Working towards the development of Ecohydrological Guidelines for Blanket Bog and Associated Habitat – A Scoping Study

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Report to:

Environment Agency,
in partnership with Natural England, Natural Resources Wales,
Scottish Environment Protection Agency and Scottish Natural Heritage

Non-technical summary

Background and methodology

Peatlands cover roughly 2.5% of the land surface area of England and Wales and around 10% of Scotland, the majority of which occur as part of an extensive blanket mire landscape. Upland mires are not covered by existing ecohydrological guidelines, and in recent years there has been a move away from target setting to an increased emphasis on restoration of natural hydrological functioning of mires in the landscape. The UK Country Agencies have perceived a need to provide more user-friendly guidelines for upland mire habitats to support work on reducing carbon emissions and natural flood management. This project has been undertaken as a scoping study aimed at reviewing information that could be used to characterise the water supply mechanisms of upland mires, and to understand how these relate to the different vegetation types of blanket mire landscapes. Sections 1–3 of this report identify the main drivers, aims and delivery of this project.

A broad aim of this study has been to determine the availability of ecological and hydro-geological data sources for individual upland mire sites that could be used for a 'bottom-up' analysis, providing the foundation for an upland mire classification. Such work would help to provide a holistic understanding of the requirements of upland mire vegetation types and provide a basis for assessing the likely outcomes of conservation actions. The process of gathering information has involved a search of the available literature, including published reports and journal articles, and unpublished work where this could be acquired. Where possible, gaps in the available information have been identified and recommendations for further work have been made.

Acquisition of data has not been straightforward because of the short timescale of the project, with most contacts very busy, some not responding at all to enquiry, and some indicating that funding would be required to pay for time spent on collating relevant data. There was also some potential sensitivity in releasing data to contractors. As a consequence the study is at the point where, although a range of data are held, other data are known to be available but their precise nature is not understood ('known unknowns'). There are also likely to be other information sources that have not yet come to light ('unknown unknowns').

Relevant information from the various literature sources has been synthesised, with particular attention paid to the basic data rather than their interpretation by authors. These data have been used to develop several discussion sections regarding the characterisation of blanket mire landscapes, mire vegetation, hydrology, and related habitat features. In addition, published and unpublished data sources have been used to develop case study accounts for a series of reference sites. These are presented in Annexe 1 and comprise the following sites or regions: South Wales; the South Pennines; North York Moors; the Border Mires of Cumbria and Northumberland; Silver Flowe (Galloway); 'Bog Woodland' sites of the Scottish Highlands; Loch Shiel Mosses; the Flow Country of northern Scotland; and a selected range of Scottish sites examined by the Scottish Peat Survey.

Section 4 of this report gives consideration to important wetland terms and the categories and concepts that underlie them, partly to clarify their meaning as used in this report, but also because they are relevant to understanding some of the ecohydrological processes that occur in mires. A brief overview is given of existing hydromorphological wetland classifications, and the rationale behind the 'Wetland Framework' approach to wetland classification (see Figure 1).

Features and characteristics of ombrogenous peatlands

Section 5 discusses the characteristics and hydrodynamics of ombrogenous ('rain-fed') peatlands.

Two main types of ombrogenous mires have generally been recognised in Britain, *raised bog* and *blanket bog*, but it is often not clear what features have led to these designations, and it appears that their classification can often be a source of uncertainty to surveyors. Some authors have categorised ombrogenous mires by their location or climate. Others have emphasised the extensiveness of blanket bog terrain compared with raised bogs or have classified sites by virtue of their proximity to other blanket bog sites. Often the presumed status of ombrogenous surfaces as raised bog or blanket bog may reflect the extent to which their sub-surface topography has been investigated, rather than any fundamental differences in the character of their ombrogenous surfaces. To initiate a more robust and useful categorisation of ombrogenous mires and related peat deposits, their most important characteristics have been collated in this report, focussing upon upland mires but with some reference to lowland examples for comparative purposes.

Two main sets of developmental processes have frequently been identified in mires: *terrestrialisation* of open water, and *paludification* (wetting up) of dry ground, both of which can lead to the development of ombrogenous mire. There is a third starting point, which may also be considered to be a form of paludification, in which mire initiation occurs in poorly drained hollows or on flat ground that is wet but not flooded. Some researchers have considered that blanket bogs have developed by paludification whereas raised bogs developed via terrestrialisation, though others have considered that the only requirement for raised bog formation was an almost level surface with impeded drainage.

In terms of composition and characteristics of ombrogenous peat, perhaps the most widespread type is peat dominated by the macrofossil remains of *Sphagnum* mosses and cotton-grasses, with varying amounts of heather. This occurs widely across sites that are referred to as raised bog and blanket bog, though remains of deergrass in the peat can become more prominent further north and west. Layers of peat dominated solely by *Sphagnum* mosses also occur widely in ombrogenous bogs, sometimes reaching several metres in thickness, and whilst these are particularly a feature of some raised bogs, they are also present in sites regarded as blanket bog.

Many workers have accepted the conceptualisation of ombrogenous peatlands as *diplotelmic* ('two-peat') systems, with a thin, relatively permeable upper *acrotelm* layer overlying a much thicker and less permeable *catotelm* layer, with the main runoff of excess precipitation occurring laterally through the acrotelm. More recently other workers have suggested that this approach is too simplistic, and that there is a need to consider horizontal variations in hydraulic properties as well as depth variations (see Figure 2).

Where ombrogenous mires have developed on flat ground, peat accumulation tends to be greatest at the least well-drained location (*i.e.* the centre of the site), where peat depths can reach 10 m or more. Consequently a raised dome of peat may develop independently of the underlying topography, its surface typically flattest at the centre and steepening towards the margins. The height and shape of the peat dome are partly determined by its area, but also depend upon age, rate of peat decomposition, and the effects of artificial drainage and peat digging.

In cooler, wetter, and often more upland contexts, the dominant form of ombrogenous peatland is often described as blanket bog. Ombrogenous peat has been reported on relatively steep slopes, and extensive, quite shallow deposits (≤ 2 m depth) can occur across hillslopes, constituting the typical 'hill peat' of many upland districts. Although on more steeply sloping ground there may be little evidence for any peat mounding other than as a reflection of the underlying topography, true domes of ombrogenous peat do appear to be quite widespread in blanket bog contexts, though they are often rather small. They are usually associated with shallow basins or poorly drained flattish ground, and whilst some examples are clearly defined, in others peat-covered adjacent slopes may obscure the margins of the dome. In areas of very irregular terrain, several small peat mounds may occur in separate basins, linked by shallower peat across ridges, and in some cases the peat can be 'punctured' by hillocks of mineral ground. Despite this, where a domed surface is drained by radial water flow it is likely to retain the hydrological features and often the vegetation characteristics of a lowland raised bog. However, where an ombrogenous peat dome has developed upon a gentle slope, there is a greater potential for drainage to be distributed asymmetrically down the main direction of slope and for the dome of peat to be located eccentrically.

An ecohydrological distinction can be made between different elements of upland ombrogenous slopes. The topmost, flatter areas, in a watershed location, are likely to be irrigated almost exclusively by precipitation, whilst downslope areas will also receive down-slope flow. In some situations, this may be augmented by runoff from adjacent non-peat slopes, sometimes giving rise to areas of more fen-like vegetation. Water movement in sloping peatlands is dominated by overland flow and near-surface seepage through the peat, and their hydraulic characteristics may resemble the sloping edge (rand) of raised bogs. In addition, there is a strong tendency for flow to become concentrated into flow-tracks and small streams. Sub-surface pipes and gullies can occur widely, and the collapse of peat pipes has been identified as the beginning of gully erosion at some sites. Recent studies of sloping bogs have demonstrated that most surface runoff is generated in the upper 5 cm of peat, and that macropores (>1 mm diameter) are important runoff pathways, connecting the surface layer with deeper peat pipe networks (Figure 2) and allowing the flux of sediment and nutrients from deeper peat layers. Runoff flow through pipes appears to be more important for smaller rainfall events, whereas flow through the surface peat and over the surface are more significant during heavier rainfall.

A distinctive feature of some ombrogenous peatlands is the occurrence of surface patterning, the two main types being hummock–hollow and ridge–pool surfaces. The various components of surface patterning have been categorised in terms of their vertical zonation and distinctive vegetation types by Lindsay *et al.* (1988) (see Figure 9). The amplitude of the hummock–hollow or ridge–pool patterning is strongly related to climate, and different patterns are broadly associated with different parts of Britain. Larger ridge–pool surfaces, often with crescent-shaped pools aligned across the slopes, are generally found only on bogs in northern and western Scotland, whilst in England and Wales surface patterning, when present, is mostly represented by the more subdued hummock–hollow microtopography. Steeper ombrogenous slopes typically support a more uniform vegetation, usually lacking a conspicuous hummock–hollow surface relief, and are generally associated with thinner peat deposits.

Although pools are a common feature of many peatlands, relatively little is known about their hydrological functioning, though there is evidence that pools can be important sources of methane, dissolved organic carbon (DOC) and particulate organic carbon (POC). Connectivity between pools and the surrounding peat appears to be greatest within a few centimetres of the peat surface, indicating that heavy rainfall events are important for flushing out the carbon and other nutrients that have been processed within the pools. Where studied, pool complexes have often been found to be situated over some form of hollow in the underlying mineral ground, and pool complexes appear to have gradually spread outwards from their initial focus.

Section 6 describes other types of mires and habitat that are often associated with ombrogenous peatlands, particularly minerotrophic mires and areas of marked water flow within ombrogenous mires. The potential ecohydrological significance of lateral water flow is that it can increase nutrient availability and oxidation status of the peat, and it is often marked by different types of vegetation. Such 'flow tracks' are quite widespread in ombrogenous mires, but they appear to be a more prominent feature in wetter parts of Britain. Minerotrophic mires often form a distinctive component of upland areas but are sometimes subsumed within dominant ombrogenous habitats and can thus be overlooked. Minerotrophic mires may be largely peripheral to ombrogenous mires, embedded within them, or they may occur as complex mixtures of ombrotrophic and minerotrophic surfaces.

Vegetation and habitat conditions of ombrogenous peatlands

Section 7 discusses the types of vegetation and habitat features often associated with blanket bog landscapes.

Blanket bog landscapes support mainly ombrotrophic and weakly minerotrophic vegetation types (Table 9). Many of these plant communities support a similar suite of species and can sometimes be difficult to separate floristically, especially when the vegetation is impoverished. Vegetation classifications such as the National Vegetation Classification (*NVC*), which are based on floristic composition rather than species dominance, are important because they are better able than some broader 'habitat'-based systems to differentiate between plant communities that appear structurally similar (because they are dominated by one or a few species) but that support a suite of different associated species (Figure 5). Since the *NVC* scheme was published, some additional communities have been proposed – modifications relevant to upland peatlands include bog-bean bog pools, *Molinia*-dominated vegetation, and common sedge–lesser spearwort mires.

The *NVC* plant community M18 is characteristic of wetter surfaces, and on steeper slopes can be replaced by communities such as M15b, M19 and, sometimes M17, although it can be difficult to distinguish between M17 and M18. In general, M18 can be separated from M21 by the presence of bog rosemary and hare's-tail cottongrass. M20 is a very species-poor community dominated by hare's-tail cottongrass that appears to be a degraded form of M19 (Figure 6).

Some plant species are associated with habitat conditions such as wetness, which can make them useful proxy indicators of environmental conditions. Where bog surfaces show patterning with pools, ridges, hollows and hummocks, this niche separation can lead to the formation of vegetation mosaics at various scales, and this structural diversity provides a range of habitat niches for other species in bog ecosystems, particularly invertebrates and birds. A detailed sampling protocol has been used by some workers to characterise variation of vegetation based upon the microtopographical characteristics of blanket mires, but this is best seen as an adjunct to a standard *NVC* sampling of mire surfaces, not as an alternative.

Blanket bogs supporting 'active' bog vegetation are recognised by the EC Habitats Directive as habitats of international importance, although the term 'active' is poorly defined and ambiguous. The EUNIS classification of European habitats includes a confusing mixture of units based on various criteria, and the lack of detail and poor characterisation of many of the units, and the top-down nature of the classification, limits the value of this scheme in the description of British mires, particularly in the development of any understanding of their ecohydrological processes and the tolerances of distinctive vegetation. Other broad schemes such as the UK Priority Habitats, or the recent UKHab system, can be similarly unhelpful. Despite its limitations, the National Vegetation Classification provides a better general tool.

Environmental data, particularly those that can be linked to vegetation types, are generally sparse for upland peatland habitats. As far as is known, there is no dataset for habitat conditions in upland mires, particularly ombrogenous examples, comparable to that which was available from lowland England and Wales for the former Wetland Framework project. In addition, although there are several published studies on various hydrological aspects of upland mires, the information they provide is often highly processed, and it is not possible to extract from them underlying baseline data. To extend the Wetland Framework approach to upland ombrogenous mires there is a need to obtain linked vegetation and unprocessed hydrological datasets.

Restoration potential of damaged blanket bogs

Section 8 briefly summarises the potential for, and value of, restoration of damaged blanket bogs. A large proportion of the blanket bog resource in Britain has been damaged in one way or another by activities such as drainage, burning, atmospheric pollution, over-grazing and afforestation, and as a consequence the cover of bog vegetation has in many places become degraded. Bogs are an important carbon sink and the prevention of carbon loss from peatlands is a major governmental priority, as is the reduction of runoff and peak flow rates, which are believed to have an impact upon downstream flood risk. Degradation of bog sites can have a profound effect, generally causing a decrease in botanical diversity, a reduction in the extent of *Sphagnum* bog-mosses (where they were formerly present), and an increase in cover of dwarf shrubs, cotton-grasses, and purple moor-grass. Removal of degradation pressures can increase the cover of species considered to be indicative of good quality bog habitat (e.g. *Sphagnum*), and a high cover of *Sphagnum* species has been correlated with a significant reduction in overland flow. Restoration of vegetation cover on bare peat has been shown to result in reductions of particulate organic carbon flux and runoff rates, probably because of increased surface roughness. Ditch blocking has been seen to increase water tables and cover of 'wet bog' indicator species such as *Sphagnum* bog-mosses. In recent years there have been attempts to transplant *Sphagnum* into damaged bogs, although establishment has not always been successful. In some cases this may be because inappropriate locations have been selected, including areas that have not naturally supported a significant *Sphagnum* cover. An important omission from many restoration initiatives has been a failure to collect before-and-after vegetation data, especially in a way that can be related to *NVC* plant communities.

