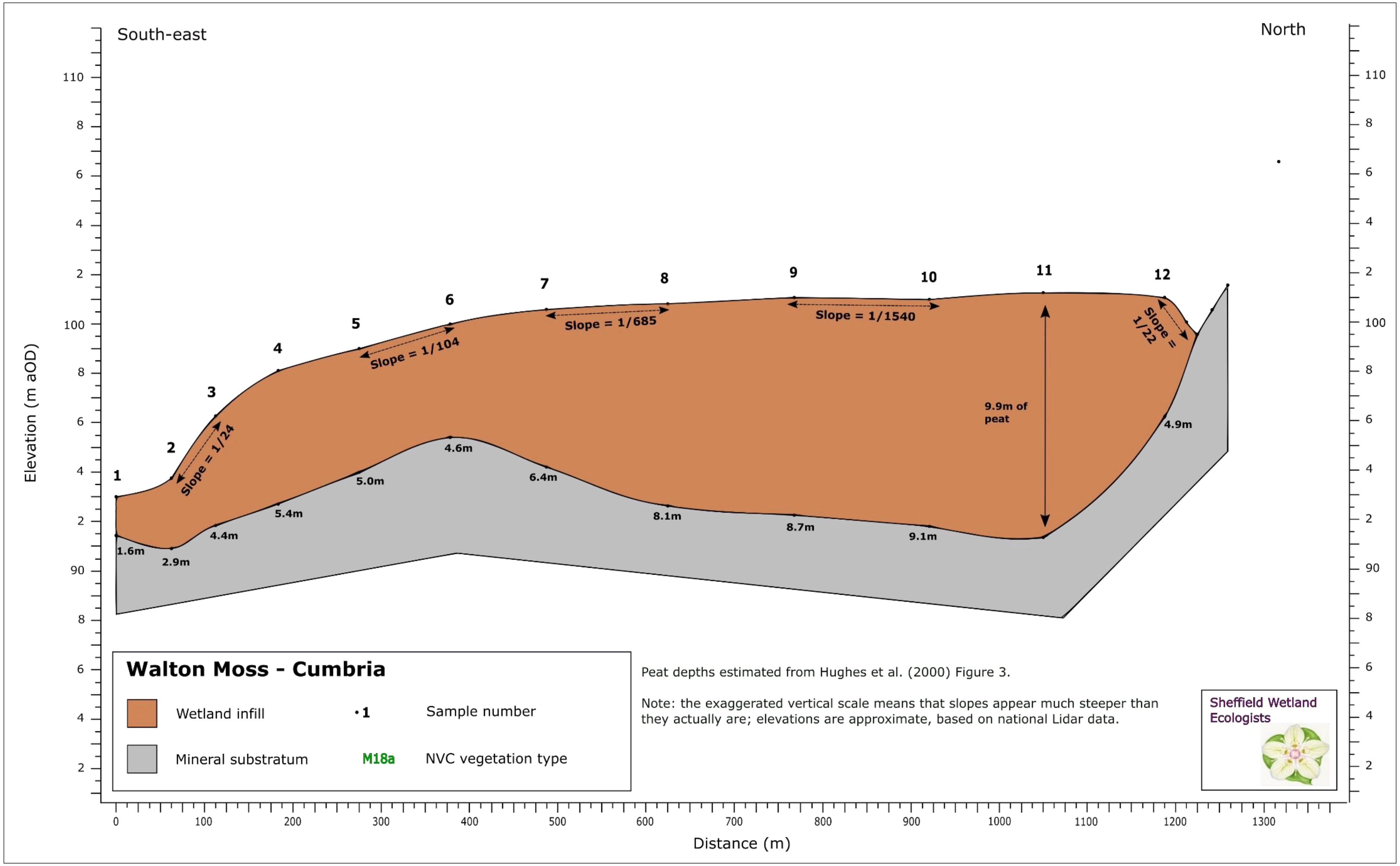

Figure A 53. Walton Moss SE–N section

11.3 Annexe 3. Site transect location maps

See Annexe 2 for schematic drawings based on the transects

11.3.1 Wales

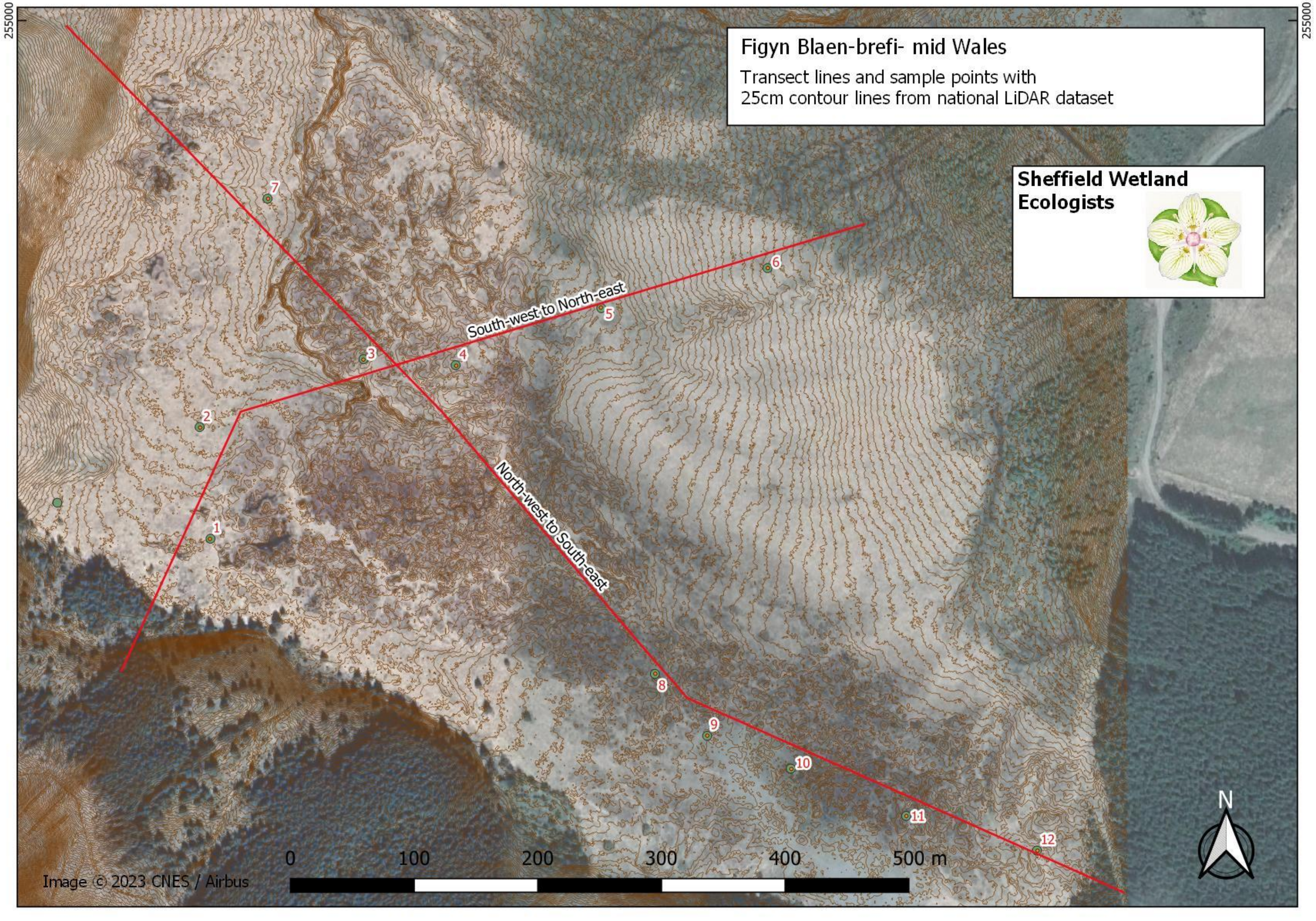

Figure B. 1. Figyn Blaen-brefi transect locations.

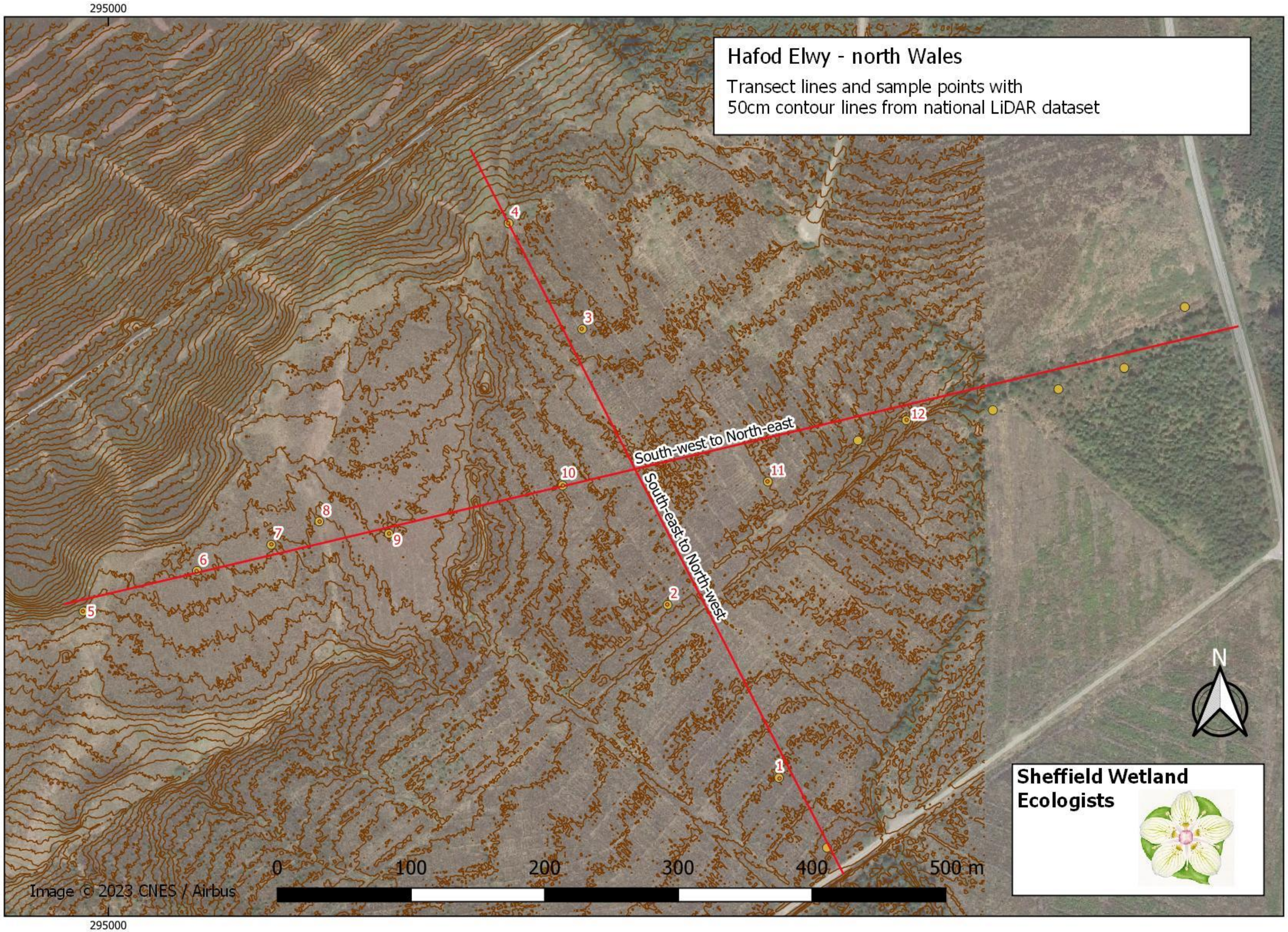

Figure B. 2. Hafod Elwy transect locations.

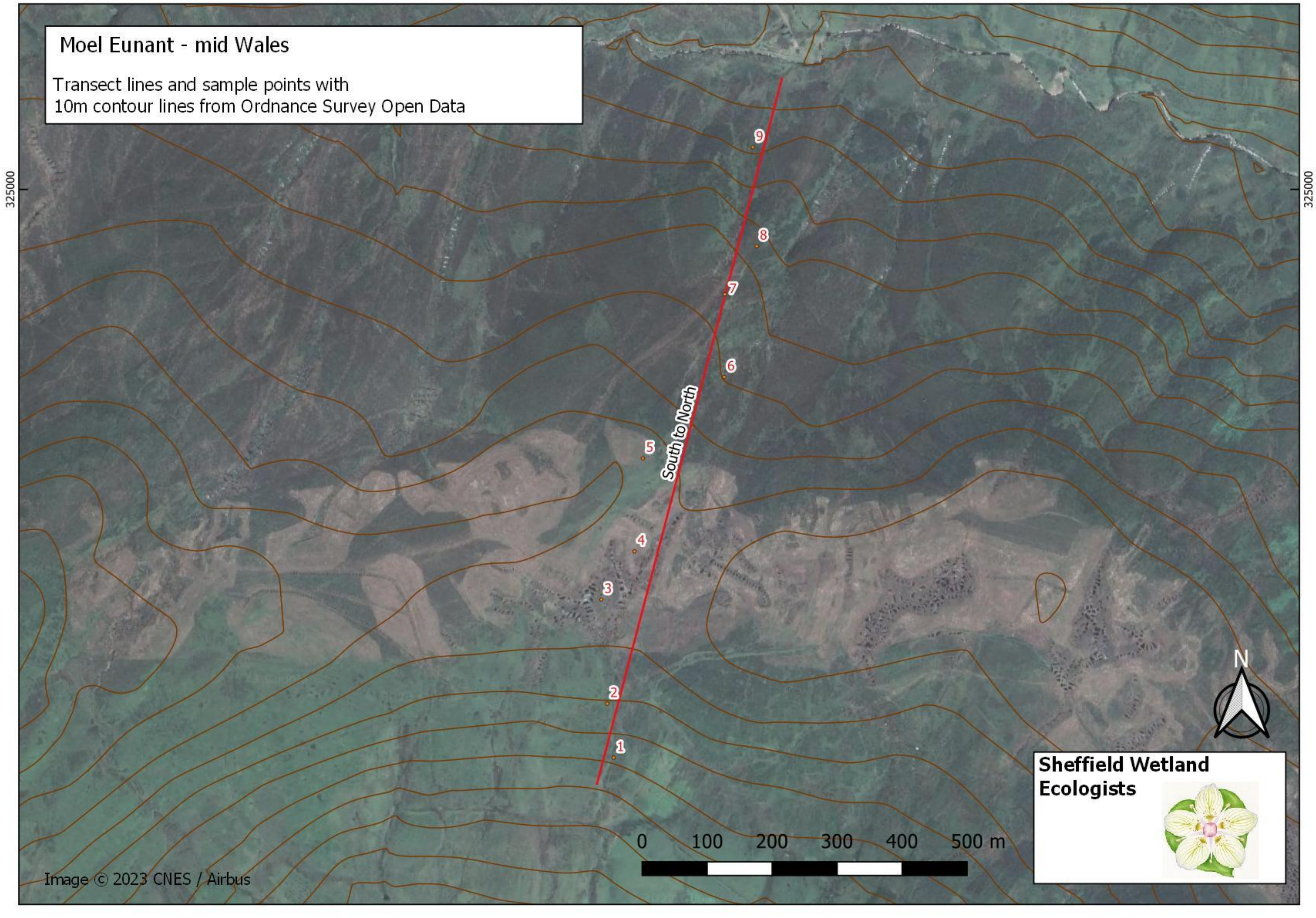

Figure B. 3. Moel Eunant transect locations.

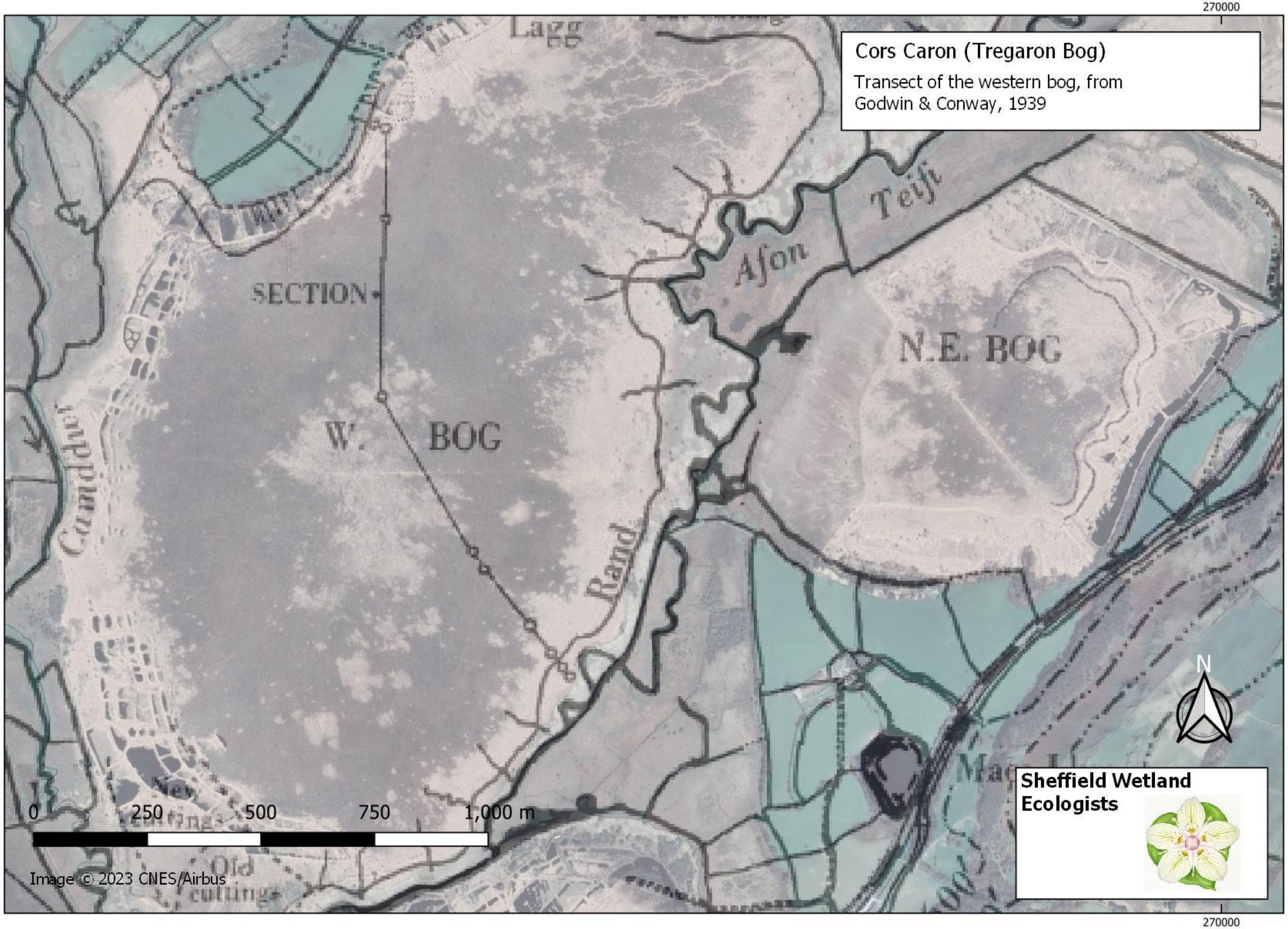

Figure B. 4. Cors Caron (Tregaron Bog – West) transect locations.

11.3.2 South Pennines

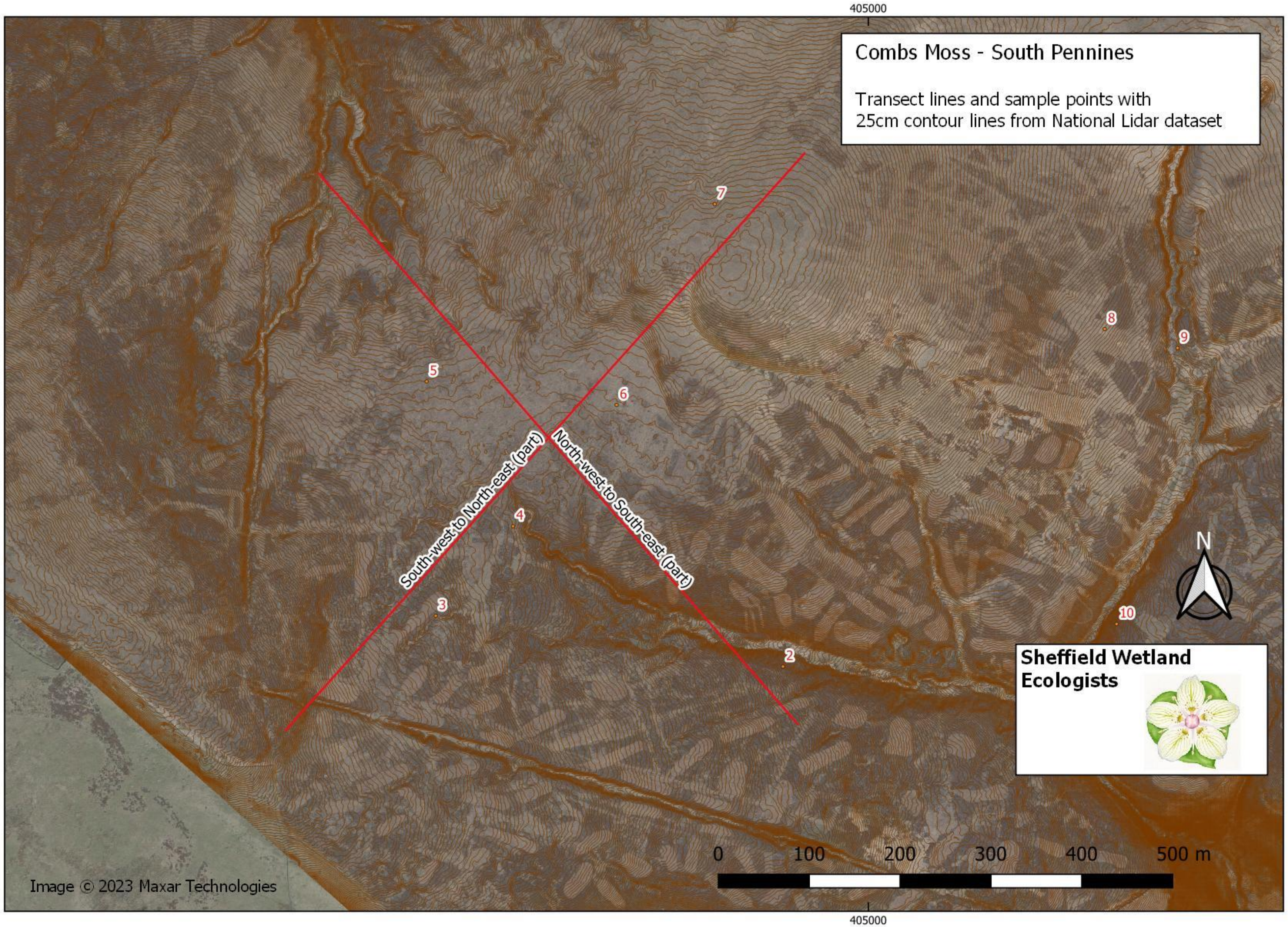

Figure B. 5. Combs Moss 'transect' locations.

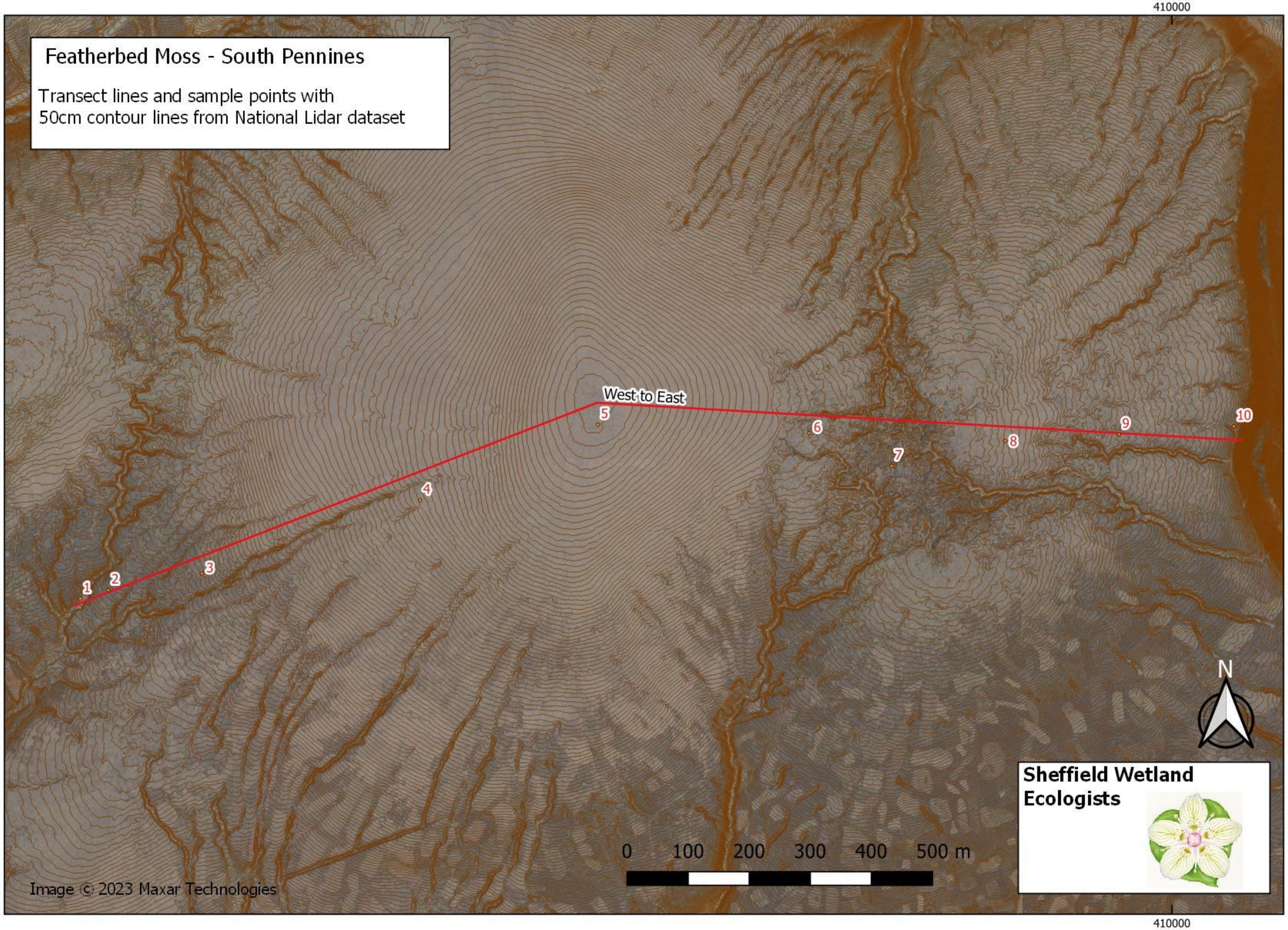

Figure B. 6. Featherbed Moss transect locations.

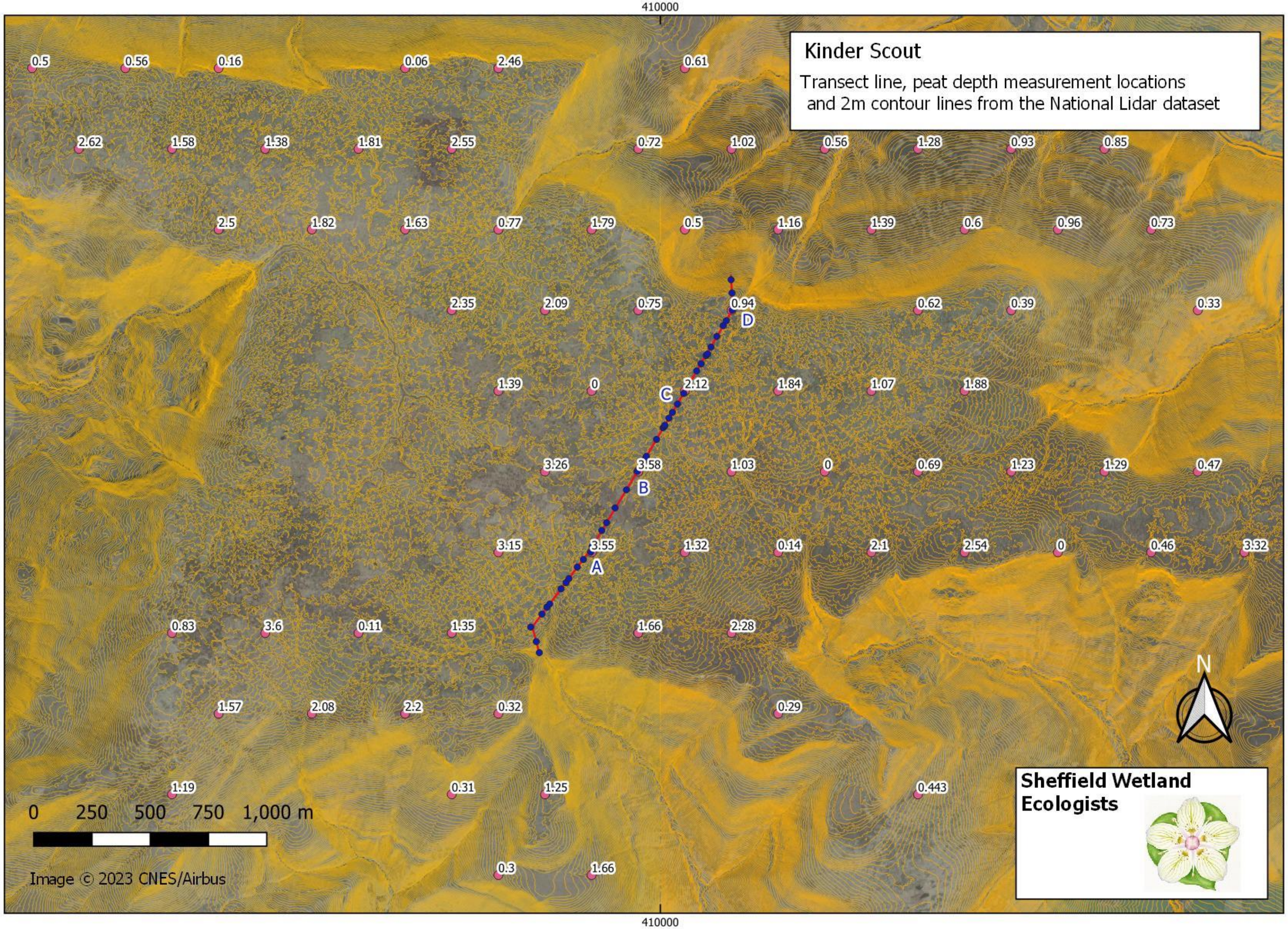

Figure B. 7. Kinder Scout transect locations.

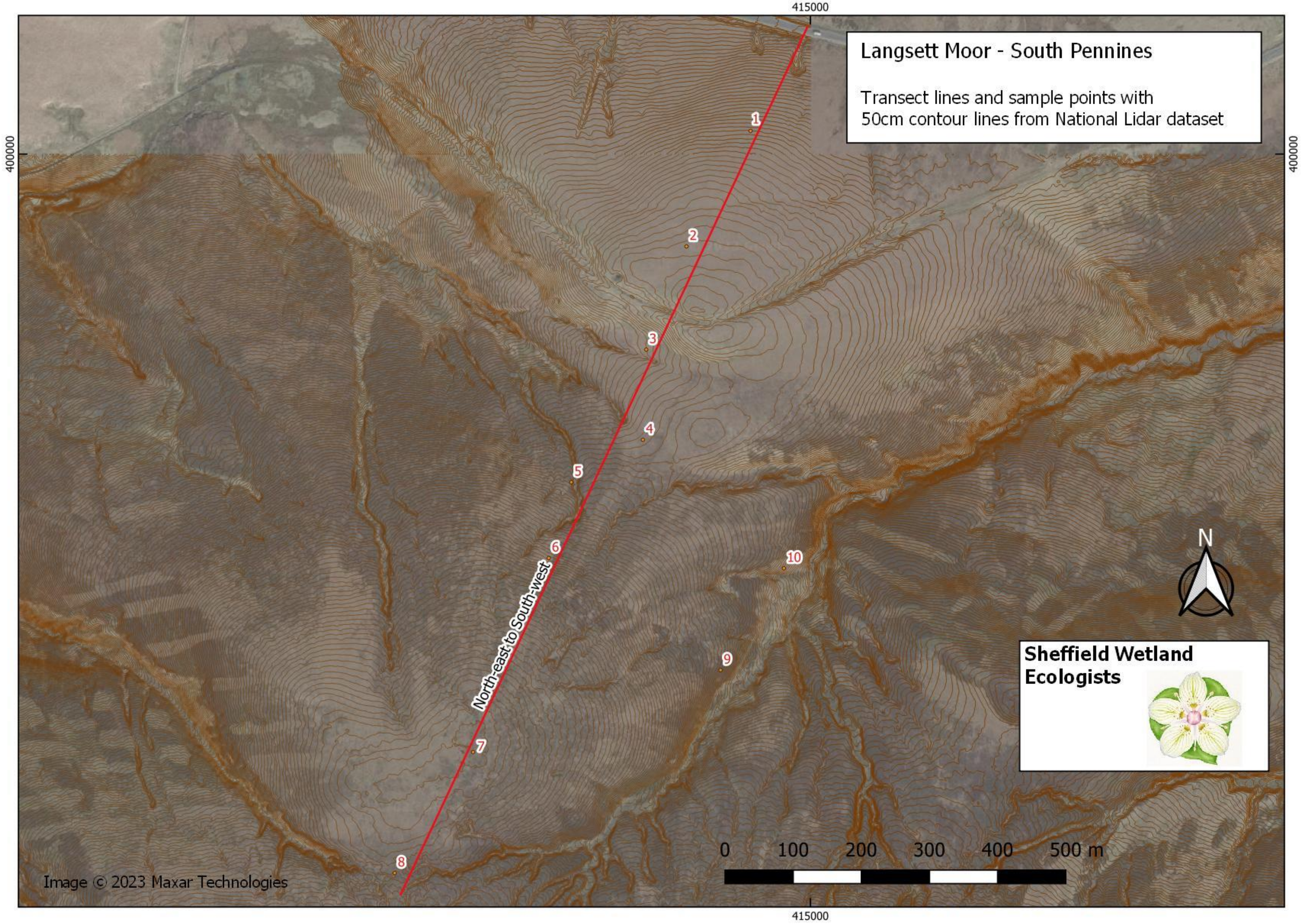

Figure B. 8. Langsett Moor transect locations.