Classification of ombrogenous peatlands

Section 9 provides an assessment and critique of the current understanding of different types of ombrogenous peatlands in Britain, with particular regard to types of 'blanket bog'. The term 'blanket bog' is an informal and variable unit that represents a broad range of upland ombrogenous peatlands. Variations in character include peat depth and peat type, surface topography and patterning, and position in the landscape. JNCC (1994) recognised several sub-types of blanket bog based primarily on the topographical location of the mires in the landscape, but these are generally ill-defined and poorly described units that appear to represent the more 'interesting' structurally and botanically diverse versions of blanket bog that are typically associated with deeper peat and distinctive surface features and patterning. The JNCC typology appears to exclude the thinner forms of blanket bog whose surfaces follow the underlying topography of mineral ground, even though these are very widespread and extensive. These 'less interesting' botanically and structurally uniform ('bog standard) surfaces can themselves be divided into a small number of sub-types, but these are not obviously part of the JNCC typology. Because the JNCC sub-types depend upon landscape location, similar examples of blanket bog may be classed as different blanket bog sub-types, thereby creating overlapping entities. There appears to be little consistent distinction between the JNCC categories of 'valleyside mire' and 'spur mire', whilst the category of 'watershed mire' has affinities with both 'valleyside mire', and with lowland raised mire. However, its field characteristics seem to have been very poorly investigated and characterised.

The two main ombrogenous peatland units that have been recognised in Britain – *raised bog* and *blanket bog* – may often be assumed to have similar status and parity both in concept and compass, but this is not the case. In general, 'raised bogs' show relatively little variation, and their gross-form and characteristics are largely predictable. By contrast, sites and surfaces that are generally called 'blanket bog' are much more variable in form and character and, overall, consist of a melange of units, some of which have greater affinities with 'raised bogs' than with some other versions of 'blanket bog'.

It would be desirable, both for ecohydrologists and conservation managers, to develop a more coherent and comprehensive characterisation of blanket bog surfaces, to identify their salient characteristics, and thereby help distinguish more rigorously and clearly the different types of blanket bog, and to clarify their relationships with more lowland examples of ombrogenous peatlands elsewhere in Britain. This would require examination of additional unpublished sources that have been unavailable to this project as well as acquisition of additional carefully targeted field data. Conservation managers would benefit from the development of an objective typology of ombrogenous upland peatland based on ecohydrological data, since different units are likely to vary in their hydrodynamics and vulnerabilities, and may require different conservation targets. SSSI Selection criteria and Common Standards Monitoring thresholds would probably need to be revised as part of this process.

Recommendations

Section 10 provides some recommendations for future work. It should be noted that many of the sources of information used in this scoping study were published journal articles and unpublished reports in which the original data have been interpreted by the research authors. For the purposes of this project it is important to be able to view, and potentially re-analyse, the raw data; whilst it is possible that the field data upon which these articles are based are in existence somewhere, it is not possible for us to verify this without direct communication with the research scientists.

Similarly, it seems likely that there are other potentially useful datasets in existence for a range of blanket bog studies that we were unable to locate or access as part of this scoping study. In some cases this is because the data-holders require funds to collate the datasets that they have gathered (e.g. Moors For the Future Partnership, Yorkshire Peat Partnership); for others there may be issues with releasing data prior to publication of research (e.g. peat depth and stratigraphic data for

Munsary, northern Scotland); for yet others the lack of response to a request for information makes it difficult to ascertain whether relevant data exist (e.g. Scottish Power Renewables, United Utilities).

It has become clear during the course of this work that in general there is a dearth of ecohydrological data available for blanket mires, including basic topographical and peat depth data, especially at a 'whole site' or 'hill slope' level. There is variable *NVC* coverage and there are a few detailed vegetation datasets for blanket bogs. The majority of studies of blanket bogs are hydrological or relate to restoration, and the vegetation of the studied areas is often not sampled, or if it is, it is often not sampled in a way that allows cross-referencing to *NVC* plant communities.

In order to progress this project so as to extend the Wetland Framework approach to blanket bogs and associated mire types and to develop ecohydrological guidelines for these areas, it is necessary to acquire more linked environmental and vegetation datasets for blanket bog sites. This will require continued communication with the data-holders identified during this scoping study, development of data-sharing relationships, with payment where necessary for data extraction and collation, and carefully targeted collection of new environmental and vegetation data from carefully targeted bog sites. Once such data are available, they can be analysed using multivariate classification and cluster analysis procedures, as used in the original Wetland Framework approach. In addition, it would be useful to undertake systematic hydrological modelling of selected bog sites using the DigiBog programme developed at the University of Leeds.

Consequently, it is suggested that the project should continue beyond this scoping stage, and that the extended project should have a longer timescale to allow for the anticipated slow progress in accessing datasets, and considerable budget provision for obtaining datasets, visiting agency offices, carrying out targeted fieldwork, processing data, and detailed report writing. It is anticipated that the final output, a Wetland Framework-style set of ecohydrological guidelines, would be an important tool for upland and wetland land managers.

Contents

FIGURES

TABLES

SEPARATE AND ELECTRONIC DOCUMENTS

	Filename
Report summary	**SWE EcoHydro Report Summary Aug 2020.pdf**
Report main text	**SWE EcoHydro Report Main text Aug 2020.pdf**
Annexe 1: Reference Sites *List of sites is given in Section 13* **Annexe 2: Classification of 'Upland' Peat Soils.**	**SWE EcoHydro Report Annexes Aug 2020.pdf**
Annexe 3: Literature sources. Spreadsheet catalogue of literature sources	**SWE Ecohydro literature 09-03-2020.xlsx**
Annexe 4: Datasets. Spreadsheet catalogue of datasets	**SWE Ecohydro datasets 09-03-2020.xlsx**
Annexe 5: Scottish lowland peatland *NVC* types. Spreadsheet of Scottish peatland *NVC* plant communities, collected as part of a comparative survey of a wide range of habitat conditions related to specific plant community-types in lowland minerotrophic mires in Britain, by Wheeler and Shaw (unpublished)	**SWE Ecohydro ScotHabQ 09-03-2020.xls**

Acknowledgments

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Frequently-used terms

The following terms are used frequently in this report. A more detailed glossary is provided in Section 12.

Mire	Unconverted permanent telmatic* wetlands. Includes wet sites on both peat and mineral soils but excludes former wetlands that have been badly damaged or converted into another habitat.
Peatland	All areas with peat, including sites with natural or semi-natural vegetation and areas converted to agriculture or forestry or used for peat extraction.
Bog**	Acidic (pH < *c.* 5.5) mires (mainly on peat, but some mineral soils).
Fen**	Base-rich (pH > *c.* 5.5) mires (peat and normally wet mineral soils).
Topogenous	Wetness resulting from topography and poor drainage (such as hollows).
Soligenous	Wetness resulting from moving water supply (such as seepage slopes).
Ombrogenous	developed under the exclusive influence of precipitation
Ombrotrophic	Surface irrigated directly and exclusively by precipitation.
Minerotrophic	Surface irrigated both by precipitation and telluric water
Eutrophic	High fertility conditions, rich in nutrients.
Mesotrophic	Moderately fertile conditions.
Oligotrophic	Low fertility conditions, nutrient poor.
Meteoric water	Precipitation.
Telluric water	Water that has had some contact with the mineral ground
Water table	Below-ground free water surface
Water surface	Surface of standing water
Water level	Used generically to include water table and water surface
Stand	A relatively uniform patch of vegetation of distinctive species composition and appearance. Can vary in size from very small (in m^2) to very large (in ha).

* Wet, semi-terrestrial wetlands (not aquatic wetlands)

** These definitions of 'bog' and 'fen' differs from common usage. Many workers follow Du Rietz (1949) in equating 'bog' with ombrotrophic peatlands and 'fen' with minerotrophic sites. However, Du Rietz's distinction, based mainly on water source, does not relate well to hydrochemical or vegetational differences between the habitats. The definition suggested here is used in the Wetland Framework (Wheeler *et al.*, 2009) and follows the proposals of Damman (1995) and Wheeler and Proctor (2000), and comes very close to the original meaning of the terms as used by Tansley (1939).

1. Introduction

1.1 Project drivers

The current suite of Ecohydrological Guidelines was developed between 2004 and 2010, and has been widely used across the UK to support regulatory decision-making including:

- assessment of Groundwater Dependent Terrestrial Ecosystems (GWDTEs) as part of groundwater status assessments for River Basin Plans;
- development of effective catchment-based measures in support of River Basin Planning;
- assessment of impacts on wetlands from abstraction licensing and other planning pressures;
- protection of wetlands from diffuse pollution;
- wetland restoration and conservation management.

In recent years there has been a shift in the approach to defining wetland needs. The current guidelines are now 10–15 years old and there has been a move away from ecohydrological target-setting towards restoration of natural hydrological functioning of wetlands in the landscape. In addition, many recent studies have been undertaken that have the potential to improve the existing guidelines and our understanding of how wetlands function. There are several habitats, including upland wetlands (e.g. blanket bog) that are not covered in the existing guidelines. Given the current climate crisis and government move towards net zero carbon emissions by 2050, understanding and restoring the hydrology of these habitats is now even more critical.

Updating the Ecohydrological Guidelines will ensure the Environment Agency and its external partners continue to use the best science to make regulatory decisions affecting internationally and nationally important wetland habitats across the UK. In particular, the planned work will help to:

- ensure groundwater body status assessments (based on the GWDTE test) use the latest evidence and target those GWDTEs most at risk from groundwater abstraction and quality pressures;
- support ongoing work by Environment Agency Operations on identification of catchment measures in River Basin Plans;
- contribute to achievement of net zero carbon emissions through restoration of upland habitats;
- ensure that multiple catchment benefits delivered by Surface Water Dependent Ecosystems (SWDTEs) are recognised during programmes delivering catchment measures for River Basin Plans, and also other catchment programmes (e.g. Defra-funded Working with Natural Processes / Natural Flood Management programme).

1.2 Project aim

The main objectives of the overall project are to:

1. apply ecohydrological knowledge of upland habitats in order to prepare ecohydrological guidelines for blanket bog and associated wetlands, to support work on reduction of carbon emissions, and to work with natural processes and natural flood management;
2. prepare user-friendly ecohydrological guidelines for upland habitats for a range of stakeholders;
3. carry out internal training within Country Agencies to raise awareness of the new updated Ecohydrological guidelines.

Due to the short timescale and limited budget available, this first phase of the project has been viewed primarily as a scoping study, and has been limited to gathering, collating and reviewing relevant information. Key tasks were, as far as possible, to characterise the ‘ecohydrological conditions’ related to plant communities of blanket bog landscapes, to characterise water supply mechanisms of upland mires and to make recommendations for the next phase of the work.

1.3 Project delivery

Sheffield Wetland Ecologists were appointed in November 2019 as specialist contractors to progress the first phase of the project. To support this, they undertook a literature search and contacted as many organisations as possible in an effort to obtain linked vegetation–environment data.

A Steering Group was established, the members of which had a formal role in the project to steer the scope and progress, and quality assure the delivery and outputs. The Steering Group members are shown in Table 1.

Table 1. Steering Group members

Name	Organisation and Role
Dr Mark Whiteman **Project Manager**	Environment Agency, Senior Advisor, Groundwater team, Environment & Business Directorate.
Claire Campbell	Scottish Environment Protection Agency, Senior Ecologist
Dr Peter Jones	Natural Resources Wales, Lead Specialist Advisor – Peatlands
Dr Katharine Birdsall	Environment Agency, Wear Catchment Co-ordinator
Iain Diack	Natural England, Senior Wetland Ecologist

Phase 1 of the project has two main project outputs:

1. A technical report (presented here), which includes a review of existing, available information, an assessment of the scope for developing ecohydrological guidelines for upland carbon-rich habitats, and proposals for work needed for a continuation of the project.
2. An inventory of relevant information, comprising Excel spreadsheets containing summaries of sources of information that could be used to develop ecohydrological guidelines for upland peatland habitats.

It had initially been intended to begin the development of a generic database in spreadsheet format, set up to receive a variety of data types, and partially populated with those data that have been provided in digitally tabulated format. However, the overall paucity of readily available and relevant datasets has made this an unrealistic output at this stage.

2. Scoping study methods

2.1 The Wetland Framework approach

In the lowlands, component ecohydrological units of several wetland habitats of conservation importance were identified and described in the Wetland Framework (Wheeler *et al.*, 2009). The environmental conditions associated with several plant communities of conservation importance (including some of the wetland communities described in the Wetland Framework) were used to develop ecohydrological guidelines for lowland wetland plant communities (Wheeler *et al* 2004).

The essence of the Wetland Framework project was to combine and review ecological and hydrogeological data sources for about 200 wetland sites, including over 1,500 stand samples. At its core was the identification of the main distinctive wetland habitats, and wetland water supply mechanisms ('WETMECs'). A bottom-up approach, based on an analysis of field data from wetlands, was used to detect the recurrence of sets of conditions and species and to use these as the foundation for a classification. The main data analysis procedures were multivariate classification and cluster analysis, in particular canonical correspondence analysis (CCA) and Ward's method.

The different sets of Framework units developed (Figure 1, Section 4.4.2) provide both a vocabulary and basis for descriptions of wetlands, help to develop a holistic understanding of the requirements of different vegetation types, and provide a basis for assessing the likely outcome of conservation or potentially damaging activities. In addition, framework categories help to establish appropriate conservation objectives for individual sites. Developing conservation objectives that are in keeping with the ecohydrological character of particular WETMECs mean that conservation objectives work with the ecohydrological 'grain' rather than against it.