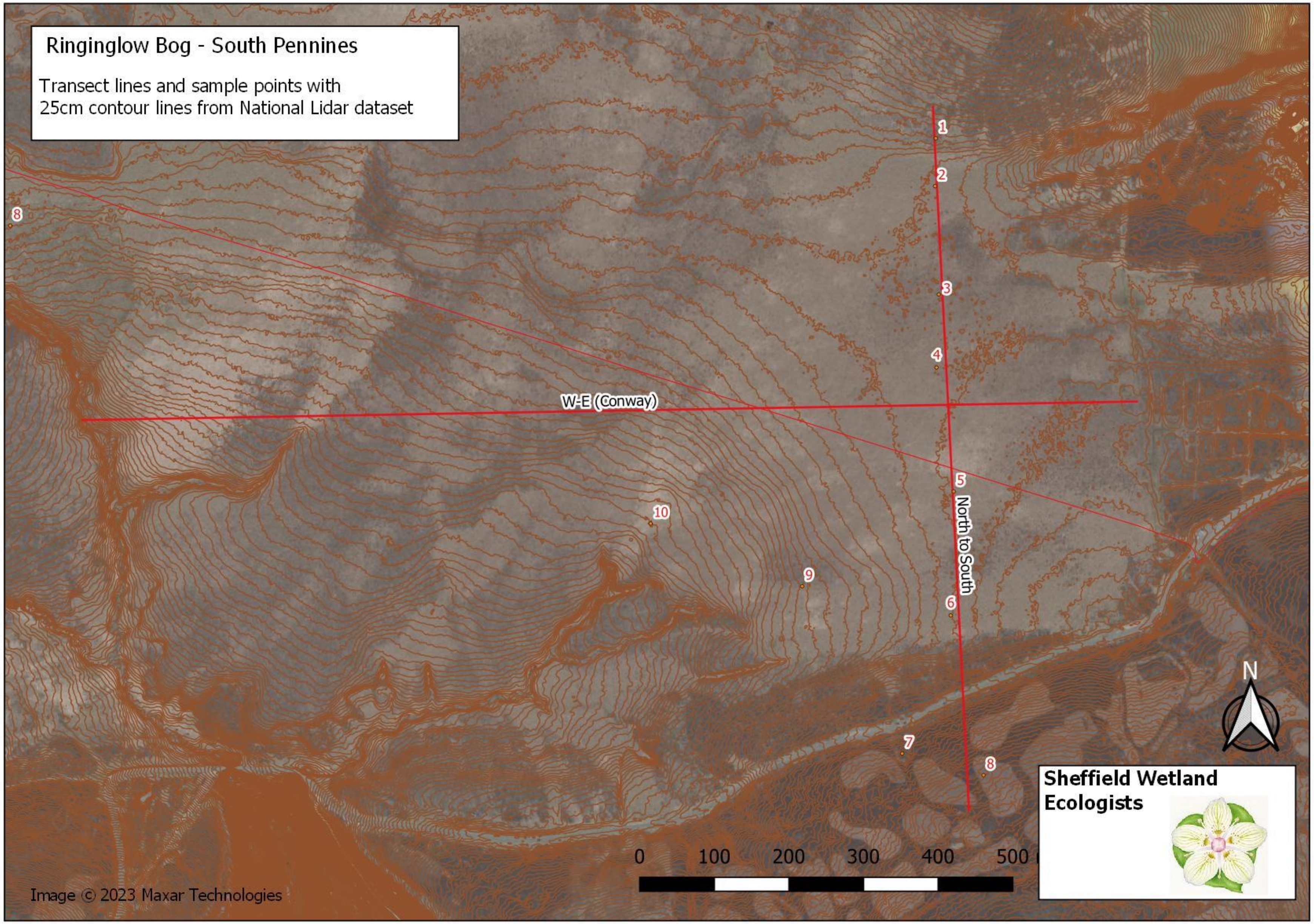

Figure B. 9. Ringinglow Bog transect locations.

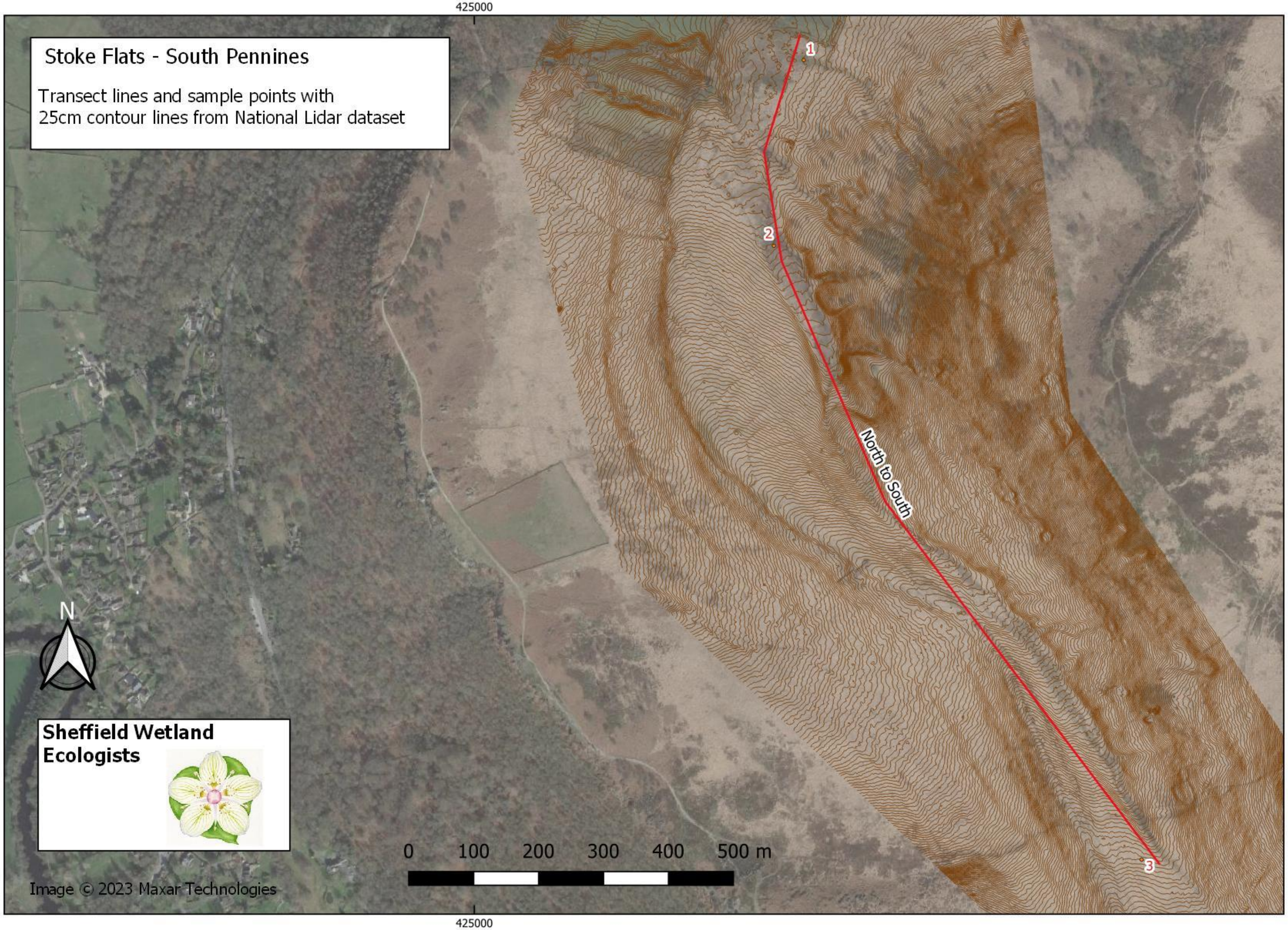

Figure B. 10. Stoke Flats transect locations.

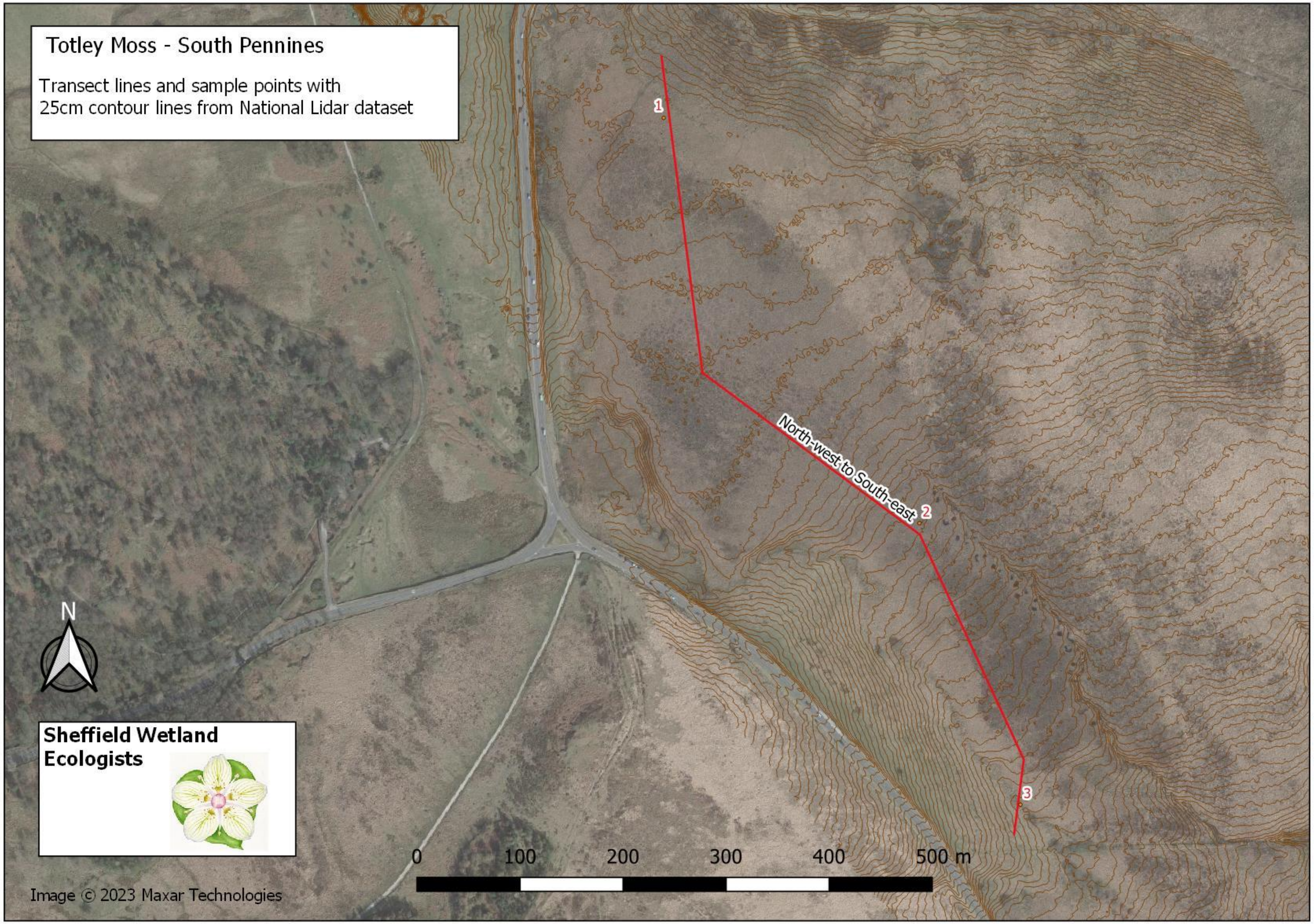

Figure B. 11. Totley Moss transect locations.

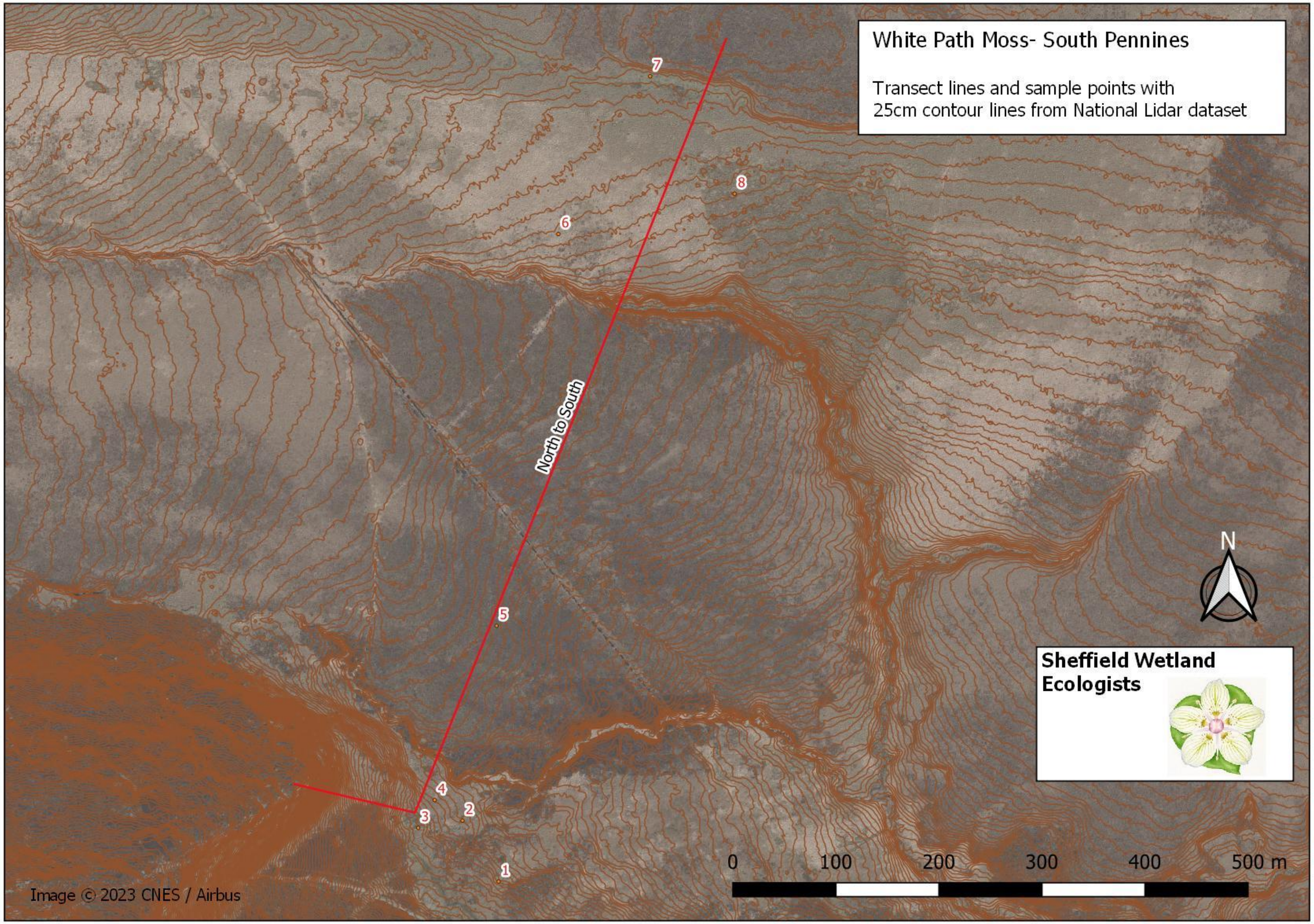

Figure B. 12. White Path Moss transect locations.