A focus of the present scoping study has been to evaluate the existence and quality of available data that could be used to extend the Wetland Framework approach to upland carbon-rich habitats (*i.e.* 'blanket bogs' and associated mire types). Examination of linked datasets for individual sites would facilitate understanding of relationships between important environmental factors such as topography, nutrient status, base-status, water supply mechanism, management *etc* to vegetation types. This approach allows large sites to be broken down into subcomponents so that areas that are influenced by different hydrogeological conditions can be distinguished from each other.

2.2 Process of enquiry and information gathering

Information has been gathered from a range of sources:

- Published literature
- Unpublished survey and research reports
- Theses (when available digitally)
- Datasets held by ShefWets on FenBASE and in unpublished survey reports
- Datasets held by various government agencies, research institutes and academics
- Cartographic information

2.3 Data handling

The available information was catalogued in two spreadsheets, one for literature (journal articles, reports, theses *etc*) and one for received datasets, and each information source was evaluated for relevance to this project. These spreadsheets accompany this report, and are named as follows:

- Literature Catalogue – 'SWE Ecohydro literature 09-03-2020.xlsx'
- Dataset Catalogue – 'SWE Ecohydro datasets 09-03-2020.xlsx'

Following a review of relevant published articles, PhD theses, and unpublished reports, information that was gleaned from these was used to produce a series of 'case study' accounts for different regions of the UK. The gathered information was also used to produce a synthesis of current understanding of the classification and ecohydrology of blanket mire and associated habitats, and to describe the vegetation types that are associated with upland and northern peatland habitats.

3. Results of data acquisition

3.1 Information sources

A list of contacts, with a brief summary of information/data holdings, is provided in Table 2. These include government agencies; non-governmental organisations such as RSPB and Yorkshire Peat Partnership; National Parks and Areas of Outstanding Natural Beauty; Universities and academic institutes; Utility companies; and independent ecological and hydrological consultants.

Whilst many of the people and organisations that have been contacted have provided reports, links to journal articles, or datasets, some have not yet responded (as of 9 March 2020). Consequently, it is not clear whether or not they may hold relevant information. In other cases, respondents have stated that they have information that might be relevant to this study, and are happy to share those data, but have not yet provided the reports or datasets. A final category comprises data-holders who have indicated that they hold potentially relevant datasets, but extraction of those data is likely to require some form of payment to cover time taken to identify and collate the relevant data. Information gaps are summarised in Table 3.

3.2 Literature review

Approximately 265 journal articles, theses and unpublished reports were collected and briefly assessed for relevance, of which about 140 were used in the case study accounts of reference sites, and in reviewing and synthesising information about blanket bog landscapes, classification, mire vegetation, *etc*. A reference list of all articles and datasets used directly in the main text of this report is provided in Section 11. References specific to the reference site and other accounts are provided in Annexe 1 and Annexe 2.

Full details are provided in the spreadsheet catalogue 'SWE Ecohydro literature 09-03-2020.xlsx', which gives information about the types of data available and their relevance to this project.

As part of this project it was considered essential to characterise the full range of upland mire types throughout the UK, and requests were made for information from all regions. Where sufficient material was made available for a comprehensive synthesis to be made for a particular area, these have been developed into Case Study accounts, which are provided in Annexe 1. The case study areas are listed below:

- South Wales
- Southern Pennines
- North York Moors
- Border Mires of Cumbria and Northumberland
- Silver Flowe (south-west Scotland)
- Scottish 'Bog Woodland' sites (Scottish Highlands).
- Loch Shiel Mosses (western Scotland)
- Flow Country (northern Scotland)
- Scottish Peat Survey sites (selected)

Other areas are certainly worthy of their own reference site account (e.g. Dartmoor and Exmoor; central and northern parts of Wales), but insufficient information has been made available at this stage for a comprehensive account to be made for them.

3.3 Ecological & hydrological datasets

To date an extremely limited number of datasets have been received. These are summarised in Table 4 and further details are provided in the spreadsheet catalogue 'SWE Ecohydro datasets 09-03-2020.xlsx'.

Table 2. List of contacts, with summary of information/data holdings

Organisation	Areas covered	Information/data holdings	Availability
NATIONAL / INTERNATIONAL			
IUCN Peatland Programme	National	Overview of what data may be available from whom.	N/A
ShefWets	Mainly England, with some from Scotland & Wales	Data for a wide range of 'moorland fringe' sites. These include vegetation data, pH & EC, peat depths, wetness indices, hydro-geological information	Available to project
PeatDataHub	International	Not yet up and running. Will incorporate a wide range of peatland measurements, beginning with site metadata and water-table depth	Uncertain
SCOTLAND			
RSPB	Scotland (esp. Flow Country)	Ongoing work at Forsinard, forest to bog restoration, drain blocking & wildfire recovery, gas flux & veg survey. Also Cairngorms restoration of eroded bog, water quality & flow. No data received but may be available in future.	May require funding to make available.
Scottish Environment Protection Agency		SEPA-funded upland survey data comprising hourly water levels from selected peatlands – possibly all lowland so may not be directly relevant	Yes
Scottish Natural Heritage 'Peatland Action' programme	Scotland	Includes peat depth data and water level logger data for various sites. Vegetation (quadrat) data also available	Yes
Scottish Natural Heritage	Scotland	No response.	Unknown
Scottish Natural Heritage Library	Scotland	Andrew Coupar's thesis on Rannoch Moor requires scanning. Photocopy of abstract & contents would help determine whether worth paying for scanning the thesis. Request for an SNH report was blocked by the author (Olivia Bragg) for unknown reasons.	Thesis would cost c. £70 to scan
Scottish Power Renewables		No response to date. May have monitoring data from peat restoration trials for sites such as Black Law windfarm	Uncertain
Scottish Water		No response to date. May have peatland monitoring data for DOC, water colour, and possibly water tables.	Uncertain
ENGLAND			
Environment Agency	EA National Peat Hub	EA-funded JBA Consulting report for Forest of Bowland	Yes

Organisation	Areas covered	Information/data holdings	Availability
Environment Agency	EA National Peat Hub members	Limited response to date; large datasets from the 'Mires on the Moors' project are held by Exeter University / South West Water, but it is not clear whether they would be willing to share these.	Uncertain
Moors For the Future Partnership	Mainly Peak District National Park (Dark Peak)	Large data holdings from monitoring peatland restoration programmes. Includes some linked vegetation and water table; some hydrological and water chemistry data.	May require funding to make available.
Natural England	England	NE-funded upland survey data and reports, particularly for Border Mires sites.	Yes
Natural England	England	Border Mires reports	Yes
Northumbria Water Ltd	Project in the North Pennines, Yorkshire Dales and Forest of Bowland,	Partner in the Pennine PeatLIFE programme, delivering 1,353 hectares of peatland restoration	Uncertain
United Utilities SCaMP project	Northern England	No response to date. May have data from blanket bog restoration projects in Cumbria and Lancashire	Uncertain
Yorkshire Peat Partnership	Yorkshire Dales National Park, Nidderdale AONB, North York Moors National Park and northern parts of the South Pennines.	Large data holdings esp. from peatland surveys. Includes habitats, management, vegetation community, watercourses.	Will require funding to make available.
North Pennines AONB Partnership	North Pennines	No response to date	Unknown
Southwest Water Ltd	Exmoor Mires	No response to date	Unknown
WALES			
Brecon Beacons National Park	Brecon Beacons National Park	Data from Waun Fignen Felin, include water level data (some time series), plus some peat probe data, peat stratigraphy and veg descriptions. Data for Waun Fach may soon be available, which includes water levels, peat profiles, peat stratigraphy, some veg data	Yes, but still awaiting Waun Fach report

Organisation	Areas covered	Information/data holdings	Availability
Natural Resources Wales	Wales	Several NRW-funded upland survey reports and small datasets have been provided, but still awaiting: • Lowland Peat Survey reports from M18 blanket bog sites • Gors Lwyd report by Mires Research Group • SAC site veg data linked with hydrology • Paul Hughes stratigraphic data (if available)	Yes, but not all received
	Northern Ireland	Contact has not yet been made with Bobby Hamill; data are available, but it is not clear how much are from the uplands.	Uncertain
University of Leeds	National	Advice and multiple journal articles	Yes
James Hutton Institute	Scotland	Suggestions provided for other contacts. May have available some unpublished water level and veg data from Forsinard Flows.	Uncertain
University of Exeter	National	PhD thesis and several journal articles	Yes
University of Leeds	National	Journal articles for Keighley Moor. Also have water table and hydrochemical data if required	Yes – would need to request WT/chem data
University of the Highlands & Islands	National	Several published articles on Flow Country bog research. Also some unpublished peat depth & stratigraphy data	Uncertain regarding unpublished data
INDEPENDENT			
Rigare	National	Hydrological survey of Waun Fignen Felin: water table data	Yes
	National	Several vegetation and peat stratigraphy survey reports	Yes

3.4 Information gaps

Table 3. Summary of information gaps.

Information	Details
Datasets requested but not yet received	
Waun Fach, Brecon Beacons National Park	Datasets still being collated by data holder
Natural Resources Wales	Awaiting several reports / datasets: • LPS reports from M18 blanket bog sites • Gors Lwyd report by Mires Research Group • SAC site veg data linked with hydrology • Paul Hughes stratigraphic data
Unpublished report to NCC, Bragg & Ingram (1984)	Refused access by surviving author, for unknown reason
Data availability uncertain	
RSPB research in the Flow Country	Various ongoing research projects, may require funding to extract or collate data
Andrew Coupar's thesis on Rannoch Moor	Copy of abstract & contents would help determine whether to pay to scan entire thesis.
EA National Peat Hub, south-west England datasets	Possible issues with data sharing
Moors For the Future Partnership	Various research projects, may require funding to extract and collate data
Northumbria Water Ltd, Pennine PeatLIFE restoration programme	Lack of information regarding data availability
Yorkshire Peat Partnership, extensive peatland survey datasets	Will require funding to make these available
James Hutton Institute, Rebekka Artz	Uncertain whether unpublished data from Flow Country sites can be made available
UHI, Roxane Andersen	Uncertain whether unpublished data from Flow Country sites can be made available
Unknown / No response to request	
PeatDataHub	Website is not yet running
Scottish Power Renewables: monitoring data from peat restoration trials	No response
Scottish Water: monitoring data from peat restoration trials	No response
United Utilities SCaMP blanket bog restoration projects in Cumbria and Lancashire	No response
North Pennines AONB Partnership	No response
South West Water Ltd	No response
Northern Ireland blanket bog data	No contact made
Other organisations	It is possible other organisations should be contacted, but time constraints have prevented this

Table 4. Summary of relevant electronic tabulated data made available to the project by 9th March 2020.

*More details can be found in the spreadsheet '*SWE Ecohydro datasets 09-03-2020.*xlsx'*

Area	Type of data	Source	Comments
English Midlands and Northern England	Linked vegetation, peat depth, pH/EC, topography for a range of moorland fringe sites.	SheffWets for Natural England.	
Border Mires	Peat depth data from some of the Spadeadam Mires	SheffWets for Natural England.	
Scotland	Peat depths from 139 Scottish peatland surveys	Peatland Action project 2012–19	Needs to be assessed for relevance to the current project
Scotland	Water level data from Scottish peatland restoration	Peatland Action project	Needs to be assessed for relevance to the current project
Scotland	Rain gauge data from Scottish peatland restoration	Peatland Action project	Needs to be assessed for relevance to the current project
Scotland	Vegetation quadrat data for nine Scottish blanket bog sites (quadrat data can be requested if necessary).	Penny Anderson Associates for Peatland Action	
Wales	Claerwen NNR dipwell data for April to December 2019	Natural Resources Wales	At present no other data to link this with
Wales	Waun Fignen Felen dipwell data for Feb 2017 to December 2019	Rigare Ltd, by permission of Natural Resources Wales	Linked with other site information by way of a report.

4. Wetland terms, categories and concepts

Wetland terminology is rich and notoriously complex, not least because of a tendency for different workers to use the same term with somewhat different, sometimes very different, meanings. Here some consideration is made of some salient wetland terms, and the categories and concepts that underlie them. This is done partly to make clear the meaning of these terms as used in this report, but also because the terminology – and also terminological inconsistencies and confusion – is relevant to understanding some of the ecohydrological processes that occur in mires and the practicalities of protecting or managing them as sustainable ecological systems.

4.1 Water source terms

Wetlands receive varying amounts of water from aquifers, surface drainage and precipitation. Two main water-source types have generally been recognised by peatland ecologists – METEORIC WATER and TELLURIC WATER – though others (such as THALASSIC WATER (sea water)) can be identified for relevant circumstances.

4.1.1 Meteoric water

This term relates to water of recent atmospheric origin, that is, direct precipitation (rain, snow, mist, frost, condensation and so on). Meteoric inputs are highly variable geographically in terms of amount, periodicity, and chemical composition.

4.1.2 Telluric water

This term refers to water that has been in contact with the mineral ground as opposed to direct precipitation (METEORIC WATER). It is a useful generic term which encompasses (most) GROUNDWATER and SURFACE WATER. TELLURIC WATER is typically more rich in bases, sometimes much more so, than is METEORIC WATER, though in some instances TELLURIC WATER sourced from unreactive rocks, or with a short residence time within these, may have a chemical fingerprint that is little different to that of rainwater.

Groundwater

The term 'groundwater' can be particularly confusing when used in a wetland context, partly reflecting its dual use referring on the one hand to water *within* a wetland deposit, and, on the other, to the *source* of water supply to that deposit from an adjoining mineral aquifer. For example, the water in the peat of a rain-fed bog may be regarded as 'groundwater' by hydrologists, but it may have been sourced exclusively and directly from precipitation and differ considerably in its water source, supply mechanism and hydrochemical characteristics from water sourced from a mineral aquifer. There is a real need for terms that distinguish between water source and water state, but these do not yet seem to exist.

'Groundwater' as used here primarily refers to water in, or sourced from, a bedrock or drift aquifer. Water within a peat aquifer is not explicitly described as groundwater unless it is thought to be sourced primarily from a mineral outflow. Instead, it is referred to generically (and noncommittally) as 'mire water'. Moreover, where wetland sites receive groundwater flow from an adjoining aquifer, this is usually referred to as 'groundwater outflow from a mineral aquifer', except where the context is sufficiently obvious as to not need clarification. Thus, the mire water in the peat of an ombrogenous bog is *not* generally referred to here as groundwater.