11.3.3 Forest of Bowland

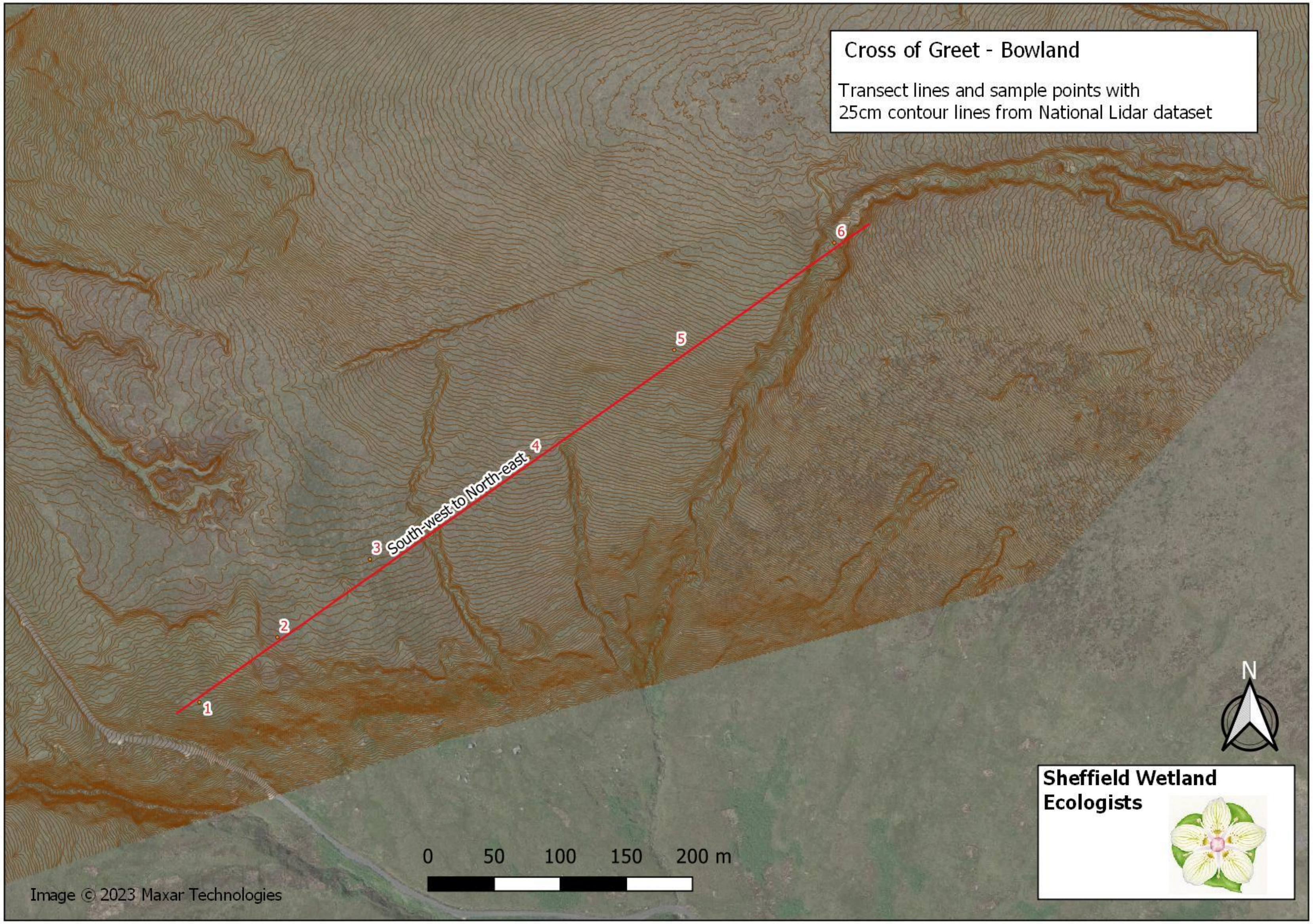

Figure B. 13. Cross of Greet transect locations.

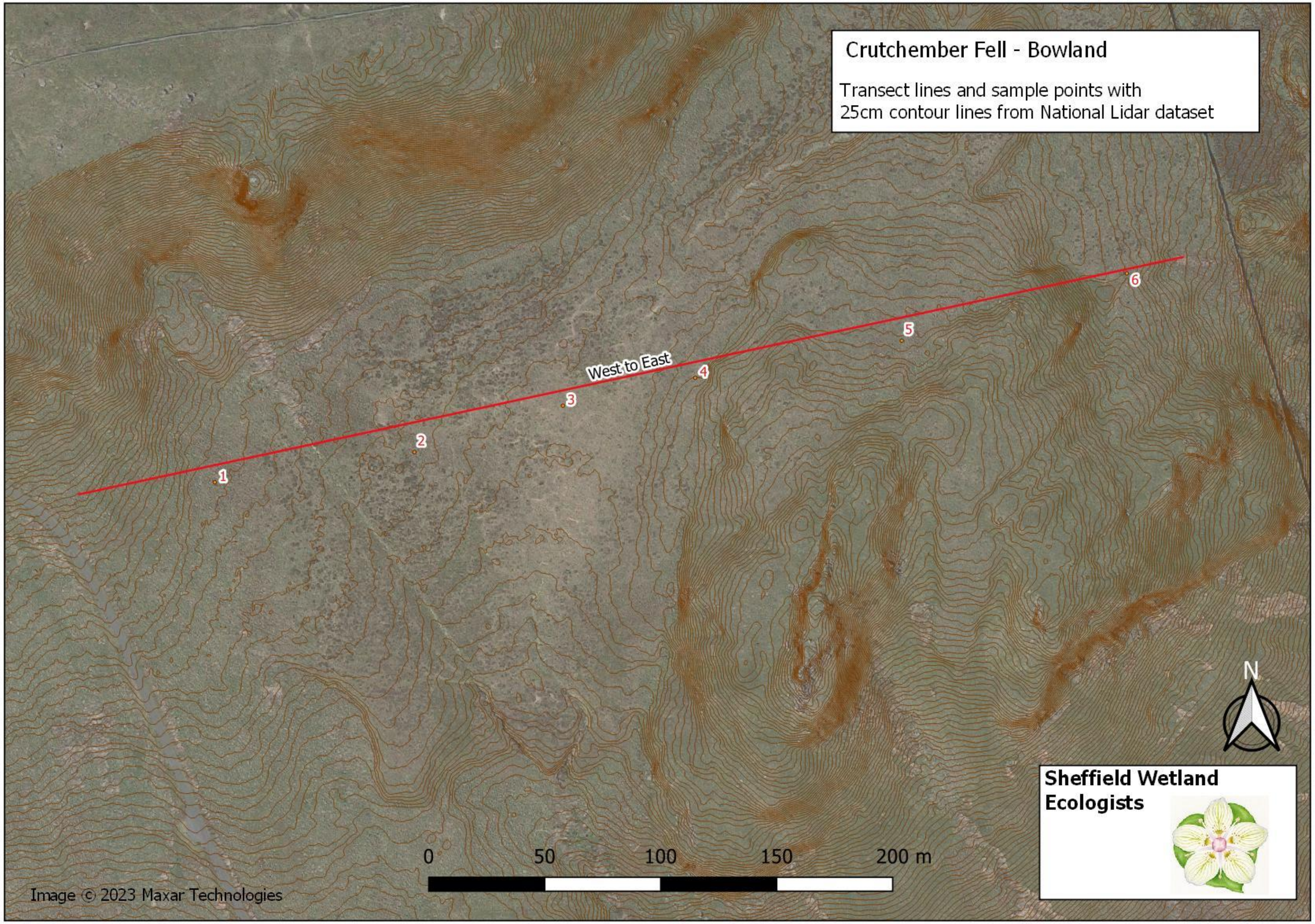

Figure B. 14. Crutchember Fell transect locations.

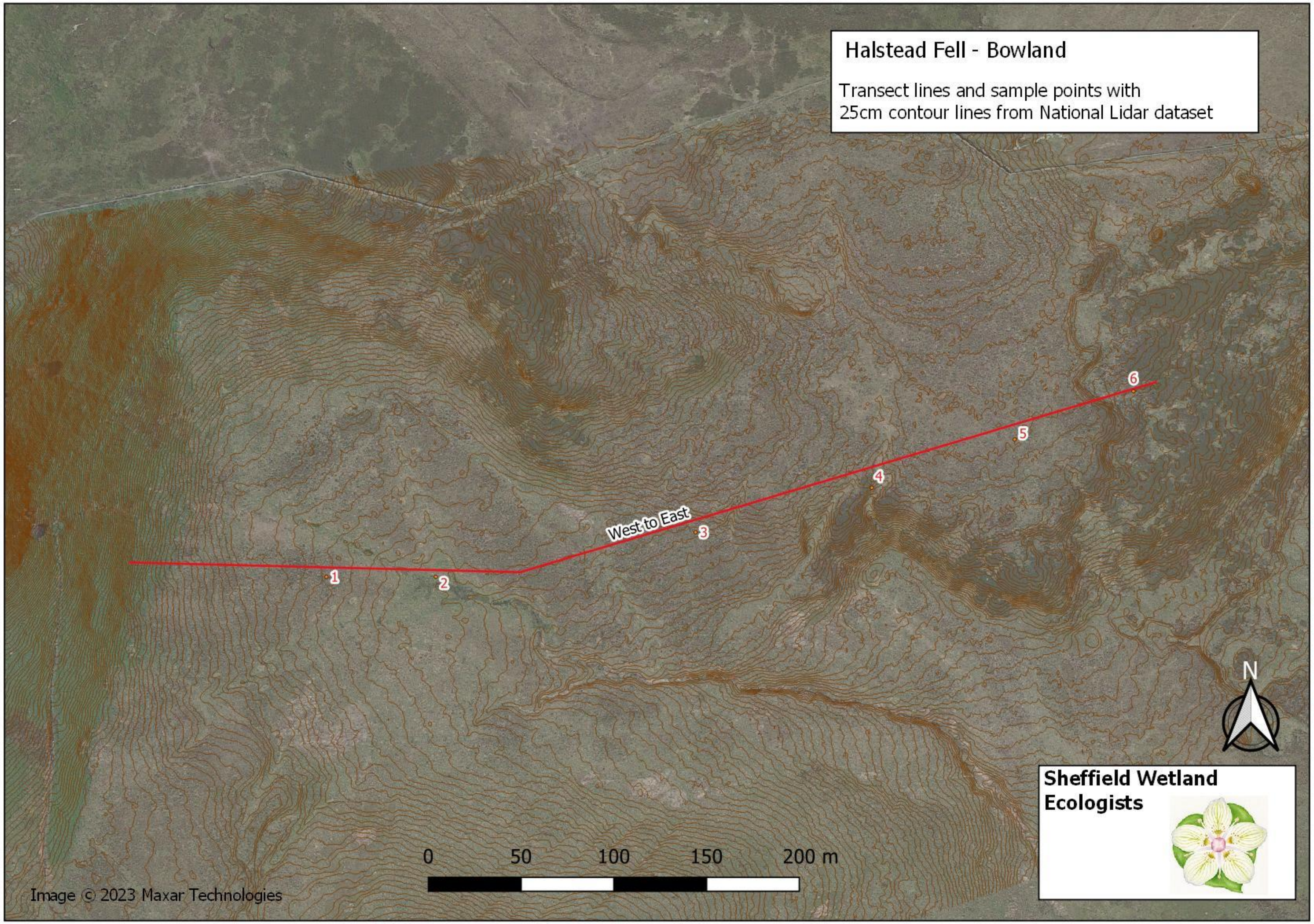

Figure B. 15. Halstead Fell transect locations.

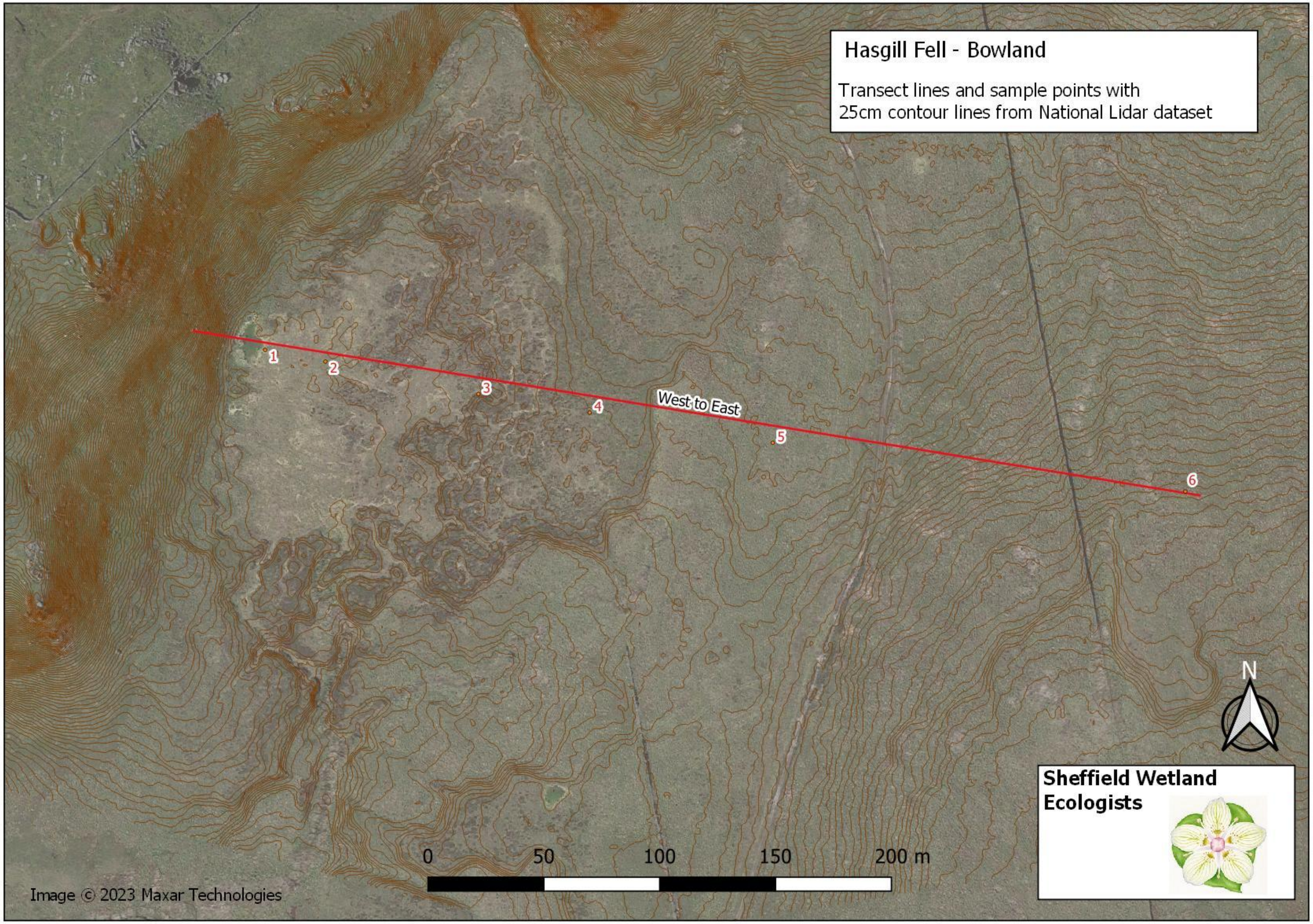

Figure B. 16. Hasgill Fell transect locations.

11.3.4 Greater Manchester, North Yorkshire, North Pennines & south Cumbria

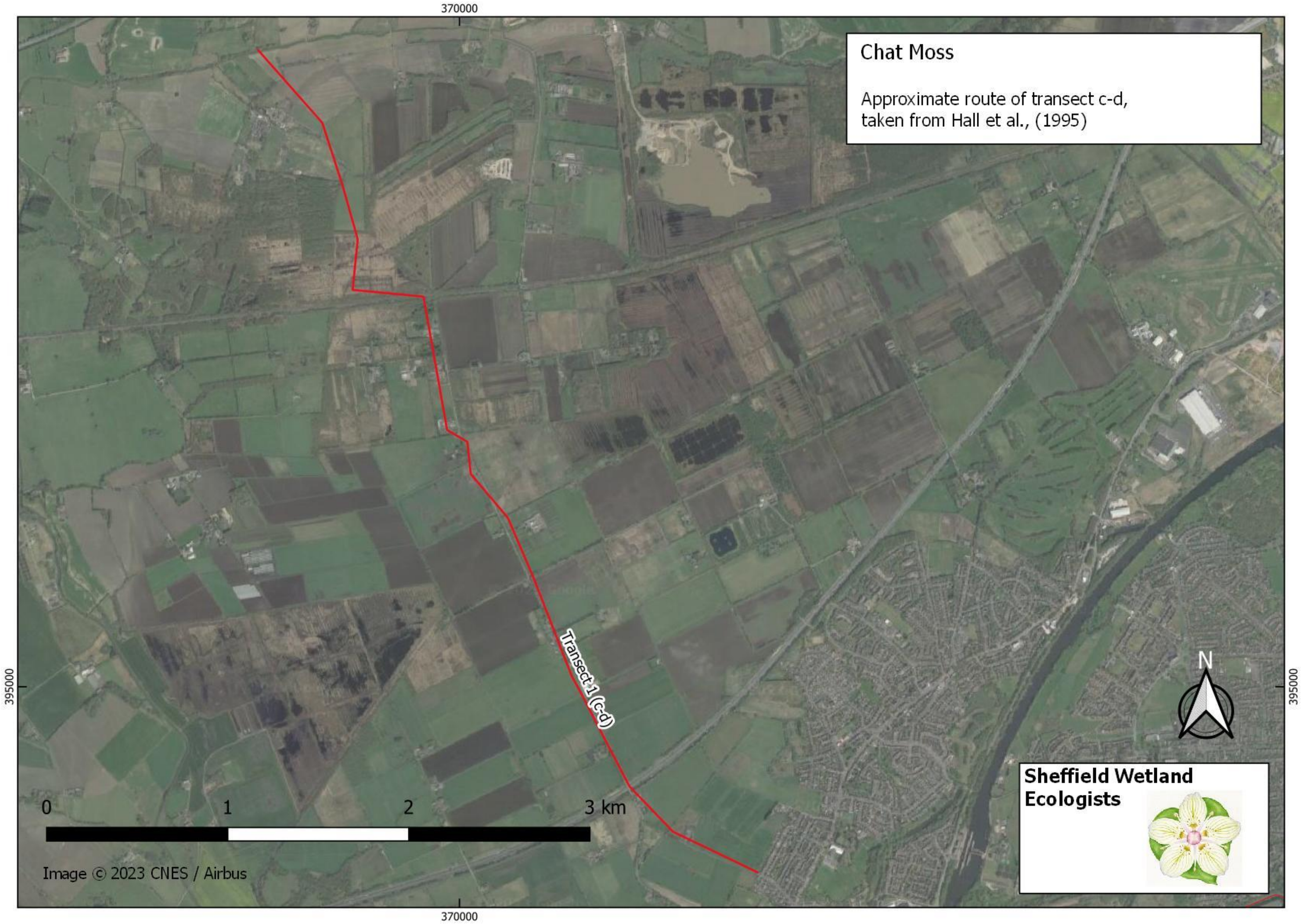

Figure B. 17. Chat Moss transect location.

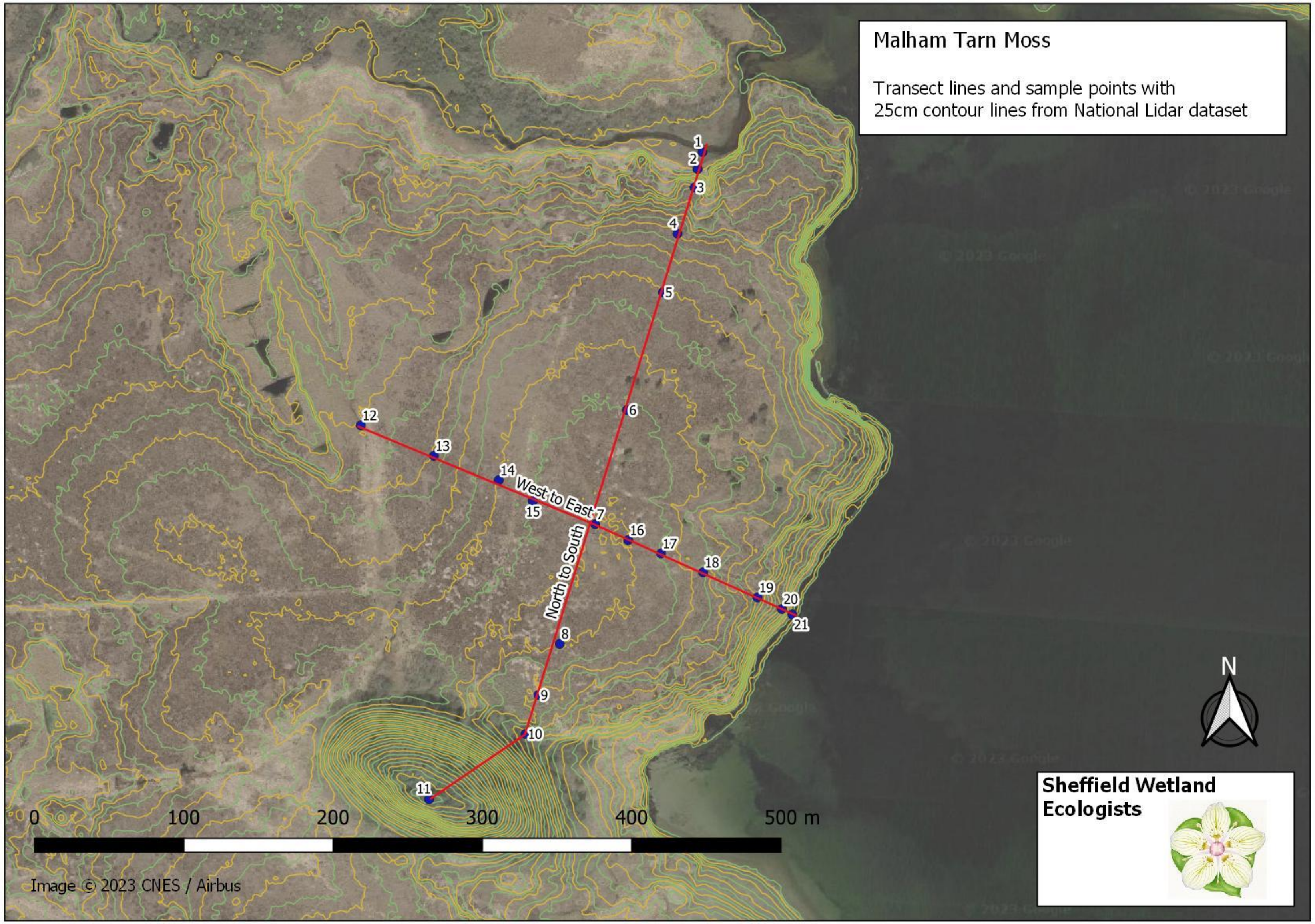

Figure B. 18. Malham Tarn Moss transect locations.

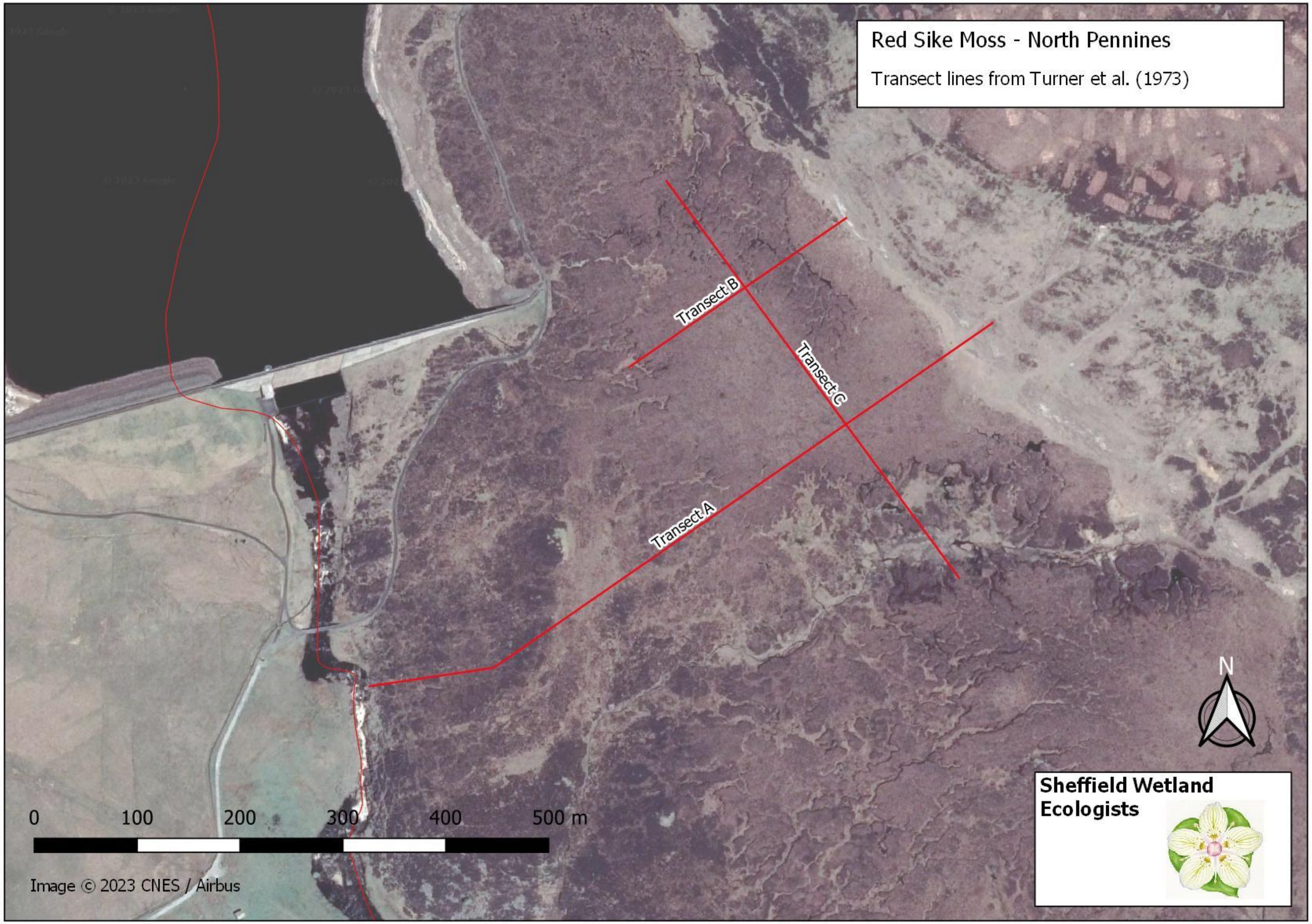

Figure B. 19. Red Sike Moss transect locations.

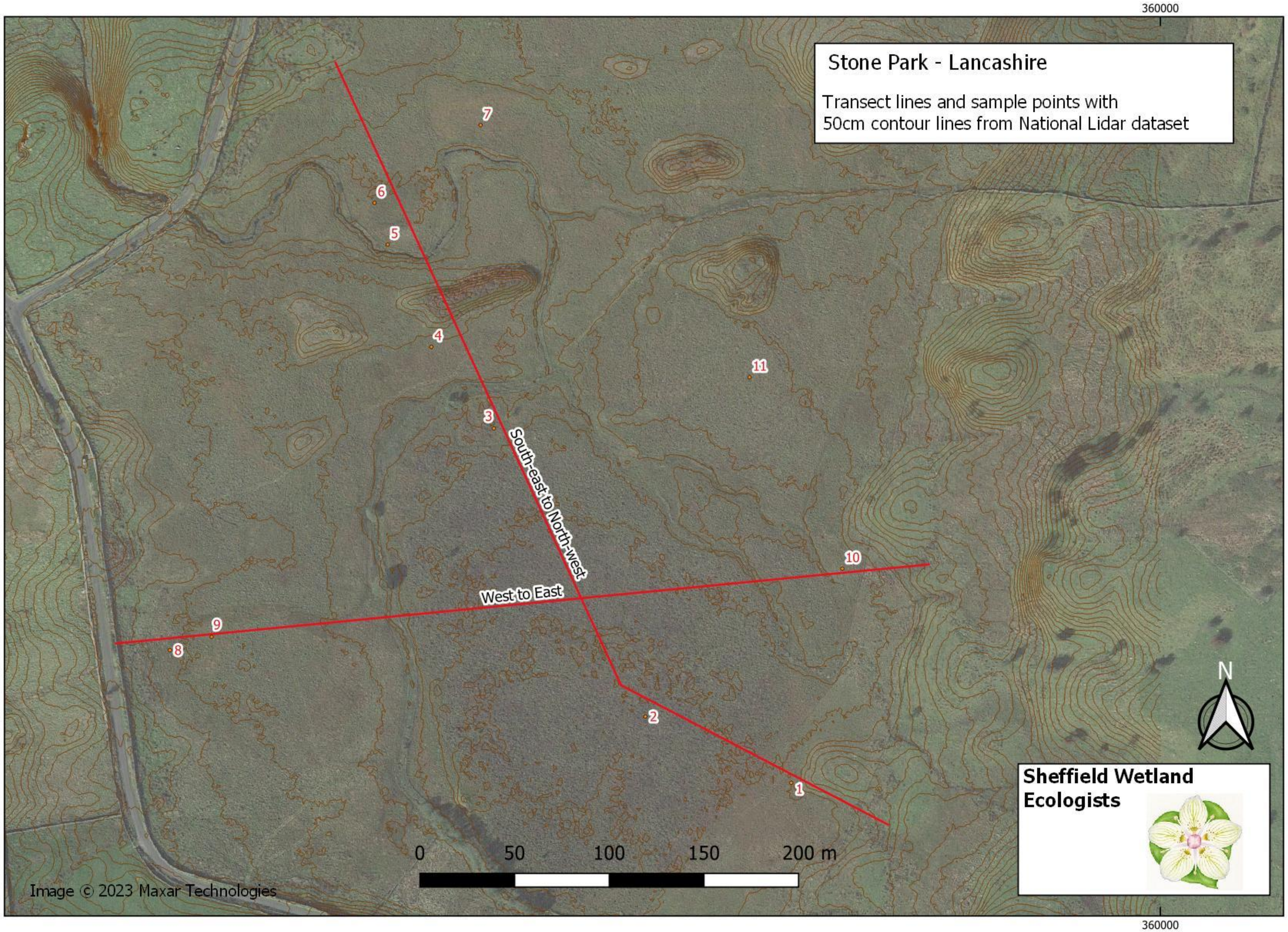

Figure B. 20. Stone Park transect locations.

11.3.5 Cumbria and Northumberland (including the Border Mires)

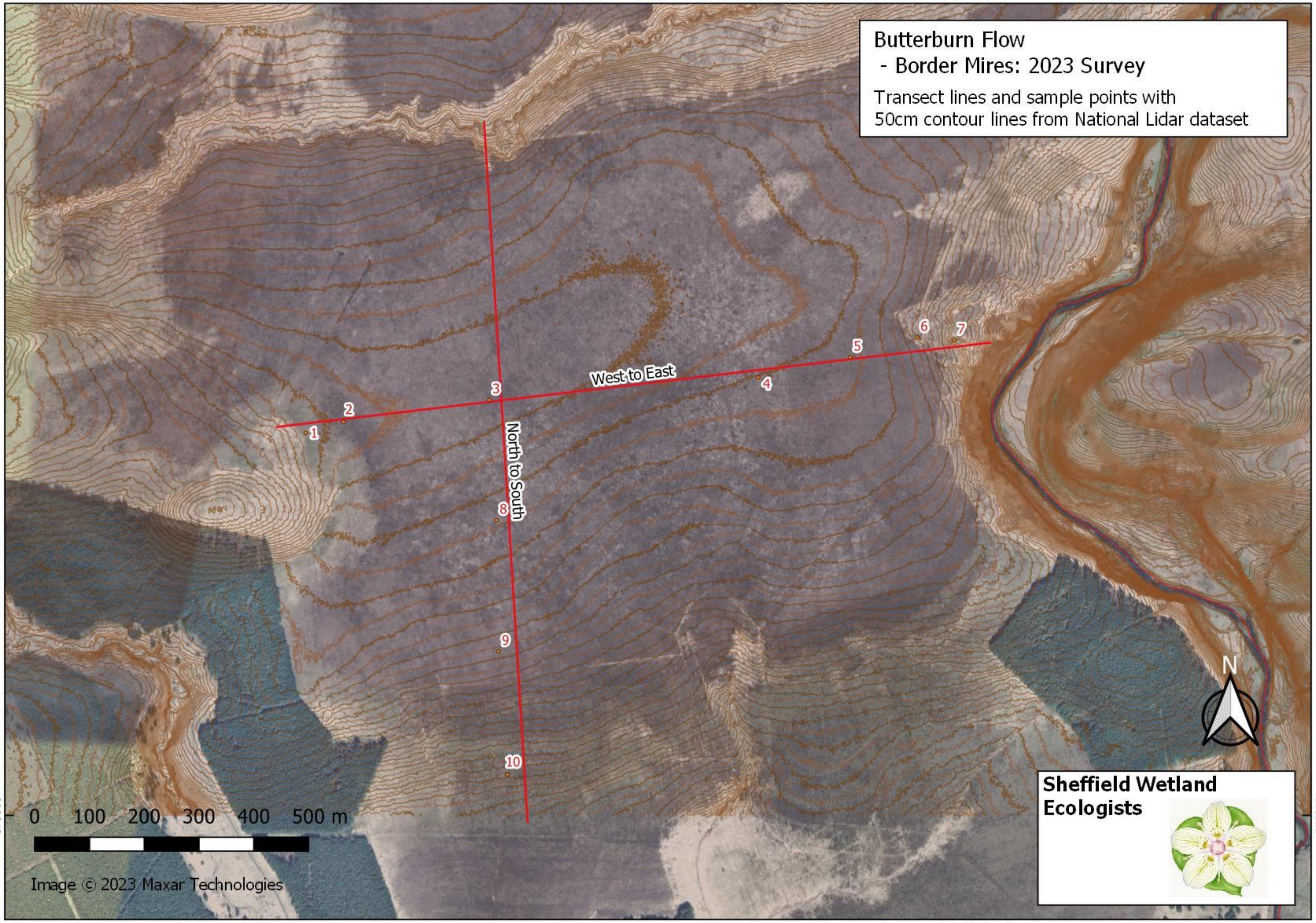

Figure B. 21. Butterburn Flow transect locations.