Where groundwater outflows directly onto the surface within a wetland, the water in pools, streams and runnels primarily sourced thereby is either not specifically named or is described as groundwater-sourced; it is not referred to as SURFACE WATER. However, where streams and other bodies feeding the wetland originate from well outside the site, their water is described as SURFACE WATER, even though it may be principally sourced by groundwater outflow. Within a site, if water in groundwater-fed streams is clearly supplemented by other sources (including rainfall), the water is described as surface water. This solution to this particular nomenclatural problem may seem to be rather confused and 'messy', but it is considered to be preferable to available alternatives

Surface water

Surface water is used here as a generic term for surface water flows that are not considered to be GROUNDWATER (even though some SURFACE WATERS may be substantially sourced by GROUNDWATER outflows). Thus 'surface flow' or 'surface run-off' is used here as a generic term to include rain-generated run-off, tile drainage, and stream and ditch flows into a mire. 'Surface water body' is used as a generic term for watercourses, pools, lakes and so on.

Endotelmic Flows

Endotelmic ('within peatland') flows are flows that originate within the body of a peatland rather than from its surroundings or an underlying aquifer. Where the peatland itself is essentially telluric, or where apparent endotelmic flows in an otherwise rain-fed wetland are actually sourced from groundwater outflows into the peat, or which have been in contact with the underlying mineral ground through peat pipes *etc*, these are unambiguously telluric and are regarded as 'surface water flows'. However, it is more of a moot point whether surface water flows that have originated entirely from within a mire surface fed exclusively by precipitation and are focussed into flow paths, can most usefully described as being of 'telluric' or 'meteoric' water. In general, here all such flows are regarded as surface water flows, with caveats where appropriate.

4.1.3 Soligenous, topogenous, ombrogenous

These three terms, which originate in part from the ideas of von Post and Granlund (1926), have been widely used by mire ecologists, though not always in consistently the same way. For example, some workers have restricted the term SOLIGENOUS to refer to seepages and flushes (*e.g.* Wheeler *et al.*, 2009) whereas others have adopted a much wider concept, including within it some wetlands of river floodplains (Rodwell, 1991). This may partly reflect uncertainties around the meaning intended by von Post and Granlund. The approach adopted here is based upon a broad assessment of the main topographical and water supply reasons why individual wetland sites (or parts of sites) are 'wet', and is considered to have the benefit of clarity and simplicity (Table 5), though it should be recognised that the categories may intergrade.

Table 5. Water source categories of wetlands based broadly on the main reasons why they are 'wet'.

	Telluric water important (minerotrophic)	**Maintained by precipitation (meteoric water)**
Maintained primarily by high rates of water supply (often sloping)	**SOLIGENOUS** [FENS] (*e.g.* seepages, flushes, soakways, water tracks)	**OMBROGENOUS** [Sloping or Hill BOG] 'blanket bog' *p.p.*
Water level maintained partly by impeded drainage (basins, floodplains *etc.*)	RHEO-TOPOGENOUS (significant lateral water flow) **TOPOGENOUS** [FENS] STAGNO-TOPOGENOUS (limited lateral water flow)	**OMBROGENOUS** [Topogenous BOG] 'raised bog' *p.p.* 'buoyant bog' *p.p.*

Soligenous

Soligenous wetlands are kept wet primarily by high rates of supply of TELLURIC water rather than by a topographically determined impedance to drainage, and they are most typical of slopes where groundwater outflow or rain-generated run-off input produces surface wet conditions. Such wetlands frequently have thin deposits of peat and water movement may be more by surface flow than percolation through the peat. TELLURIC is a generic category for both groundwater and surface water-fed mires in appropriate topographical contexts and includes both FLUSHES and SEEPAGE slopes. GROUNDWATER-fed peatlands on flat or near-flat surfaces or wetlands in troughs with significant horizontal water flow are not generally classified as being soligenous unless they have a fairly skeletal substratum, are usually small, and effectively form a flat version of a soligenous slope. Instead, they are considered to be RHEO-TOPOGENOUS wetlands (below). The scope of 'soligenous' as used here is thus considerably narrower than that apparently adopted by some workers (such as Rodwell, 1991, 1995), but is perhaps more in keeping with the original concept of von Post and Granlund (1926) with its etymological basis of being 'soil made' (formed by the immediate influence of water sourced from the mineral soil).

Topogenous

Topogenous wetlands are considered here to be TELLURIC wetlands in which high water levels are maintained by significant topographical constraints upon the drainage of their water inputs (which may include precipitation, land drainage, river flooding, runoff, and groundwater). Thus, whilst SOLIGENOUS surfaces are kept wet mainly by high rates of telluric water supply, topogenous wetlands are kept wet more by impeded drainage. Examples of topogenous wetlands include open water fringes, basins, floodplains and troughs. Impeded drainage is typically a product of landscape configuration, but it may also be induced by the topography of the wetland itself, the accumulation of peat or, for example, by river water levels and by artificial water management. Nonetheless, some topogenous wetlands may experience high rates of telluric water supply and those subject to significant water throughflow are considered to be RHEO-TOPOGENOUS, and are transitional conceptually (and sometimes spatially) to soligenous wetlands. Examples with little or insignificant water throughflow and where their wetness is largely a consequence of impeded drainage, are designated as STAGNO-TOPOGENOUS. Mires in topogenous locations where their surfaces are fed exclusively by precipitation, are regarded as being OMBROGENOUS.

Ombrogenous

Ombrogenous wetland surfaces are those that have formed under the exclusive and direct influence of precipitation. The ombrogenous peat surface is raised above the level of telluric water, fen peat or mineral soil, sometimes to produce a dome or ridge of peat that can be independent of sub-surface topography. Some workers use the term *ombrogenous* more or less interchangeably with *ombrotrophic*, but others make some distinction between these terms. *Ombrotrophic* ('rain fed') is often used to refer to surfaces that are more or less exclusively and directly rain-nourished, whereas *ombrogenous* ('rain made') refers to surfaces (or, sometimes, whole peat deposits) that have formed in ombrotrophic conditions. In many instances the two terms are effectively synonymous, but this is not always the case. This is because the surfaces of some areas of MINEROTROPHIC mire (*i.e.* mires irrigated generally with telluric water) may have become fed exclusively by rainfall, either because peat and vegetation has accumulated above the influence of telluric water, or (and in many locations more frequently) because drainage has lowered the level of the telluric water table below a former minerotrophic surface. [To help make this distinction, Wheeler *et al.* (2009) distinguished such surfaces as 'ombrotrophic legacy telluric'.]

Ombrogenous *surfaces* are usually always ombrotrophic, at least when they are unmodified and growing, but circumstances have been reported where changes in water conditions have led to flooding of ombrogenous surfaces by telluric water. This may particularly be found where the height of a deposit of ombrogenous peat has been lowered in consequence of drainage or peat removal, but it does on occasion also appear to be more of a natural process. For example, in the Somerset

Levels, on part of Shapwick Heath, Godwin (1941) reported two layers of fen peat sandwiched within ombrogenous peat in this raised bog, pointing to two episodes in the first millennium BC when flooding in the valley, presumed to be sourced by base-rich water from the adjoining hills, was sufficient to overtop the surface of the accumulating ombrogenous deposit, at least for a period. In the rather different context of the Flow Country in northern Scotland, Charman (1994a, 1995) observed the development of minerotrophic flow tracks across the surface of ombrogenous peats at two sites (Cross Lochs and Rhifail Loch) (see Annexe 1) and a similar feature occurs at Malham Tarn Moss (N Yorkshire), though its 'naturalness' there is less certain (Wheeler *et al.*, 2009).

4.2 Ombrotrophy and minerotrophy – 'bogs' and 'fens'?

4.2.1 The approach of G.E. Du Rietz

The Swedish ecologist G.E. Du Rietz developed the ideas of von Post & Granlund (1926) and Thunmark (1942) and suggested that the primary division of "the main formation of boreal mires" was between those that were ombrotrophic (*mosse*) and those that were minerotrophic (*kärr*) (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 whilst minerotrophic surfaces were fed also to some extent by telluric water. This work provided a much-needed clarification of some aspects of mire terms and concepts and was broadly welcomed. In English, the two main categories were designated 'bogs' and 'fens', respectively. Within fen so defined, Du Rietz distinguished 'poor fens' (*fattigkärr*), generally dominated by *Sphagnum* species, notably *S. recurvum* var. *apiculatum*, and 'rich fens' (*rikkärr*) with "a great number of species characteristic of rich fen vegetation, e.g. *Scorpidium scorpioides* ...". He also distinguished 'extremely poor fen' (*extremfattigkärr*, Eu-Apiculation) from 'moderately poor fen' (*medelfattigkärr*), and 'transitional rich fen' (*övergångsrikkärr*) from 'extreme rich fen' (*extremrikkärr*) (Du Rietz 1954).

Although his work was generally well received there are some limitations to the subdivision of 'bog' *versus* 'fen' as suggested by Du Rietz, and various (inter-related) issues have arisen.

It is implicit within Du Rietz's concept of bog that ombrotrophy is an absolute state – a mire surface is either exclusively fed by precipitation or it is not, and it is therefore inappropriate to refer, for example, to a 'gradient of ombrotrophy'. However, all fens receive rainwater inputs, and zones of mixing and intimate mosaics of ombrotrophic and minerotrophic surfaces can (and do) occur, though their separation may be tricky. Within a peat deposit, the position of the 'mineral soil water limit' will be determined by the balance between meteoric inputs (usually vertically downwards) and telluric inflows (mostly lateral or vertically ± upwards). It may well change in position seasonally and yearly and may be diffuse rather than sharp. In a well-developed ombrogenous peatland where the mineral soil water limit is well below the topographical surface, such temporal variation may have little if any influence upon surface growing conditions, but in shallower or sloping examples, or in instances where some strong telluric inputs may occur, assumption of strictly ombrotrophic surface conditions may be more difficult. Boatman (1983), possibly much influenced by Scandinavian perspectives on the indicator value of plant species, hinted at this for the Silver Flowe: "There can be little doubt that the surfaces of some at least of the Silver Flowe patterned areas are now ombrotrophic, *e.g.* the Long Loch mires and the greater part of Craigeazle mire, but it is of interest to note that they contain species which, in Finland, are characteristic of the rimpis[1] of aapamires… not in those representative of ombrotrophic mire." His implication is that other mires in the Silver Flowe may be weakly minerotrophic, though other workers have generally considered them to be ombrotrophic. Using the somewhat broader definition of 'bog' advocated by Tansley (1939), Damman (1995) and Wheeler &

[1] Water-filled 'flarks' or hollows in patterned mires.

Proctor (2000), weakly minerotrophic surfaces would be grouped with ombrotrophic bogs and uncertain differences in status become less important.

4.2.2 The 'fundamental' subdivision of mires in North-west Europe?

A wide-scale analysis of sample data from British mires led Wheeler & Proctor (2000) to recognise that whilst the ombrotrophic–minerotrophic split might be considered to represent a 'fundamental' difference in their water source, it was not coincident with the primary subdivision of either their vegetation or hydrochemistry. The main floristic and hydrochemical subdivisions they identified in mires were broadly coincident with each other and essentially divided mires into those that were 'base-poor' and those that were 'base-rich', with a diffuse separating point of about pH 5.5 in the mire water. Thus, in terms of Du Rietz's proposals, vegetationally and hydrochemically the main subdivision of British mires was between bogs + poor fens against rich fens. This view was concordant with a global assessment made by Damman (1995) and gives some credence to the earlier, if perhaps informal, use of the term 'bog' in Britain to include base-poor minerotrophic mires, such as the so-called 'valley bogs' of the New Forest (Tansley, 1939). Wheeler & Proctor (2000) 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)" [*i.e.* as the mineral soil water indicator limit].

4.2.3 Recognition of ombrotrophy

Although ombrotrophy seems to be clear enough conceptually, it has rarely been determined hydrologically, and the recognition of ombrotrophic conditions seems generally to be based on surrogate measures, such as mire topography and vegetation composition, or on hydrochemistry.

Topographical indications

In the instances of a deep peat massif on flattish terrain, where the surface is elevated well above the level of the regional water table, and where there is little hydrogeological reason to suspect significant groundwater upflow into the peat, it is reasonable to suppose that the surface is likely to be ombrotrophic, and that much of the peat is probably ombrogenous. However, many ostensibly ombrotrophic peat deposits are not like that: in many cases the peat deposit is relatively shallow, its surface may be undulating (often on account of past peat digging) or on a readily discernible, sometimes strong, slope. In these cases, assumptions of ombrotrophy, especially for all parts of the surface, are less well justified. In addition, shallow gullies on sloping surfaces may focus endotelmic water flow which, even when truly endotelmic, may have rather different characteristics from less strongly flowing water within the mire. Thus topography can often only be a reasonable proxy for assessing ombrotrophic status when used with care, and ideally when supported by levelled sections.

Indicator species

In the approach of Du Rietz, 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 a number of assumptions about the (normally presumed) indicator value of different plant species for minerotrophy, and by the possibility that 'biological inertia' may permit some 'minerotrophic species' to persist on a surface that is actually ombrotrophic. Specific indicator species for ombrotrophic conditions have not been identified, because as far as is known in Europe no species that grows on ombrotrophic surfaces does not also grow in some minerotrophic conditions, though some species may be more frequently associated with ombrotrophy.

As was recognised by Du Rietz, 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. Likewise, vascular plant species such as *Eriophorum angustifolium* and *Narthecium ossifragum*, both widespread in ombrotrophic mires in Britain, were considered to be indicative of minerotrophy in Sweden by Du Rietz. These apparent shifts in species tolerances may be part of a broad trend along an oceanic–continental gradient and may reflect greater atmospheric inputs of solutes in the more oceanic regions. Thus, the indicator value of plants for minerotrophy may be diagnostic only within particular geographical regions, and even in these it is usually based on relationships that have been assumed rather than demonstrated rigorously.

Hydrochemical evidence

In Britain, some plant species that appear to be confined to fens in the south grow widely in bogs in northern parts of Scotland (*e.g. Eleocharis multicaulis*). Whilst recognising some differences, Daniels (1985) drew specific attention to the floristic *similarities* “between the lowland ombrotrophic mires of North West Scotland and the valley mires of Southern England”, and this may be related to the difficulties that Proctor (1992) found 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. All ombrotrophic bogs receive atmospheric inputs of material of terrestrial origin, including most of their Ca, heavy metals, P and N. These inputs can vary within wide limits which overlap the range of telluric inputs into poor fens so that there is no universal distinction between the water or peat chemistry signatures of ‘bog’ and ‘poor fen’. This inevitably raises the question of whether some of the mires designated as ombrotrophic are actually fed in part by telluric water, a possibility that has been explored further in a few locations by Charman (1993) and Grootjans *et al.* (2016).

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”. But even if this assessment is accepted, it remains the case that the ionic composition of rainfall and derived ombrotrophic water shows much regional variation (Proctor, 1992) and values appropriate for indicating ombrotrophy need to be calibrated for different locations and conditions, especially where local terrestrial sources are likely to influence both rainfall and mire. Interest has focussed on the use of ionic ratios (*e.g.* Ca^{++}:Mg^{++}) to help distinguish waters from meteoric and telluric sources. Examining mires in Abernethy Forest, Proctor *et al.* (2009) concluded that a Ca:Mg ratio of 1 provided a partly arbitrary but appropriate separation of ombrotrophic (<1) and minerotrophic (>1) mire waters. Interestingly, as thus defined, *Eriophorum angustifolium* and *Narthecium ossifragum* were largely absent from the ombrotrophic surfaces, and were effectively ‘fen species’, as had been suggested by Du Rietz for Sweden[1], though *Sphagnum magellanicum* was slightly, but significantly, positively associated with ombrotrophic locations. There is, however, little reason to suppose that a Ca:Mg ratio of 1 is likely necessarily to provide an appropriate distinction of ombrotrophy in parts of Britain with different rainfall composition and land use to that found in Abernethy Forest.

Conclusions

A consequence of the above considerations is that whilst the concept of ombrotrophy may be clear enough, its practical recognition in the field can be difficult. Moreover, in some geographical regions it appears that genuinely ombrotrophic surfaces can support plant species and hydrochemical conditions similar to those that can occur also in mires fed partly by telluric water, both elsewhere and within the same geographical region. Thus, although they may be ombrotrophic, such examples may appear to be weakly minerotrophic using floristic and hydrochemical criteria. Such mires cannot be said to be any less ‘ombrotrophic’ than are examples without minerotrophic resemblances, but

[1] Proctor *et al.* (2009) suggested that the Abernethy mires might be comparable with mires in southern Sweden, possibly on account of their rather ‘continental’ location in north-east Scotland and their association with base-poor granite.

they may be particularly difficult to distinguish from mires that are actually minerotrophic. This is not just a matter of semantics but can have considerable repercussions upon the way by which mire surfaces are referred to, characterised and managed, especially by those unaware of its implications.

4.3 Base status and fertility terms

The terms EUTROPHIC, MESOTROPHIC and OLIGOTROPHIC were introduced by Weber (1907) in the context of hydroseral succession from open water rich in plant nutrients (N, P, K and other cations) to raised bog that is poor in all of them. These terms have been adopted widely by limnologists who use them to express the relative availability of growth-limiting nutrients (usually N and P) in a sense not far different from Weber's intentions (and consistent with the widely established use of the word 'eutrophication'). However, they have sometimes been used by plant ecologists, including the influential *Nature Conservation Review* (Ratcliffe 1977), to imply richness or poorness in *calcium* (or cations generally), an approach which, amongst other limitations, has had the consequence of not providing a suitable trophic term to refer to base-rich but oligotrophic (infertile) or mesotrophic mires. And whilst acidic peats are usually among the least fertile substrata, higher pH values do not necessarily coincide with greater nutrient availability – some highly calcareous fens have extremely low fertilities (Boyer and Wheeler 1989) and base-rich, oligotrophic or mesotrophic mires are widespread in Britain.

Wheeler & Shaw (1995c) examined the relation in British wetlands between their soil fertility (their capacity to support plant growth, determined particularly by the availability of potentially growth-limiting nutrients, especially nitrogen, phosphorus and potassium), various other environmental determinands, and vegetation composition. They found that the first main floristic gradient of their vegetation samples related to base-richness terms (pH, alkalinity *etc*), whilst the second main floristic gradient corresponded to changes in nutrient availability and fertility. The fertility gradient was almost orthogonal to (*i.e.* largely independent of) variation in base richness.

Wheeler & Proctor (2000) suggested disambiguation of the terminology, to provide separate assessments and categories for the base status and fertility of mires, consistent with limnological and general usage, and also with the recommendations of Bridgham *et al*. (1996) for mires. In the Wetland Framework (Wheeler *et al.* 2009) the following categorisations were adopted:

Base richness categories

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

1:	Base-rich	pH 6.5–8.0	Fen
2:	Sub-neutral	pH 5.5–6.5	Fen
3:	Base-poor	pH 4.0–5.5	Bog (~poor fen)
4:	Acidic	pH < 4.0	Bog

Fertility

Phytometric estimates of soil fertility were obtained by growing a test species (*Phalaris arundinacea*) on soil samples in controlled conditions. Values are mean shoot dry weight (mg).

Fertility categories

The fertility categories are based on an arbitrary subdivision of the phytometric scale, as proposed by Wheeler and Proctor (2000):

1:	Oligotrophic	< 8 mg phytometer
2:	Mesotrophic	8–18 mg phytometer
3:	Eutrophic	18–38 mg phytometer
4:	Hypertrophic	> 38 mg phytometer

4.4 Types of wetlands

Numerous attempts have been made to classify wetlands, using a wide variety of criteria of varying character and clarity (Moore, 1984). Wheeler & Shaw (1995b) provided a detailed review of some of this, with particular regard to Britain, and only some salient comments will be made here.

4.4.1 The Nature Conservation Review

The *Nature Conservation Review* (Ratcliffe, 1977; also Goode, 1972) proposed an informal categorisation of peatlands based on their 'hydromorphology' which has been influential and widely used.

Table 6. Hydromorphological types of peatlands in Britain (from Goode, 1972 and Ratcliffe, 1977).

Open water transition mire
Floodplain mire
Basin mire
Valley mire
Soligenous mire
Raised mire
Blanket bog

Although this approach was ostensibly 'simple', it had various attendant difficulties:

(i) The categories used are inevitably nebulous and as variable as the landscape they are intended to represent.

(ii) Some categories are particularly ill-defined: for example the term 'valley mire' has been widely used by ecologists, but not necessarily in the sense used in the *NCR* and in almost all cases subject to the same semantic limitation that in the lowlands the vast majority of mires occur in 'valleys' of some sort. Fojt (1990) proposed the more useful term 'valleyhead mires', though in certain circumstances there are mires in an area of valley that can neither reasonably be called 'valleyhead' nor 'floodplain'.

(iii) The hydromorphological units proposed are frequently nested: for example, 'open-water transition' units frequently occur within floodplains, basins and valleyheads; likewise basins can occur in valleyheads and, when they also have areas of open water this can result in triple nesting.

(iv) Whereas the first five categories are essentially a characterisation of the landscape in which the mires occur, raised mire and blanket bog refer to the mires themselves. This mismatch has occurred probably because both raised and blanket mires can be sufficiently extensive to form landscape features in their own right. But so also can floodplain wetlands, and all of them cover peat-buried landscape features that are often considerably independent of the mire surfaces. Thus, raised mires can occur in floodplains, basins and valleyheads.

(v) The categories are not necessarily useful 'functional units' for ecohydrology (or conservation management); many plant communities, 'habitats' and water supply mechanisms occur widely across a range of 'hydromorphological types', in some cases reflecting their 'nested' character. Hence, the use of 'hydromorphological types' for classifying wetlands can be akin to categorising an object by its packaging rather than by its content.

A consequence of these considerations is that, despite an apparent simplicity, this 'topographical' categorisation is not always simple to apply, nor does it provide more than a superficial indication of the functional character of the wetland. It may be appropriate as an informal and ill-defined descriptor, but it is scarcely fit for purpose for more rigorous use, such as resource assessment or ecohydrological understanding of mires. A hairdresser would recognise likewise that a categorisation of hairstyles is not primarily determined by the shape of someone's head!

4.4.2 The Wetland Framework approach

Partly in recognition of the difficulties inherent within the approach of Goode and Ratcliffe, Wheeler & Shaw (1995b) suggested a rationalisation, aimed particularly at a disambiguation of the categories. Their main proposal was to recognise two layers of categories: "The first layer identifies *situation-types, i.e.* the position the wetland occupies in the landscape, with special emphasis upon the principal apparent sources of water. Many, but not all, wetlands can be referred to a single *situation-type.* The second layer identifies *hydrotopographical elements*, *i.e.* units with distinctive water supply and, sometimes, distinctive topography in response to this. Many wetlands will contain a number of *hydrotopographical elements* and the same element may occur in wetlands belonging to different *situation-types."* The 'Situation Types' were essentially the same sort of categories as had been proposed by Goode and Ratcliffe, though somewhat modified to make them more comprehensive and consistent, and 'raised bogs' and 'blanket bogs' were not regarded as 'Situation Types' but as 'Hydrotopographical Elements'. This approach therefore provided some disambiguation of the *NCR* approach, but it was still essentially 'top-down' in character, *i.e.* the conceptualisation of the different categories had been created by 'expert judgement' and experience. The acceptability, and to some extent application, of such a scheme depends upon the expertise and experience of the individuals concerned, and it was clear that a more satisfactory approach might be 'bottom up', *i.e.* based on an objective synthesis of actual field data.

The Wetland Framework project (Wheeler *et al.*, 2009) was a development of the proposals of Wheeler & Shaw (1995b) and was sponsored by Countryside Council for Wales, Environment Agency, Natural England and the University of Sheffield. It aimed to provide an ecohydrological characterisation of a range of lowland wetlands and their vegetation types in England and Wales and was based on existing available ecohydrological data, comparable new data collected specifically for the project, and a hydrogeological assessment of each of the sites considered. The process of data acquisition, analysis and synthesis ran between 1999 and 2008.

The distinctive features of the Wetland Framework approach were that it was 'bottom-up' (*i.e.* based on floristic, environment and other data recorded from individual stands of vegetation) and that these were aggregated into a non-hierarchical categorisation in which individual samples, or groups of samples, were defined by a series of nominally-independent, superimposable layers. Five layers were used (Figure 1), of which three (base-richness, fertility and water supply mechanism (WETMEC)) were based on stand-specific measurements. A 'Wetland Landscape' layer was also adopted, as an informal 'compatibility layer' intended mainly to provide some link between the Framework and the previous hydromorphological categorisations. A 'management layer' was also proposed, based on some of the commonest categories of vegetation management, but in its existing form it is of dubious value, not because it is unimportant but because of the vagaries and variability of management regimes.

The 'base-richness' and 'fertility' layers were based on categories already identified and justified by Wheeler & Proctor (2000). The 'WETMEC' layer was innovative and was based on an agglomerative cluster analysis of a variety of water and water-related variables determined for each stand examined. The resulting clusters were objective outcomes of these analyses, but they were then interpreted, based on their contained characteristics, as 'Wetland Water Supply Mechanisms' (WETMECs), which provide some indication of the apparent hydrological conditions and relationships of the mire surfaces sampled. In principle, any one water supply mechanism can be associated with any of the four base-richness and fertility categories. Thus a 'Permanent Seepage Slope' (WETMEC 10) can variously be acidic to base-rich, or oligotrophic to hypertrophic, depending on its geological and land-use context. In practice, however, some WETMECs are associated with a smaller range of conditions. Thus all examples of a 'Domed Ombrogenous Surface' (WETMEC 1) were oligotrophic, though only 90% were 'highly acidic' – the others were 'base poor'.

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

Figure 1. The layers of the Wetland Framework, originally developed for wetlands (fens and bogs) in lowland England and Wales (Wheeler *et al*., 2009).

The Wetland Framework approach is more concerned with the recognition of distinctive ‘habitats’ (ecohydrological mire surfaces) than with whole-site mire types, and because of this has a greater degree of flexibility in application. Individual WETMECs may perhaps equate broadly with the *mesotopes* of Ivanov (1981) (see Box 2 on page 88), but they make fewer potentially unsustainable assumptions. For example, a mesotope is widely regarded as being a “mire system developed from one original centre of peat formation” (Lindsay *et al.*, 1988). Taken at face value, this definition suggests that a smallish site such as Coom Rigg Moss in Northumberland (Annexe 1) must be composed of five separate mesotopes, all of which are more-or-less the same. In terms of WETMECs, almost all of the surface of this site is occupied by WETMEC 1 (Domed Ombrogenous Surface). This is because WETMECs are based primarily upon surface and near-surface characteristics, as observed and measured, not on their mechanism of origin. It is, of course, quite possible – and is sometimes of much interest – to recognise different topographical and ontogenic circumstances from which a particular surface has arisen, and Wheeler *et al.* (2009) recognised a number of informal ‘ontogenic types’ underlying WETMEC 1. However, the ‘Domed Ombrogenous Surface’ was essentially the same ecohydrological feature across all of them.

5. Ombrogenous peatlands

Historically, two main types of ombrogenous peatlands have been recognised in Britain – raised bog and blanket bog. These terms are widely used, by telmatologists and others, but it is often far from clear on what intrinsic features they are based. For example, it is not at all obvious why both Atherden (1979) and Chiverrell (2001) considered May Moss (North York Moors) to be an example of 'blanket bog'; or why Ratcliffe (1977) regarded Claish Moss (Loch Shiel) as a 'raised bog' whereas Lindsay *et al.* (1998) decided it was an example of 'blanket bog' (see Section 5.2.2). Or just what distinction was being made by Rudeforth *et al.* (1984) when they commented (for central Wales) "As well as the wide spreads of blanket peat, there are a few raised bogs… such as Gors Lwyd on the watershed between the rivers Ystwyth and Elan in west Powys".