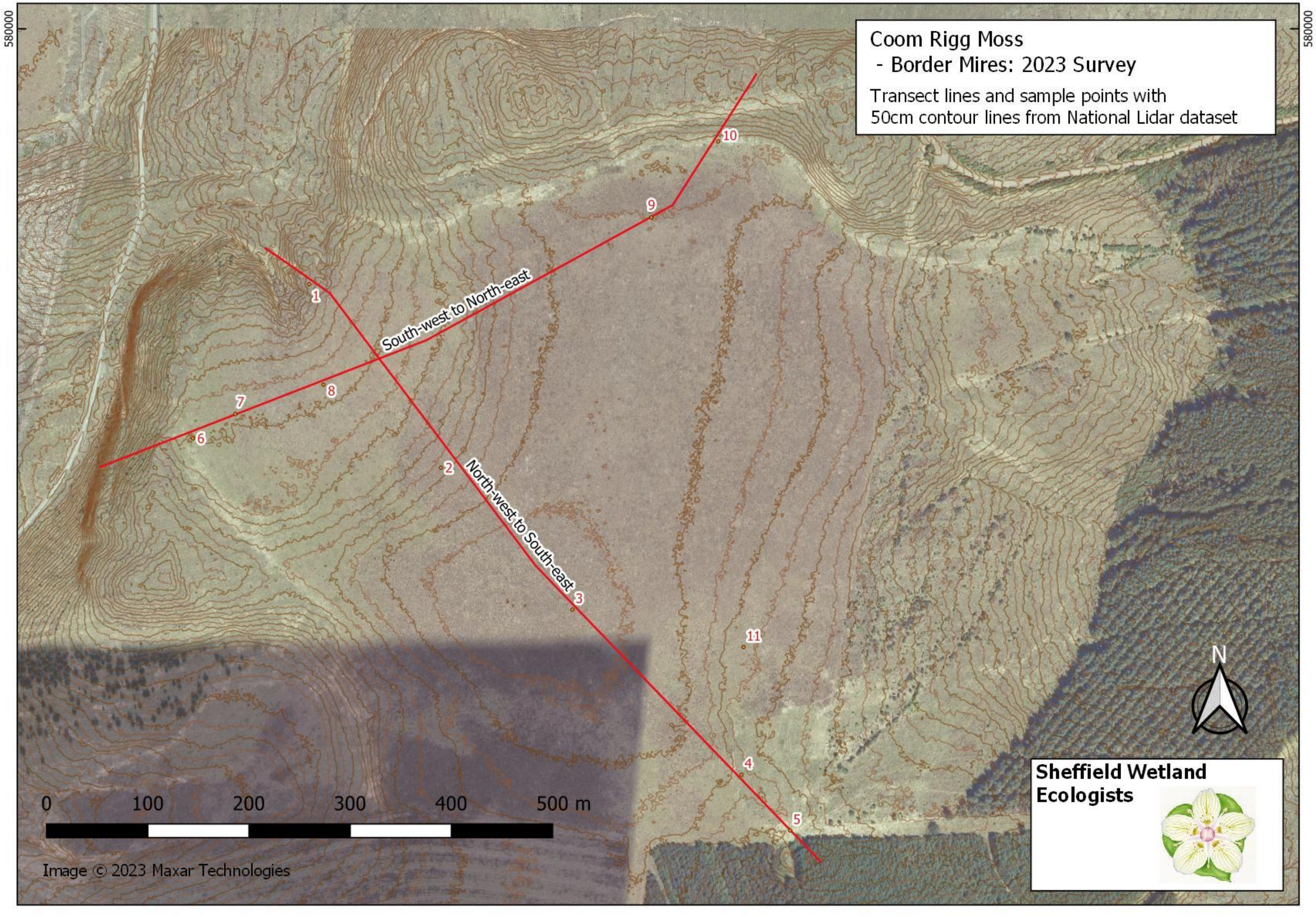

Figure B. 22. Coom Rigg Moss transect locations.

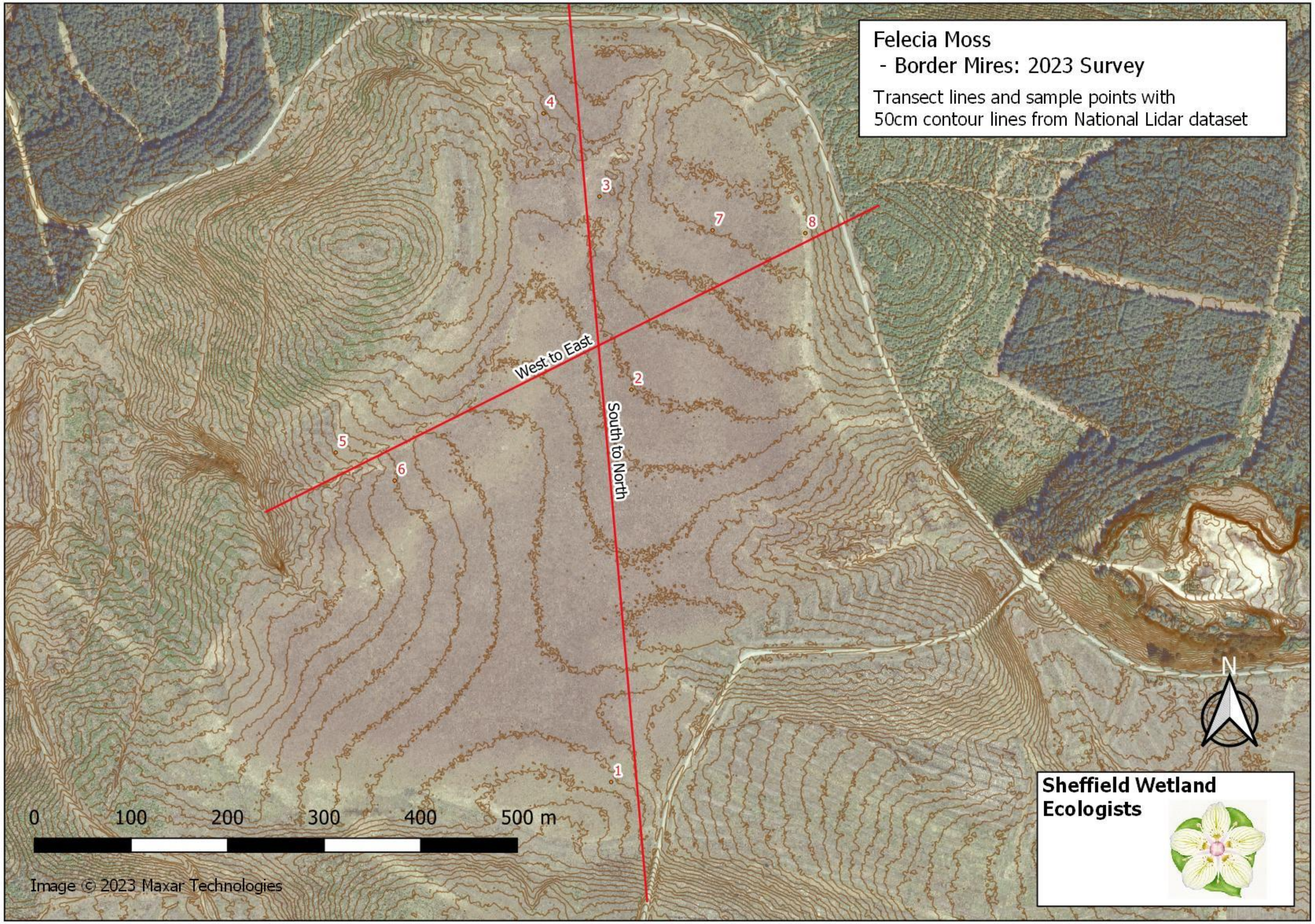

Figure B. 23. Felecia Moss transect locations.

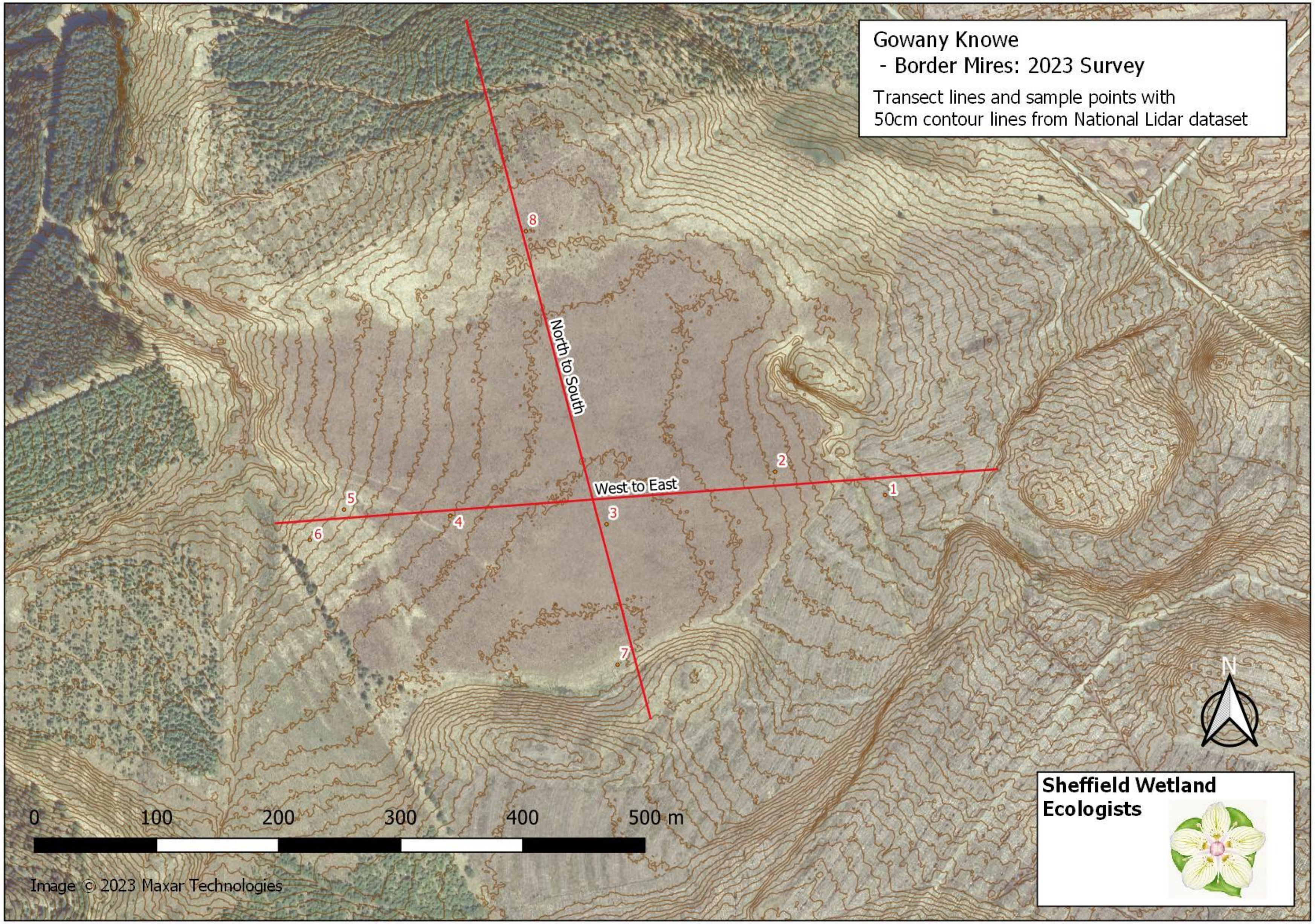

Figure B. 24. Gowany Knowe transect locations.

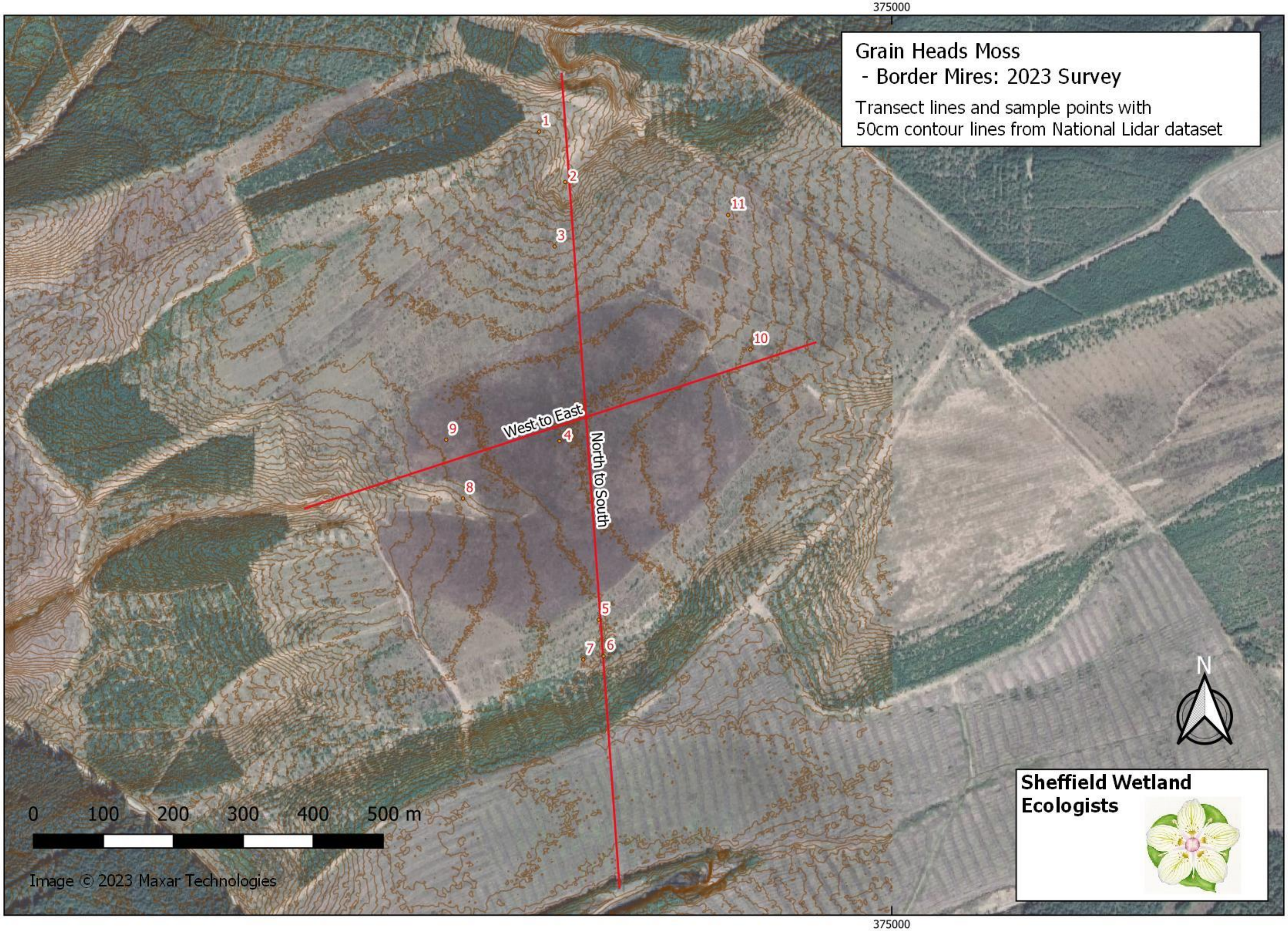

Figure B. 25. Grain Heads Moss transect locations.

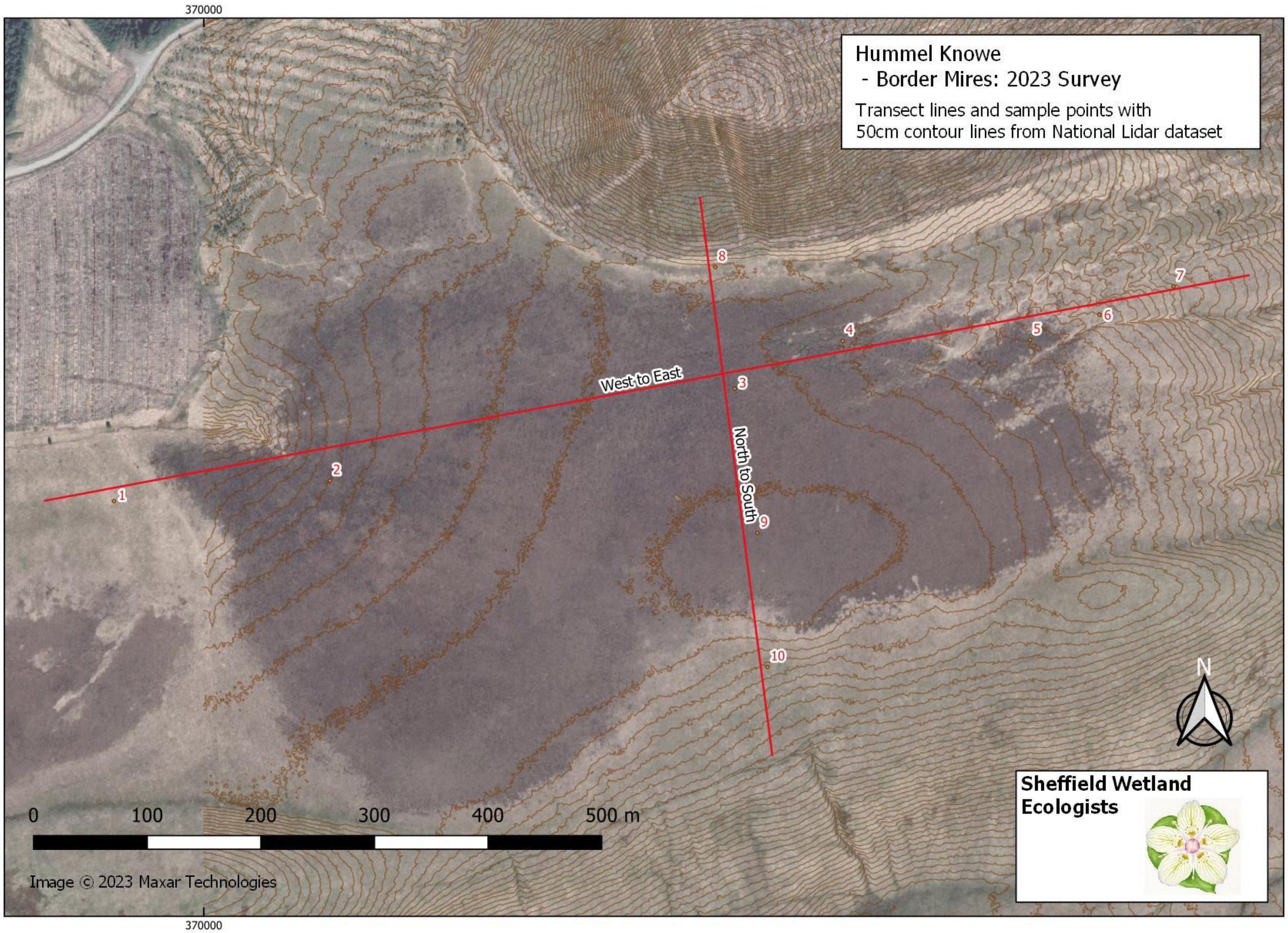

Figure B. 26. Hummel Knowe transect locations.