Common to all of these accounts is the lack of any clear statement of the physical features of the deposits in question which merited their particular designation. Presumably, it was considered to be too obvious to merit justification or reflected a bespoke concept that was obvious to the authors. In our experience, the designation of a particular example of ombrogenous peatland can be a source of considerable uncertainty to surveyors and others, partly on account of a general sparsity of clear conceptualisation and categorisation. To some extent, given the nature of the ombrogenous habitat, this may be unavoidable, but it is considered likely that some greater clarification is possible.

5.1 Historical conceptions and categorizations

In his synthesis of the character of British vegetation, Tansley (1939) recognised three main types of acidic peatland: blanket bog, valley bog and raised bog. These were grouped together into his 'Bog or Moss Formation'. Previously, in his earlier work (Tansley, 1911), they had all been regarded as 'moors' – upland moors, valley moors and lowland moors. Other workers of the time (*e.g.* Moss, 1913; Elgee, 1912) also described the upland peat areas of the Peak District and North York Moors as 'moors', but by 1939 Tansley judged that this term was unsuitable because it had, in common English usage, a much broader compass than just an area of peat. Instead he advocated use of the terms 'moss' or 'bog' (these he considered synonymous). He stated that "The plant communities which form and inhabit wet acid peat have often been divided into 'lowland' and 'upland' but they are more naturally classified as *valley bog, raised bog* and *blanket bog* – names which refer to real differences in habitat, structure and mode of development." More recently, although the name is still sometimes used, 'valley bogs' have often been dropped from this trinity of acidic peatlands, as they seem generally to be minerotrophic rather than ombrotrophic in character – though, as Wheeler & Proctor (2000) pointed out, Tansley's original grouping fitted better with the 'natural' main hydrochemical subdivision of peatlands along the base-richness gradient (see Section 4.3) than with the two main categories of Du Rietz (see Section 4.2.1).

5.1.1 Blanket moss or bog

According to Tansley, (1939) "the name 'blanket bog' was suggested in 1935", though he did not state by whom. He described this type of mire as "ombrogenous, the climatic climax (except where drainage is quite free) in regions of cool summers, high rainfall and very high atmospheric humidity, *i.e.* extremely oceanic cool temperate climate. Surface flat or with a slight slope (under 15°): hummock formation local". He further considered that "blanket bog normally develops from the acidic aquatic vegetation of pools and on the general surface of undrained, flat or gently sloping ground" by the direct colonisation of wet soil. He also recognised two main categories: (i) examples in "Western Scotland, western Ireland and outlying islands, on almost every terrain lacking free drainage, up to considerable altitudes"; and (ii) examples on "Plateaux and gentle slopes of mountain masses (Pennines, Wicklow Mountains, Dartmoor *etc*) at elevations of 1500–2200 ft. (*c.* 450–650 m) in less extremely maritime regional climates…”. These two broad categories have sometimes since been referred to as lowland blanket bog and upland[1] blanket bog.

Lindsay *et al.* (1988) have suggested that the climatic conditions required for blanket bog formation are: “a minimum annual rainfall of 1000 mm; a minimum of 160 wet days; a cool climate (mean temperature less than 15°C for the warmest month) with relatively minor seasonal fluctuation.” Lowland blanket bogs are characteristic of the high-rainfall areas of the far west of Britain, though their distribution appears to be better correlated with areas experiencing more than 250 rain days a year than with rainfall as such. Upland examples cover many flattish or undulating plateaux, mostly 400–600 m above sea level, with over 1500 mm annual rainfall and over 225 rain days a year, though the limits vary from one region to another.

5.1.2 Raised moss or bog

The name ‘raised bog’ is derived from the German *hochmoor* as “the moss as a whole is raised above the immediately surrounding fenland” (Tansley, 1939). Tansley provided the following summary description:

> “Raised moss or bog – topogenous, often based on the site of a former lake and built up above fen peat or valley bog peat, in less extremely humid climates. Surface more or less convex as a whole, with a marginal lagg or drainage channel which receives the drainage water. Surface composed in detail of hummocks and hollows determined by the constituent units of Sphagnetum…. Characteristic of the central plain of Ireland: a few in England and Wales and a good many in Scotland, especially in the south-west, the Midland Valley and parts of the eastern coastal plain.”

Ratcliffe (1964) objected, and with some justification, to Tansley’s designation of raised bogs as being ‘topogenous’ (rather than ‘ombrogenous’). It seems likely that Tansley considered them thus because he saw them as being very often the climax development from topogenous fens, and part of the same hydroseral and topographical unit as these which, considered as a whole, were not specifically ombrogenous. Ratcliffe (1964) provided some account of the character, as well as the vegetation, of Scottish bogs. With regard to their essential character, although he provided many more examples and some more detail than was given by Tansley (1939), for the most part he made the same points. He particularly emphasised the proposition that blanket bog develops by the paludification of formerly dry ground, whereas raised bog originates from a preceding phase of fen. This might seem to provide a clear basis for separating the two types of bog, were it not that some sites which are often regarded as raised bogs, or of having their features, have also apparently developed by paludification, at least in part, whilst some areas of apparent ‘blanket bog’ have developed over small basins and have progenitor ‘fen’. Moreover it is the case, almost by definition, that all examples of ombrogenous mire must have developed upon, and be bounded by, some sort of minerotrophic condition, though where ‘blanket bogs’ have developed by peat accumulation upon a mor humus this may not be very obvious.

Ratcliffe gave few stratigraphical or topographical details for the Scottish bogs, nor did he identify distinctive ‘types’ of blanket bog. He considered that:

> “The categories of raised bog and blanket bog may be regarded as the two end points of a cline, for they are linked by a complete series of intermediates. Whilst many examples may, from their clearly defined [though not clearly stated by him] topographical features, be assigned without hesitation to one category or the other, there are some bogs which just as obviously cannot be classified in this way, since they combine the features of both categories. The usefulness of the distinction then breaks down and it becomes simpler to think in terms of a single large class of ombrotrophic bog.”

[1] See Glossary for description of the terms ‘upland’ and ‘lowland’.

5.1.3 Intermediate bogs

In view of the intergradation between 'raised bog' and 'blanket bog', Ratcliffe (1964) recognised the occurrence of an additional type, *intermediate bog,* between the two extremes, though it is a moot point whether this simplified or further complicated an already nebulous conceptualisation. His concept of intermediate bog included mires that Moore & Bellamy (1974) described as '*ridge-raised mires*'. In distinguishing intermediate bogs he gave particular consideration to the absence of what he considered to be "the marginal features of raised bog such as rand and lagg" which were, "usually lacking or present along parts of the bog edge". This approach therefore gave particular attention to the peripheral features of the bog, rather than those of the main bog unit itself, and of the two features mentioned, the lagg is not part of the ombrogenous deposit and can be created by a range of possible processes and largely irrigated by various mechanisms and telluric sources.

There are several difficulties with the notion of intermediate bog, which relate partly to the meaning of 'intermediate'.

1. On the one hand, intermediate may imply a blend somewhere between two (or more) end points, just as the colour purple could be said to be intermediate between red and blue.
2. Intermediate can also refer to a mixture of discrete components, just as the boundary between red and blue on a colour chart may be composed of dots of each separate colour which, together, give the impression of purple. This is the sense in which Moore & Bellamy seem to have regarded their ridge-raised mires, in which ombrogenous peat in a raised-bog-like system is thought to have spread out from two originating basins by growing over a separating ridge, as a form of blanket bog. Whether this is then considered to be a separate type of mire, or just a complex of two distinct types seems primarily to be a matter of preference and the scale at which the system is viewed.
3. The culmination of the 'ridge-raised process' can be the development of a single dome of ombrogenous peat, in which the dome is partly based on the configuration of the subsurface topography but which is otherwise indistinguishable, in terms of hydraulic behaviour or ecological characteristics, from the dome of a raised bog that has developed upon flatter mineral ground.

5.2 Characterisation and features of upland ombrogenous mires in Britain

Some authors have essentially categorised ombrogenous mires on locational or bioclimatic criteria. For example Ellis & Tallis (2000) commented that: "Although sometimes regarded as a raised mire (Ratcliffe 1977; Goode 1997), Kentra Moss nevertheless occupies a situation which, topographically and climatically, is optimal for the development of an active oceanic blanket mire (Godwin 1941; Lindsay *et al.* 1988)." However, the proposition that an area of bog can be categorised adequately by its biogeographical location essentially bases its definition on *where* it is rather than *what* it is. At face value, such an approach is tantamount to suggesting that an individual sheep on a Scottish hillside is different to an individual of the same breed grazing a Sussex down, just on account of their differences in location. Of course, rainfall is, by definition, critical to the development of ombrogenous surfaces, and these can vary in their characteristics in different bioclimatic circumstances: surface wetness, which is partly – though not exclusively – determined by climate can influence, for example, their vegetation, microtopography and various processes such as rates of vegetation production, decomposition and peat accumulation (*e.g.* Belyea & Clymo, 2001; Morris, Baird & Belyea, 2012). However, the development of a characterisation that adequately reflects the affinities of ombrogenous deposits to one another requires an object-oriented approach in which salient and consistent features are identified for the different types of mire (*i.e. what* it is). These then may or may not turn out to be related to specific bioclimates (*i.e. where* it is). Without this type of independent approach, there is a considerable likelihood of circular reasoning, *viz.* a peatland is called a 'blanket mire' because it occupies a 'blanket mire climate' whilst a 'blanket mire climate' is defined by the presence of 'blanket mires'.

The different types of blanket mire identified by JNCC (1994) and Lindsay (1995) (valleyside mire, spur mire, saddle mire *etc*.; see Section 9.1)) are essentially locational units, defined mainly by where they are in the landscape, not by their salient features, affinities and differences. One consequence of this has been the application of different names to what is essentially the same type of mire, except for its position in the landscape. It is desirable to try to identify salient features and characteristics of ombrogenous and related mires, to provide a more robust and useful categorisation, but it should be recognised that this may not be a simple task – if it was, doubtless it would have been achieved long since.

Here an attempt is made to collate salient characteristics of ombrogenous and related peat deposits based on available information. It focuses upon 'upland' mires, but some reference is also made to lowland examples for comparative purposes.

5.2.1 Sources of information

A wide variety of sources of information has been examined, including published items, unpublished reports (when known and available), theses (when available digitally) and cartographic information. Details of relevant sources are given under individual headings and sites (Annexe 1).

Particular attention has been given to the data that have been presented by authors, rather than to their interpretation and opinions. In this regard, all of the formats available have their limitations: the contents of published work can be subject to editorial constraints on how many basic observational data can be presented, especially the stratigraphical and topographical information which is especially useful for the present investigation but which does not always fit neatly onto a published page; palaeoecologists may publish only a single core of peat, often taken from the deepest part of a mire, and present no information on its wider topographical and stratigraphical context, even when they have examined this. Doctoral theses are often more productive sources of 'basic' information, but not all of them are readily available. For example, it was found that potentially important theses associated with students of H.A.P. Ingram (University of Dundee) were not available in digital format from the British Library. These included work on the important, but poorly documented, Rannoch Moor (Coupar, 1983), and access to this thesis (and others) requires additional funds. Unpublished reports are very variable in content. In some instances, the reports themselves are readily available but the data on which they are based (often as spreadsheets) are not. Some reports contain highly relevant information and comment (*e.g.* Wells, 2001) whilst others have been unavailable, or are 'unknown' and unidentified. For example, access to a potentially important report on the Flow Country (Bragg & Ingram, 1984; cited by Ingram, 1987) was embargoed by SNH, apparently at the request of the surviving author, for reasons that have not been disclosed. Such omissions obviously constrain the range of material that can be presented here.

The approach adopted to the characterisation of ombrogenous and related mires in this report has been to focus upon particular parts of Britain, reflecting both the availability of relevant information or the apparent 'significance' or character of particular mire systems. Summary details of information for particular regions and mires have been collated and are presented in Annexe 1, but, where known, relevant information from some other sites is also included.

5.2.2 Area and aggregation

Ombrogenous surfaces vary enormously in area, from a few square metres associated with embryonic ombrogenous nuclei embedded within other habitats, to landscape features covering hundreds or thousands of hectares. According to the Soil Survey, ombrogenous peats of some sort cover some 2.5% of the land surface area of England and Wales. Around 10% of Scotland is covered by peat, though not all of this is ombrogenous. In this regard an important distinction must be made between 'blanket *mire*' as an extensive landscape feature (or *macrotope*) and the various hydrological units (minerotrophic and ombrotrophic) of which it is composed.

Lindsay *et al.* (1988) have emphasised the extensiveness of blanket bog terrain compared with raised bogs which, they suggest, "occur as isolated domes of peat, rising above a landscape which is non-peat (often agriculture) and broadly lowland". It is certainly the case that in parts of lowland Britain raised bog domes are isolated units, sometimes on account of their restriction to specific topographical circumstances, sometimes because of agricultural conversion of intervening ground, but this is not a *necessary* feature of 'raised bogs'. In the lowlands of north-west Germany, the largest raised mire complex seems to have occupied about 1000 km^2. In Britain, complexes of raised mires were smaller, but some examples, such as the bogs that once covered much of the floor of the Forth valley, were undoubtedly very large indeed. In these systems, individual domes of ombrogenous peat were separated by streams and rivers draining from the upland and, probably also by endotelmic streams and laggs; but likewise, tracts of blanket bog are similarly split into ombrogenous units bounded by streams and flow tracks (a subdivision that has been used by Lindsay (2010) and others for the recognition of separate *mesotopes*). On the Caithness plain, numerous raised ombrogenous surfaces jostle together, separated by streams and strips of minerotrophic mire. These are regarded by some as being 'blanket bog' (*e.g.* Lindsay *et al.*, 1988), but cannot reasonably be dismissed from consideration as raised bog equivalents simply because they form a herd, rather than isolated units, nor because they occupy a 'blanket bog climate' (their climate is 'lowland' and not especially wet); instead attention needs to be given to their intrinsic features and attributes.

Lindsay *et al.* (1988) also considered that Claish Moss and Kentra Moss (Argyll) were "sites which have traditionally been regarded as raised bog, but which lie within a landscape of blanket bog, [and] are more correctly termed blanket bog". Their reasoning appears to be that this is simply because they are close to other ombrogenous deposits that would unambiguously be called 'blanket bog'. However, unless proximity to another type of peatland is a consistent and necessary feature of a specific peatland type (as defined by other criteria), proximity *per se* cannot be regarded as an *intrinsic* feature that should be used for its categorisation. By contrast, area *is* an intrinsic feature of peat deposits, but because of its variability is unlikely to be of much use, except perhaps at the level of landscape (macrotope), and perhaps for distinguishing 'baby bogs' from more mature examples.

5.2.3 Sub-surface topography of ombrogenous peatlands

Taylor (1983), referring to British 'raised bogs', commented that "the term 'raised' is used here to imply some resemblance to classical *Hochmoore…* but the latter rarely occur in England and Wales. Even in Ireland (except for the central plain) and Scotland, as far as the present author knows, well-defined cupolas of ombrogenous peat are partially a reflection of the underlying topography". This observation can be illustrated by reference to a 'classic' raised bog (Chat Moss, Greater Manchester) for which sections that confirm Taylor's view have been provided by Erdtman (1928), Birks (1964), Taylor (1983) and, particularly, Hall *et al.* (1995). A similar comment can be made for some other mosses in this same area (*e.g.* Ashton Moss and Carrington Moss, which Hall *et al.* suggested might be better regarded as 'intermediate mires'). Nonetheless, whilst Taylor's claim may well have substance for some of these larger mires, it is less clear, mainly because of a lack of relevant sub-topographical data, whether it is equally applicable to some of the smaller domed ombrogenous surfaces that occur in some small basins and troughs, such as in the Slammanan plateau (south of Falkirk). It is difficult to avoid the view that the presumed status of ombrogenous surfaces as representing a 'raised' or 'intermediate' bog may more often reflect the extent to which their sub-surface topography has been investigated rather than any fundamental differences in the character of their ombrogenous surfaces. It is, however, clear that if sites in which the conformation of the peat surface in some significant measure reflects the underlying topography are excluded from the category of 'raised bogs' then many of the lowland ombrogenous mires in England that have been given that status (Lindsay & Immirzi, 1996) do not qualify for it.

5.2.4 Initiation conditions of ombrogenous peat

Two main sets of developmental (ontogenic) processes have frequently been identified in mires: *terrestrialisation* – the process by which open water is gradually infilled with sediment and peat and becomes relatively 'dry'; and *paludification* – a process by which dry ground becomes wet, for a variety of possible reasons. Both processes can lead to the development of some form of ombrogenous mire. In addition, a third starting point can be identified, one which is probably rather widespread in the sites considered here, in which mire initiation occurs in circumstances (*e.g.* poorly drained hollows) which start off 'wet', but not as open water. Some researchers, at least, regard this starting point as a form of paludification.

Probably influenced by Tansley, a number of workers (*e.g.* Ratcliffe & Walker, 1958; Ratcliffe, 1964; Chapman, 1964a) placed considerable store by the proposition that blanket bog develops by the paludification of formerly dry ground, whereas raised bog originates from a preceding phase of fen. However, Ingram (1967) was having none of this:

> "It seems likely that the only feature of the classic history which is essential for raised bog formation is an almost level surface with impeded drainage on which ombrogenous peat can accumulate. This surface need not be fen peat. It can, and in Scotland often is, a raised beach, Till sheet or other level expanse of mineral soil (Ratcliffe, in Burnett, 1964)… the authors of the terrestrialisation hypothesis of raised bog formation fail[ed] to comprehend the variety of possible horizontal surfaces upon which domes of bog peat may arise."

There is much substance to this view, though it could be commented that it depends partly on what one means by 'raised bog' and by 'fen'. This is not least because many ombrogenous habitats are likely to originate from preceding minerotrophic conditions of some sort, *viz.* 'fen' in the sense of Du Rietz (1954) and are in that sense underlain by 'fen'. However, Ratcliffe and the others may have been thinking more of 'fen' in the sense of Tansley (1939), as expressed by thick and extensive accumulations of fen peat and, considered in that sense, Ingram's comment is undoubtedly valid.

Ombrogenous nuclei may be initiated in various circumstances on a 'flat' minerotrophic surface, all dependent upon the elevation of the surface above the influence of telluric water. The process seems most generally to be envisaged as resulting from the accumulation of tumps of peat or tussocks of vegetation and a concomitant switch to an exclusively precipitation-fed surface on which the accumulation of – now ombrogenous – peat is able to continue. However, Hughes (2000) has pointed out that the fen–bog transition in stratigraphical sequences of some raised bogs is marked by a horizon suggestive of comparatively dry conditions, and has suggested that ombrotrophication could have been initiated in response to a drop of the mire water table. This possibility may well have much substance, but it is not necessary to account for the observed stratigraphical features that suggest a temporary 'dry phase'. This is because in non-buoyant contexts the fen–bog transition may normally (and perhaps necessarily), proceed *via* a phase of water table instability and autogenically-induced low summer water tables during the hydrological transition, as the mire surface switches from a telluric water-based hydro-regulation to one provided by a *Sphagnum*-based acrotelm.

Surface acidification and ombrotrophication can occur particularly readily and rapidly in some terrestrialisation sequences upon a buoyant mat of vegetation, which neither much dries out nor becomes flooded by telluric water, thereby providing ideal conditions for the establishment of some species of *Sphagnum* (*e.g.* Tratt, 1998). In many cases, at least in smaller basins, ombrotrophication of buoyant surfaces is more usually centrifugal rather than centripetal. This is because, once a buoyant mat has developed, the most 'floaty' areas are normally those towards the centre of the basin over deeper water, and where these 'float' readily above the level of the telluric water they can be subject to rapid acidification. By contrast, the 'hinge' of the raft, *i.e.* where it is attached to the margin of the basin, is more stable and has much less capacity for vertical movement. This therefore often remains influenced by telluric water and forms a persistent minerotrophic 'lagg' around a central dome of accumulating *Sphagnum* peat.

Mires that are regarded as 'blanket bogs' may also arise from an (often short) phase of preceding minerotrophic conditions, though where ombrogenous peat has developed upon mor humus[1] (and are effectively overgrown 'peaty podzols'), any initial minerotrophic influence may be slight, and the base of the blanket peat difficult to distinguish. A more significant initial phase of minerotrophic conditions may occur within poorly-drained hollows in upland locations (*e.g.* Conway, 1954), which may once have provided the focus for the initiation of upland mire but which has since become encompassed within, and may be indistinguishable from, the surrounding blanket peat surface. However, circumstances vary: Moore *et al.* (1984) have commented on the stratigraphy of Loch Ronald Moss (near Newton Stewart) in which a deep depression once contained reedswamp that developed into fen woodland and thence 'blanket mire'; perhaps more remarkably, much of the slope was also covered by carr woodland before it was replaced by blanket peat[2]. In yet other examples, ontogenic developments in depressions *etc* may persist as distinguishable surface features, distinct to a greater or lesser degree from the surrounding mire, by their topography, stratigraphy and, often, vegetation. Lindsay *et al.* (1988) also recognised that such units can occur but considered that they were "closer in character to blanket bog" (though they did not state what that character was), and that it was "not sensible to separate these elements from the rest of the blanket bog complex". Although this may seem a convenient and utilitarian solution for dealing with such areas, it is not possible to endorse it here, since if such units have a different topography and stratigraphy to the surrounding peatland then they may well also have different hydraulic characteristics and conservation management requirements.

5.2.5 Peat composition and characteristics

The macrofossil composition of peat depends primarily upon the species composition of the vegetation that formed it, together with any differential decomposition of the individual associated species. The characteristics of peat (*e.g.* humification, bulk density, state of preservation) depend upon the conditions, particularly wetness conditions, prevalent at and after the time of formation. Peat character and composition can vary considerably in mires, both horizontally and vertically. It is often possible to identify horizons that can be recognised consistently within, and sometimes between, individual mires and such layering has been used to infer water conditions on the mire surface when the peat was deposited and sometimes, by extrapolation, changes in climate conditions. Ellis & Tallis (2000) have recognised that even ombrogenous mires in highly oceanic areas can reveal an identifiable signature that may be related to water level and climate change.

Although a considerable number of peat cores with macrofossil data are available, it is quite difficult to make synoptic comparisons between sites and studies, partly because of variation in the detail recorded but also because stratigraphical variation across some individual sites can be considerable. There has not been sufficient time in the present project to attempt detailed comparisons amongst sites, but a few comments can be made. Perhaps the most widespread of all peat types, across a range of ombrogenous sites, is some form of *Sphagnum–Eriophorum* peat, though with variations both in the proportion of *Sphagnum* and species of *Eriophorum*, and in the contribution of *Calluna.* Such peat occurs widely, both in sites that are referred to as raised bog and sites referred to as blanket bog, though further north and west remains of *Trichophorum* can become more prominent within ombrogenous peat.

Sphagnum-dominated peat also occurs widely in ombrogenous bogs, varying from rather thin layers within or at the top of the peat deposits, to thick *bouffant* caps of fresh *Sphagnum*, which are

[1] A mor humus soil has few micro-organisms to decompose organic matter, leading to the development of a strongly compacted humus layer overlying the mineral ground. Mor humus soils are usually acidic and typical of cold regions and high altitudes.

[2] It is not certain, from the information provided, whether this surface was completely ombrogenous, but the composition of upper peat is essentially *Sphagnum–Eriophorum*.

sometimes some several metres thick. Such thick deposits are a particular feature of certain raised bog sites in Cumbria (Walker, 1966; Barber, 1981; Hodgkinson *et al.*, 2000), stretching north into the lowlands of central Scotland (Scottish Peat Survey, 1965), but they also occur in some sites that were not regarded as raised bogs by Lindsay & Immirzi (1996). They may once have been more widespread in some other lowland regions of England (but since lost as a consequence of agricultural conversion *etc*.), but equally they are not a prominent feature of the two largest extant raised bogs of Wales (Cors Fochno and Cors Caron, Ceredigion), in which *Sphagnum–Eriophorum* peat seems to be the principal deposit (and whose soils are included in the same unit as those of 'blanket bogs' (Rudeforth *et al.*, 1984), see Section 5.2.6). On the other hand, there is a striking contrast between the raised bogs of the Silver Flowe (Galloway) (where Boatman (1983) complained that the peat was too humified to permit field identification of most macrofossils), and some of the relatively fresher *Sphagnum*-rich peats of certain of the bogs around the Solway estuary (including the Moss of Cree, which is some 20 km south of the Silver Flowe).

5.2.6 Soil types in upland ombrogenous bogs

A variety of soil types and Soil Associations occur in poorly drained upland locations, but here attention is given to those most often associated with significant areas of deep ombrogenous peat, as mapped by the Soil Survey. The characteristics of upland and related peat soils in England and Wales have been summarised by Findlay *et al.* (1984) (South West England), Jarvis *et al.* (1984) (Northern England), Ragg *et al.* (1984) (Midland and Western England) and Rudeforth *et al.* (1984) (Wales). Burton & Hodgson (1987) have also provided much relevant information, though their work was focussed mainly on lowland deposits of peat. In Scotland, soil information has been provided by the Soil Survey of Scotland (1982, 1984), but is limited by a different conceptual system of soil classification, in which, amongst other things, it can be difficult to separate ombrotrophic from minerotrophic peats. More details are provided in Annexe 2 (Section 14).

The soils of England and Wales have been mapped nationally at 1:250,000 scale (Soil Survey of England and Wales, 1983). The mapping unit used has been the *soil association*, a somewhat heterogeneous unit which can contain a number of related *soil series*. These latter can be seen as more 'fundamental' conceptual and descriptive units, but their mapping is not available in published material, except where more detailed Soil Survey Records are available. Burton & Hodgson (1987) have provided useful comment on the occurrence of soil series within some of the peatlands they have considered.

In England and Wales, most of the soils of the more upland stretches of ombrogenous peat have been accommodated within three main Associations. In England these are dominantly the Longmoss and the Winter Hill Associations; in Wales they are dominantly the Crowdy 1 and Crowdy 2 Associations.

Within the Longmoss Association, the Longmoss series essentially consists of a top 'reference layer' of *Sphagnum*-dominated peat of variable thickness, usually underlain by a *Sphagnum–Eriophorum* peat (Kilgour, 1985). In some sites this is associated with soils allocated to the Floriston series, a unit described as a semi-fibrous grass and sedge peat. The relationship between this and the Longmoss series is complex and, in the absence of appropriate mapping, confusing. In some locations Floriston soils are said to have developed in consequence of the removal of overlying Longmoss soils; in others, they may be underlain by *Sphagnum* peat (Kilgour, 1985). In a number of raised bog sites, Longmoss series soils occur in the more central locations, with a variable extent of Floriston series soils around the margins, and in some sites (*e.g.* Bowness Common), Floriston series soils are said to predominate (Burton & Hodgson, 1987). Floriston series soils have been described as being derived from 'basin peat' (Jarvis *et al*, 1984) and of 'low ground' (Kilgour, 1985) and are not necessarily strictly ombrotrophic in character.

The Winter Hill Association forms a very extensive unit which essentially corresponds to what is commonly regarded as blanket peat. Its "soils include the Winter Hill series, which is predominant, and, in hollows the Floriston (Kilgour, 1985) and Longmoss series. Soils of the Crowdy series are found where the vegetation is dominated by *Molinia*" (Jarvis *et al.*, 1984). Its reference section essentially consists of a humified *Eriophorum–Sphagnum* peat.

Jarvis *et al.* (1984) provided the following part of a key for separating soil series within the Winter Hill Association:

Blanket peat, with moss and cotton grass remains	**WINTER HILL**
Raised peat, with moss remains	**Longmoss**
Basin peat, with grass and sedge remains	**Floriston**

As moss-dominated and moss–cotton-grass peats can occur in close juxtaposition in some ombrogenous deposits, it is tempting to suspect that the primary basis of identification of the soil series may sometimes have been its topographical context (blanket, raised or basin), which raises a question of the extent to which the soil series forms an independent basis for characterising ombrogenous peatlands.