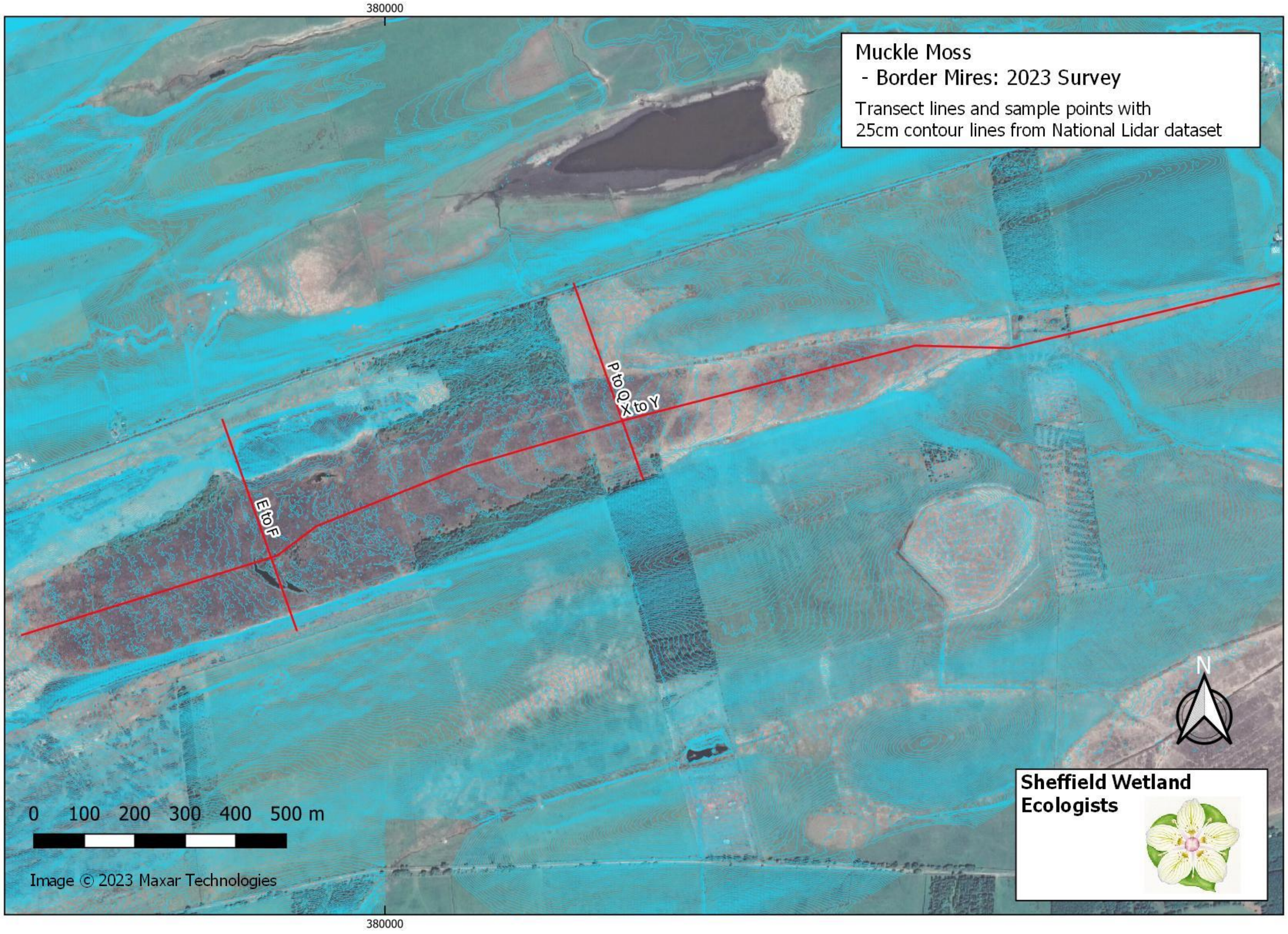

Figure B. 27. Muckle Moss transect locations.

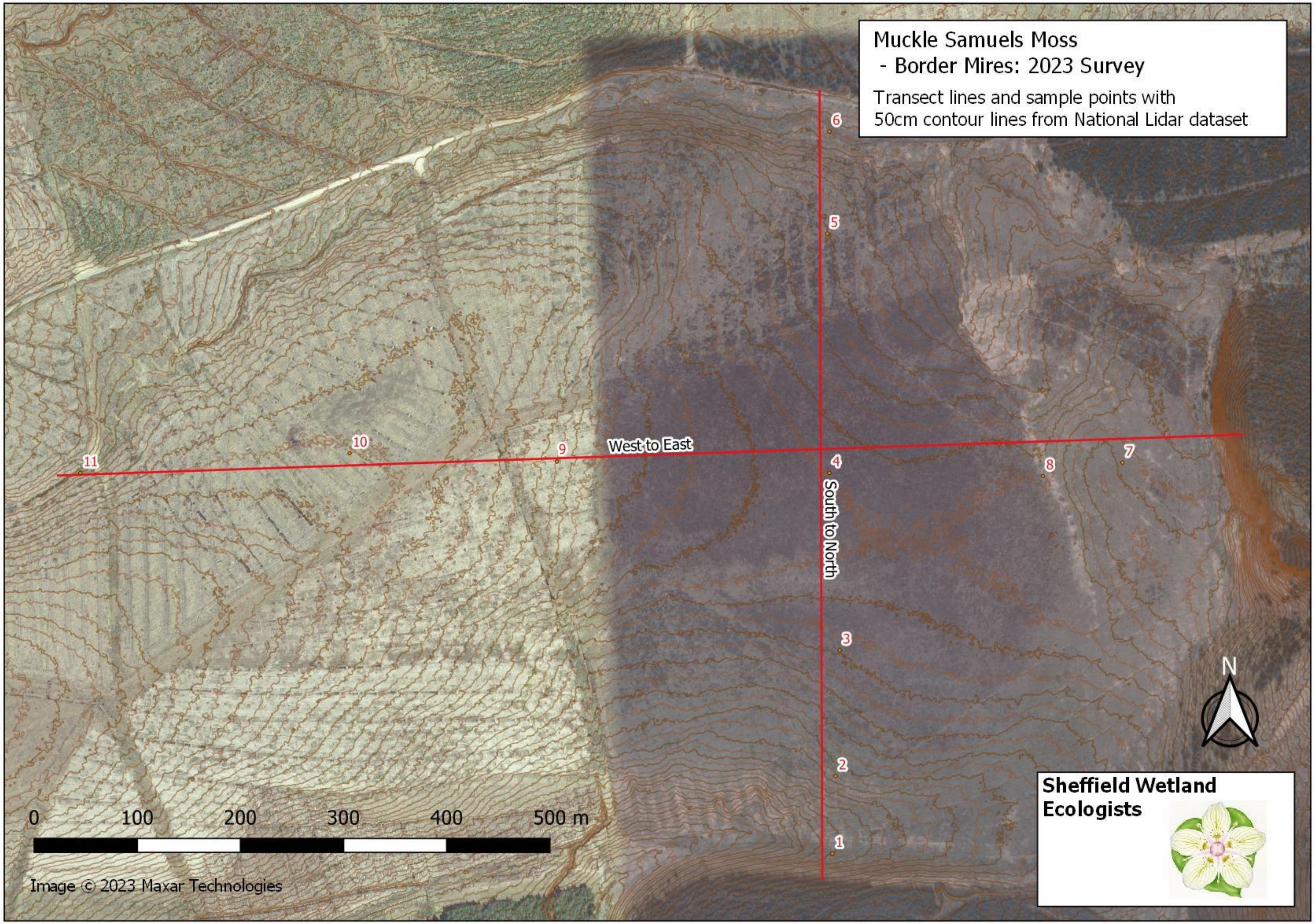

Figure B. 28. Muckle Samuels Moss transect locations.

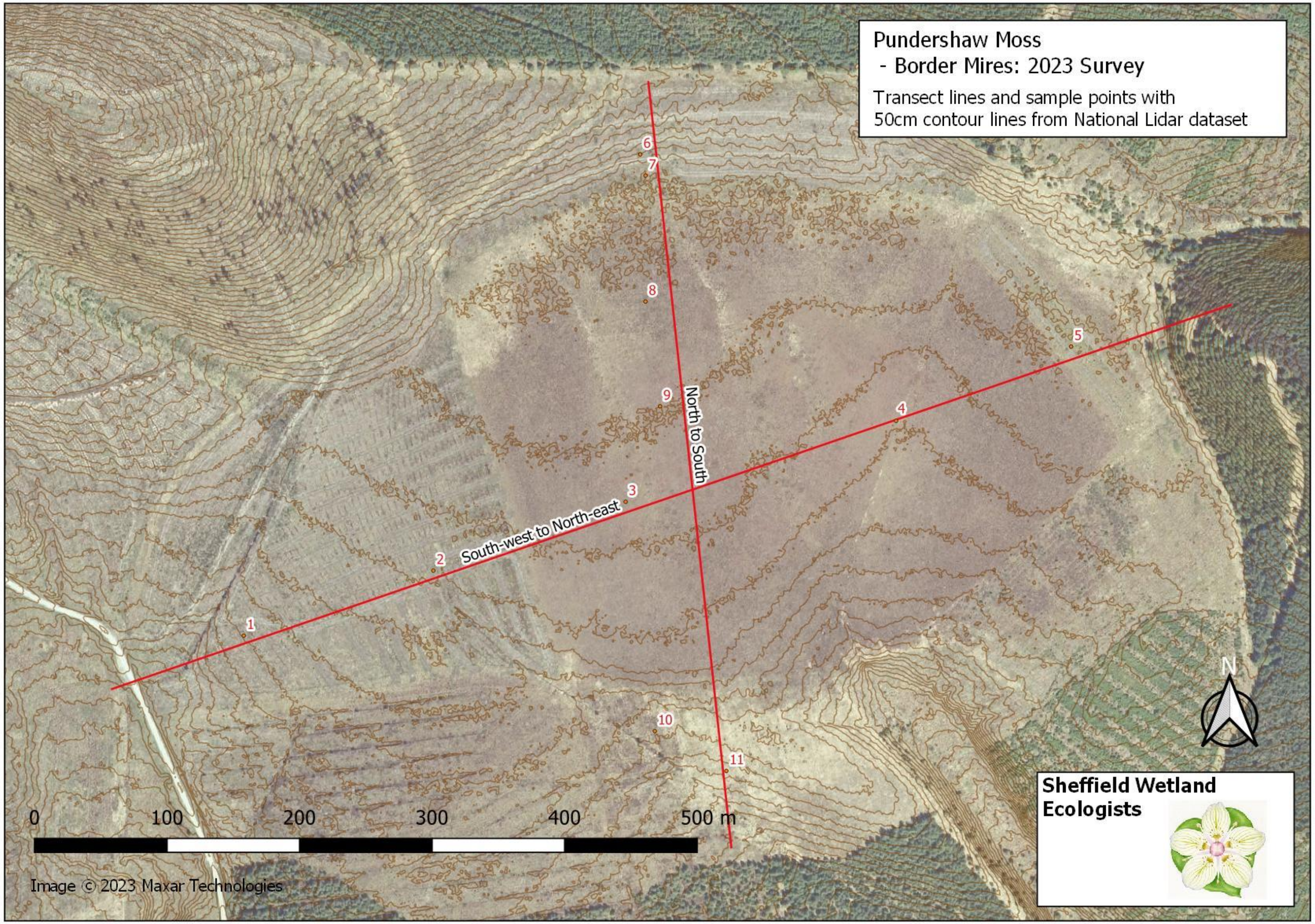

Figure B. 29. Pundershaw Moss transect locations.

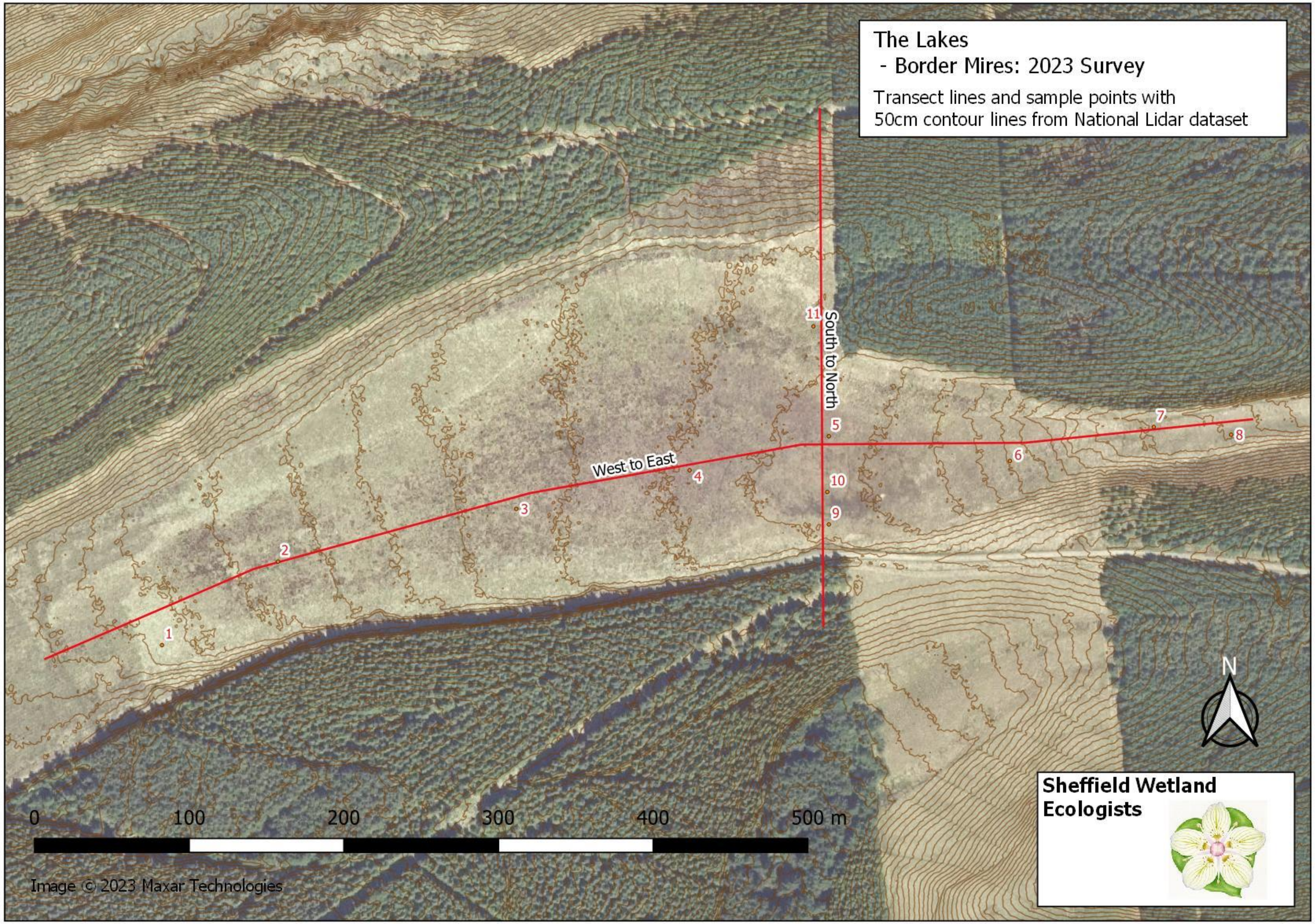

Figure B. 30. The Lakes transect locations.

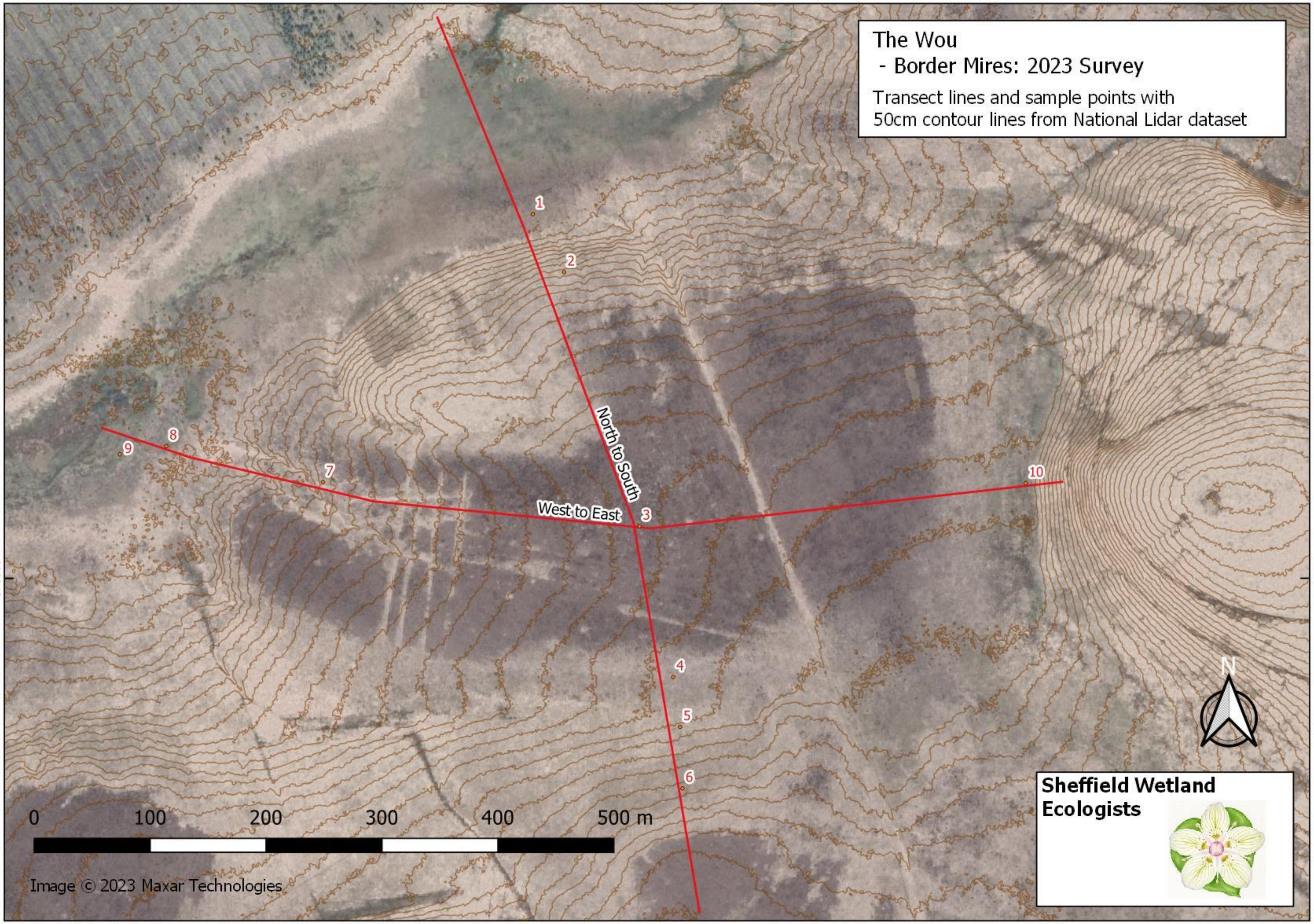

Figure B. 31. The Wou transect locations.

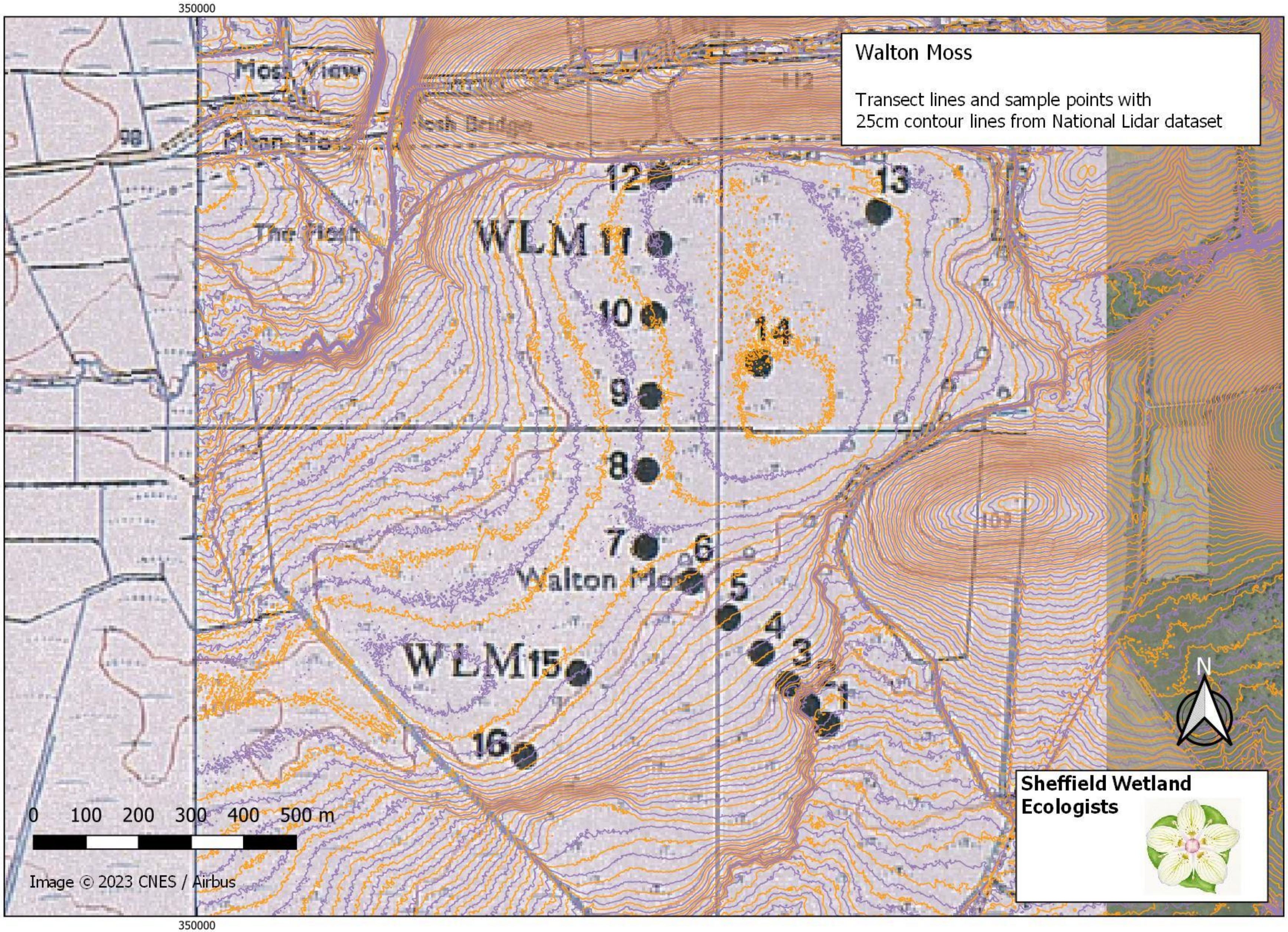

Figure B. 32. Walton Moss transect locations.

11.4 Annexe 4. Selected site photo names and descriptions.

(Photos are provided as a separate resource – see zip folder "BlBogGuidelines_FD_Annx4_25-06-2023")

Border Mires

Butterburn Flow

Bburn Wlagg – view of lagg zone at western end of transect looking north

Bburn typical – view from middle of transect looking east

Bburn S5pools – transverse pools at eastern edge of site

Bburn S2 – near W end, heather cottongrass, Sphagnum abundant

Bburn NPools – Google Earth view of northern part of site (not visited) showing pools

Bburn M19-m slope – *Molinia*-dominated M19a slope at E end of transect above the Butterburn river

Bburn excl – shows old exclosure near W end of transect

Bburn EastPools – Google Earth view of transverse pools at eastern end of transect

Coom Rigg Moss

CoomRigg Phrag2 – patch of *Phragmites* in M19a bog vegetation at eastern side of site looking north

CoomR M18 N – M18a veg on the north side of the site looking south

CoomR M19a N – northern outflow area with M19a veg looking west

CoomR M20 W – M20 veg in western lagg zone, looking NE

CoomR M20 SE – M20 veg in SE corner of site looking S

Hummel Knowe

HummelKlagg – view of lagg zone at northern edge of site, looking east

HummelKview – view from mineral slopes north of site, looking SW

HumK M18a – sample 3 M18a veg near the crown of the bog looking S

HumK M18n – S4 M18 with much *Narthecium*, wet, blocked channels, looking W

HumK M19 – S5 M19a veg and *Molinia* channel on NE side of site looking NE

HumK M20-m – S1 M20 *Evag* and *Molinia* veg on slope on W edge of site looking NE

The Wou

TheWou M18-n – S1 M18-n looking NE. Anomalous wet M18 in broad shallow valley bottom on north side of deep bog areas, O'Reilly named it 'M20-wet', but it was *Sphagnum*-rich with *Andromeda*, just dominated by Eriophorum vaginatum.

TheWou M18-a – S3 M18a looking west, in main area of deep bog peat

TheWou M6c – S10 M6c in lagg zone at eastern edge of site below low mineral ridge, looking SW

TheWou M4 – S8 M4 at edge of broad shallow valley at eastern edge of slope down from main bog, looking N

TheWou M25 – S5 M25 on very gentle slope leading up from main area of deep peat to a smaller deep peat lens to the south. Looking West.

Grains Head Moss

GHM M19b S1 – Sample 1 M19b looking south, previously afforested sloping edge to the bog, spruce regen

GHM M6c S2 – Sample 2 M6c looking N, an outflow channel from the bog on the north side, influenced by ditching

GHM M19a – S3 M19a looking north, on the fringe of the open bog centre that was not afforested

GHM M18a – S4 M18a looking N, centre of the open bog

GHM M6c&M4 – S7 M6c & M4 in lagg zone at southern edge of open bog below mineral slope with shallow peat

GHM M25 – S8 M25 *Molinia* strip looking west, situated on a submerged mineral ridge, slight slope

GHM M19b S10 – Sample 10 M19b looking NE, on north-eastern side of the main open mire in furrowed formerly afforested area, gentle slope and shallow peat

Muckle Samuel's Moss

MuckleSam S1 M6c – rushy stream at southern side of bog, looking W

MuckleSam S2 M19a – previously afforested, ditched slope, looking W

MuckleSam S3 M18a – centre of mire on deep peat, looking E with Muckle Samuel's Crags in the distance

MuckleSam S5 M19a – Previously afforested and ditched mire on north side of main bog; looking SE, with MS crags in the background, just in front is shallow peat with *Eriophorum vaginatum*, in front of that is a broad belt of lagg vegetation and water flow track.

MuckleSam S7 M20 – Shallow peat below the crags, looking E

MuckleSam S11 M6c – looking west, a small stream flowing E between two peat lobes, cut down to mineral, apparently endotelmic as it originates a short distance west within the peat.

Pundershaw Moss

Pundershaw S2 M19a – previously afforested, furrowed, looking N to afforested mineral ridge.

Pundershaw S3 M18a – 'crest' of the bog dome / ridge, looking NE toward mineral ridges

Pundershaw S4 M18a – ditched axial flow line marked by abundant Eriophorum angustifolium, looking North

Pundershaw S7 M6c – lagg zone at northern edge of the mire, looking E

Pundershaw S11 M25 – Dense *Molinia* on sloping dry thin peat, looking N towards open mire

The Lakes

TheLakes view SW – looking 'upstream' from near S1 to where the valley narrows and becomes forested

TheLakes view E – looking 'downstream' towards the broadest part of the mire.

TheLakes S2 M20 – looking N across the mire towards low forested mineral slopes.

TheLakes S4 M18a – looking E towards the narrowing of the mire into the 'neck' and flanking mineral slopes, where the ground drops down to S7 and S8.

TheLakes view W – view from the NE corner on a low mineral ridge, looking W. A narrow rushy lagg is visible in the foreground, curving away around the deep peat of the mire, visible n the RHS of the image.

TheLakes view S – looking from the same NE mineral ridge southwards across the mire to a low ridge with the road.

TheLakes S7 M6c – looking E along the ditched outflow channel within the 'neck' below the main mire, with mineral slopes either side.

TheLakes S8 M23b – looking W from the 'neck' up to the slope of the main mire in the background, mineral ridges either side.

TheLakes S10 M21 – looking west along a broad water flow track on quaking peat.

Felecia Moss

Felecia view SW – looking SW from the road on the E edge of the bog, towards the forested mineral ridge and main outflow from the bog.

Felecia view S – looking S from the road on the E edge of the bog, toward the southern edge of the mire and the SE outflow.

Felecia S8 M25 – looking N along the eastern lagg zone with *Molinia* and *Juncus effusus*.

Felecia S1 M20 – looking N from the southern edge of the bog within an M20 'lagg'

Felecia near S3 M18a – looking SW along a dammed former erosion channel towards the western mineral ridge edge.

Gowany Knowe

Gowany view SW – looking SW from a rocky knoll at the NE corner of the mire, looking towards rising forested mineral and peat slopes; 1km beyond lies Felicia Moss.

Gowany view NE – looking back at the rocky knoll at the edge of the mire. This has a pronounced small but steep rand and lagg between the edge of the bog and the knoll.

Gowany near S2 M18a – looking south across the centre of the bog towards the mineral slope at its southern edge.

Gowany S4 M19a – looking NW along a water flow track with stunted *Phragmites*, possibly leading from the lagg at the southern edge.

Gowany S6 M20 – looking N towards the stream that marks the western edge of the bog. Adjacent is another strip of stunted Phragmites.

Southern Pennines

Combs Moss

Combs S2 H12 – Dry heath vegetation on deep peat of clough side, looking NW

Combs S5 M19a – wet bog on saddle top, deepest peat, near monitoring points of Moors for the Future, looking SW

Combs S8 M19m – *Molinia*-dominated sloping bog looking SE above a small clough

Combs S9 M6c – Soft-rush dominated clough bottom, looking NE

Featherbed Moss

Feather S1 M6c – rushy base of Withins Clough, looking SW

Feather S2 M19-h – dry heather-dominated bog between two gullies on moderate slope, looking SW

Feather S3 M19a – moderately diverse wet bog where *Andromeda* has been seen previously, looking NE

Feather S4 M20 – *Eriophorum vaginatum* dominated flank of Featherbed Moss, looking SE

Feather S5 M20 – gently rounded summit of Featherbed Top, looking SE

Feather S6 M19 – gullied area on bench to east of the summit where two headwaters meet, looking SE

Feather S7 M19 – restoration area on bench, looking E

Feather S10 H12 – deep peat (2m) on very edge of plateau, fence marks edge of peat and steep scarp, looking S

Bowland & Lancashire

Cross of Greet

CofG S2 M19a – sloping hill bog looking East

CofG S6 M6c – gully near top of hill, looking NE

Crutchember

Crutch S1 M20 – western edge with abundant *Eriophorum vaginatum*, looking NE

Crutch S3 M18a – wet axial flow zone with some shallow pools, looking NW

Crutch S6 M19a – shallower peat at eastern edge, looking NE

Halstead

Halstead S2 M19a – ditched axial flow, M19 dominated by *Eriophorum vaginatum* with some M2 pools, in the background the heather marks M18 and M19a, looking W

Halstead S5 M18a – separate lobe of deeper peat near the eastern end of the bog, looking North.

Hasgill

Hasgill S2 M19a – peat-cut central part of the bog now supporting much *Eriophorum vaginatum*, looking SW

Hasgill S3 M18a – peat cut edge, looking SW

Hasgill S4 M18a – most diverse part of the bog, looking NE.

Stone Park

Stone S2 M18a – central bog dome, looking NW

Stone S7 M4 – M4 vegetation at edge of ditched stream, looking SE

Stone S11 M19a – bog vegetation in foreground, pale strip is a small stream, dark vegetation in the background is the bog dome, looking SW.

Wales

Hafod Elwy

Hafod S1 H12 – previously afforested SW part of the site, dry ridge and furrow, looking W

Hafod S2 M2 – Blocked ditch now supports strips of bog pool veg, looking NE

Hafod S6 M19a – this section has not been afforested, peat 2–4m deep, looking NE

Hafod S9 M18a – unforested, looking toward cleared area, forest in the background on a descending slope. Foreground tree marks a deep axial channel, possibly part ditched, with a huge peat pipe.

Figyn Blae-brefi

Figyn S2 M4 – gently sloping quaking water track with *Carex rostrata* in the SW corner of the site, looking N

Figyn S3 M19-m – dammed and bunded erosion area along central axis, looking NE; mineral ridge in background with forestry, willow scrub at base of slope.

Figyn S8 M18a – wet *Sphagnum* hollows and low heather haggs along eroded axis near watershed, looking NW

Figyn S10 M2 – bog pools with *Rhynchospora* & Sphagna on 'saddle' summit (5m peat), looking N.

Moel Eunant

MoelEunant S1 M6c – rush-filled gully on steep slope below the hill summit, looking S

MoelEunant S3a M19a – Ridge summit, recent damming of large erosion gullies (2.7m peat), looking south

MoelEunant S3b M19a – as above, looking NW

MoelEunant S8 H12 – foreground: dry heath on shallow peat; background: deeper peat and rushy gullies, looking SE

MoelEunant S9 M6c – looking N, illustrates landscape of gentle slopes with deep peat (1–3m) and steeper slopes with shallow peat or none, divided by streams and small rivers.