In Wales, the Crowdy 1 Association is dominated by "amorphous raw peat soils of the Crowdy series" and "Some fibrous peat soils of the Winter Hill are included". Rudeforth *et al* (1984) noted that:

> The association is distributed discontinuously across the main north to south watershed of Wales, generally above 350 m O.D., at the heads of streams and on saddles between the major hills. As well as the wide spreads of blanket peat, there are a few raised bogs… such as Gors Lwyd on the watershed between the rivers Ystwyth and Elan in west Powys. In these bogs the nutrient status is even lower than in blanket bog.

The Crowdy 2 Association is similar to Crowdy 1, but differs in its representation of soil series, with a greater proportionate contribution of Winter Hill series soils (Rudeforth *et al.*, 1984):

> "Raw acid peat soils dominate this association which occupies wide upland tracts of blanket bogs and scattered peat-filled basins in Wales and South West England… Well humified peats of the Crowdy series are most extensive whilst the chief associate is the more fibrous Winter Hill series (Carroll et al. 1979) with visible Eriophorum–Sphagnum remains…
>
> Altitudes range from sea level in west Wales to more than 600 m in the east. The famous lowland raised bogs at Borth and Tregaron[1] are included. These have floristic and pedological affinities with blanket bogs having both amorphous and semi-fibrous layers unlike the dominantly fibrous peats of raised bogs elsewhere."

Of particular interest in this account is that both of the Associations are considered to be represented in blanket bog and raised bog and, in particular, that the lowland 'raised bogs' of Borth and Tregaron are mapped into the same soil unit as 'blanket bog'. The authors have not recognised in the main areas of ombrogenous peat in Wales a soil series comparable with the Longmoss series of northern England, presumably in reflection of the more humified and less *Sphagnum*-rich character of the Welsh raised bogs. This may point to a greater pedological affinity between the two largest lowland raised bogs of west Wales and those of parts of western Scotland, such as Silver Flowe (Galloway) and Claish Moss (Argyll), rather than with some of the large bogs of north-west England. However, it is not easily possible to make a direct comparison between peat soils in England and Wales and those in Scotland, because the latter have a different (simpler) conceptual and classificatory basis (Soil Survey of Scotland, 1982, 1984) (see Annexe 2, Section 14).

5.2.7 Ombrogenous raised bogs – form and hydrodynamics

In Britain, Ingram (1982) pointed out that ombrogenous peat deposits accumulate essentially in response to impeded drainage of precipitation. He was concerned particularly with the hemi-elliptical accumulations of ombrogenous peat that occur on flat, or flattish, surfaces and which have traditionally been referred to as 'raised bogs' and he recognised that their hydrodynamics can to some considerable extent be understood in terms similar to that of the drainage of mineral ground,

[1] Borth Bog and Tregaron Bog are now known as Cors Fochno and Cors Caron respectively

with the important difference that the accumulation of ombrogenous peat, and its associated water table, is essentially a recursive and on-going process – *i.e.* natural drainage develops to fit the peat available. More than twenty years earlier, in a little-documented report on Cors Caron, it had been recognised that drainage equations could be used to account for the size and shape of the raised bog (Childs & Youngs, 1961). This approach 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 essence, the equation predicts that the water table (and hence the surface) of a raised bog will be curved, to form a hemi-elliptical when viewed in section. This has come to be known as the ‘Groundwater Mound Hypothesis’, though here, because of ambiguities in the usage of the term ‘groundwater’ (see Section 4.1.2) we refer generically to a ‘water mound’. Accumulation of peat to ‘fit’ the modelled water mound is in some (variable) measure countered, and eventually balanced, by its decomposition, a process which is partly, but by no means entirely, regulated by water conditions at the mire surface (Belyea & Clymo, 2001). Clymo (1984) considered that, as a result, maximum peat depth is usually between 5 and 10 m.

Acrotelm–catotelm concept

Using ideas that were prevalent amongst some Soviet telmatologists (Ivanov, 1981), Ingram (1978) introduced into Britain the concept that raised bog peatlands could be regarded as *diplotelmic*[1] (*Greek* = ‘double-mire (peat)’) systems in which a relatively permeable upper peat formed a thin layer (*acrotelm*) (*Greek* = ‘tip’ or ‘topmost-mire (peat)’), almost a ‘skin’, atop a generally much thicker, and much less permeable, body of peat (*catotelm*) (*Greek* = ‘down’ or ‘below-mire (peat)’) (see Figure 2). The catotelm was defined as the zone of permanent saturation, which is ‘fed’ with water from the acrotelm, and which contains the accumulated residue of plant remains (*i.e.* peat) that have not already been lost from the acrotelm by aerobic decomposition. Although he recognised (Ingram, 1983) that the catotelm peat was not necessarily of the consistently low permeability suggested by some other workers, the simple diplotelmic model provided an appropriate basis for conceptualising the hydrodynamics of ombrogenous deposits and for accounting for their profiles. His considerations of size and shape focussed almost completely upon the hydraulics of the catotelm, which constitutes almost the entirety of most ‘raised bog’ deposits. In essence, considering a dome of peat on an ‘impermeable’ mineral base, precipitation excess (*i.e.* precipitation inputs to the surface that are not lost through evapotranspiration) is removed laterally to the margins of the deposit. Some of the inputs serve to recharge the catotelm, whence there will be some loss by slow lateral seepage, but in many instances the main discharge of precipitation is thought to occur laterally through the acrotelm, However, whilst the hydraulic characteristics of the catotelm can be accounted for, to greater or lesser extent, by drainage equations, the hydrodynamics of the acrotelm have generally been much less well characterised.

Ingram (1987) conceptualised the relationship between water in the acrotelm and catotelm thus: “If seepage in the catotelm may be thought of as the source of base-flow in the mire’s drainage system, the acrotelm provides both a route by which excessive fluxes generated by storms are dispersed without harm to the surface vegetation and a means of protecting the catotelm from drought.”

Since then, the term ‘acrotelm’ has come to be widely used by telmatologists (Morris *et al.*, 2011), and by bog conservationists and restorers, though various recent workers have suggested that it is too simplistic and rigid to account adequately for the range of variation found in peatlands in the field (Box 1) . Its importance to practitioners is partly because it is seen as the support-system for bog vegetation and surface ‘habitat’, not just physically but also because it has a variable supposed capacity for some measure of hydro-regulation, based on a number of attributes (Bragg, 1982; 1989; Joosten, 1993); and also because it is the layer most readily damaged or destroyed by drainage, burning or extensive peat extraction. Restoration of an acrotelm is therefore often seen as a primary

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[1] *Greek.* τέλμᾰ (télma) = stagnant water; marsh (hence derivative ‘mire’ or ‘peat’). It does not mean ‘layer’, as is sometimes suggested, though in the instances here it may be equivalent with this).

objective in bog restoration (*e.g.* Joosten, 1993; Wheeler & Shaw, 1995a; Money & Wheeler, 1999). Such usage has, however, led to a more informal notion of the character of the 'acrotelm' than was envisaged by Ingram (1978), and it is not always clear what individual workers mean by it. In some instances, especially in bog restoration, it seems to be considered synonymous with a 'spongy *Sphagnum* surface' (Money & Wheeler, 1999).

Box 1. Perspectives on the concept of *acrotelm* and *catotelm.*

Ingram (1978) considered that the split between the acrotelm and catotelm was essentially hydrological: the lowest level to which the water table falls during drought conditions. There has since been some discussion about whether the mean lowest water table (averaged over all years) might have been a more appropriate measure. It was also recognised that the two layers thus distinguished differed in various characteristics additional to the behaviour of the water table, particularly in hydraulic conductivity and rates of peat decomposition. Little attention has been given to what marks out the upper boundary (surface) of the acrotelm. For example, in an area of bog woodland does the 'acrotelm' extend upwards to the top of the tree canopy?

Morris *et al.* (2011) and Baird *et al.* (2016) have contested the standard acrotelm–catotelm model as being too simple and have suggested that, amongst other things, there is a need to consider lateral variations in hydraulic properties as well as depth variations. Baird *et al.* (2016) found at Cors Fochno that, locally, catotelm peat could be as permeable as acrotelm peat, and that, within the catotelm, *K* (hydraulic conductivity) values varied laterally by up to two orders of magnitude, across contrasting surface microforms. They concluded that spatial variations in peat permeability are more complex than are allowed for in Ingram's standard model, but they recognised also that the likely significance of this to the hydrodynamics of the mire as a whole was far from clear, partly because any impact of variation in *K* is likely to depend critically upon the continuity of any higher permeability peats. Peat pipes are also difficult to represent in the diplotelmic model, but again their influence on the mire as a whole may be strongly localised and difficult to predict or model.

There is a potential mismatch between an acrotelm defined hydrologically (as by Ingram, 1978) and its associated hydrophysical characteristics. This is readily evident in the extreme example of a residual block of part-drained, cut-over peat, from which the natural acrotelm has been removed. In this case, an acrotelm can still be recognised hydrologically, in terms of the position of the water table, but the top layer consists of former catotelm peat and retains its characteristics of low permeability *etc.* Wheeler & Shaw (1995a) and Money & Wheeler suggested the rather unsatisfactory term 'functional acrotelm' to distinguish a more 'natural' acrotelm (*i.e.* one that had some hydroregulatory function) from the periodically dry surface of a block of cut-over peat, or similar.

In his work on peat formation and 'bog growth', Clymo (1984) subdivided the peat column into two main layers: an upper oxic layer with relatively high rates of peat decomposition, and a lower anoxic layer in which decomposition rates were relatively slow, and he melded these (respectively) into the concepts of acrotelm and catotelm. However, Morris *et al.* (2010) pointed out that, even in more natural systems than cut-over peatlands, not all hydrological, ecological and biogeochemical processes were necessarily coupled to the same layer boundary. They considered that although depth is a powerful predictor of many peatland variables, it is difficult to justify the assumption that all threshold changes occur at the same depth, e.g. at the absolute lowest water table; changes from high to low hydraulic conductivity, and high to low peat decay rates are related but not necessarily coincident. They suggested "that the solution is simple: allow for multiple, asynchronous boundaries reflecting the processes and properties under consideration… under this more flexible scheme, it is possible to define as many layers and variables as required." Nonetheless, they also recognised that for some variables and processes "mechanistic links cause the boundaries between layers to be broadly coincident", and it is hard to see how, in principle, this view differs much from the concept of an 'acrotelm' and 'catotelm', but separated by a fuzzy boundary rather than an exactly-specified limit (and which is probably how many workers have usually regarded it). As an alternative Morris *et al.* (2010) suggested that three-dimensional 'hot spots' could be recognised "within a peatland where ecological, hydrological and/or biogeochemical process rates are elevated relative to the rest of the peatland". But unless these are seen just as bespoke entities, based on comprehensive data sets appropriate only for individual peatland sites, rather than as generic, conceptual units that are broadly applicable to many sites, this amalgam of different features would seem to be potentially as subject to the difficulties of disambiguation of which these workers complained for the acrotelm–catotelm split, perhaps more so. It is not clear that 'hot spots' and 'cold spots' provide an answer to the limitations of the simple diplotelmic model, though they may well be valuable for specific research endeavours.

'Water Mound' hypothesis and peat 'domes'

In a simple situation, such as an ombrogenous mire of circular plan on top of a flat, low-permeability surface, radial drainage through the acrotelm into the surroundings will occur around the margins of the deposit. Unless there is marked spatial variation in the character and permeability of the peat, the least well-drained location will be more-or-less in the centre of the deposit, where conditions will be wettest (or wet conditions will be sustained longest) and peat accumulation greatest. The result is a radially draining, hemi-elliptical dome of ombrogenous peat, flattest in the centre and often steepening towards the margins. This steepening increases the hydraulic gradient and can be considered, as Ingram (1987) pointed out, "necessary to disperse the yield from an upslope [*i.e.* 'up-dome'] catchment whose area also increases in the same direction". Steeper marginal slopes have often been called the *rand*, though in many instances this feature has been removed, or sharpened, by peat extraction or agricultural conversion around the ombrogenous peat. The mire margins often appear to be better drained (have a lower water table) than the centre of the dome, at least during 'dry' periods, and this may be expressed in some locations by the occurrence of trees around the margins of some ombrogenous domes.

Overall, in a little-modified mire, the water mound reflects interactively the dimensions of the peat body, as the mire water is necessarily contained within, or upon, the surface of the peat. The height and shape of the water mound is partly determined by the area and basal plan of the peat deposit, with larger areas potentially supporting a higher water table and peat surface in the centre of the raised deposit. However, where tracts of ombrogenous peat are extensive the actual maximum height of the water table and peat surface may fall well short of the potential hydrological ceiling, either because there has been insufficient time for peat accumulation to reach the predicted hydrological limit, or because on-going decomposition of existing peat ensures that the potential hydrological maximum can never be reached. This is one of the reasons why small deposits of ombrogenous peat, in small basins or troughs, can appear to be much more strongly domed, and have a more pronounced rand, than is the case in larger examples, which often appear to be rather 'flat' over quite large areas. This is the case, for example, at Lochar Moss (Dumfriesshire), Flanders Mosses (Stirlingshire), Cranley Moss and Ryeflat Moss (both Lanarkshire) (Annexe 1). However, reduction of doming has also been attributed to drainage (Meade & Mawby, 1998). Peat digging can also modify the natural profile of bogs, though in general past domestic peat digging most usually has been focussed around the margins of the mires, where it helped to modify or destroy the character of any natural rand rather than the main mire expanse. There are also examples of ombrogenous surfaces in which a rand appears to be poorly developed for other reasons. This may be the case, for example, where a dome of ombrogenous peat has developed across a convex interfluve. This is sometimes seen as a feature of 'blanket bogs', but is a feature also of some ombrogenous deposits elsewhere, including for example some of the bogs of Polesie, described by Kulczyński (1949), which are certainly not considered to be 'blanket bogs'. The absence of a significant rand is also often found in the very different context of 'Buoyant Bogs' (WETMEC 2 (of Wheeler, Shaw & Tanner, 2009)), where a raised surface of ombrogenous peat has formed upon a semi-floating raft of minerotrophic vegetation, but these have not generally been the subject of groundwater mound models.

The form and shape of a dome of ombrogenous peat can be independent of the underlying topography, at least where the net sub-surface topography is 'flat' and when any ridges are insufficiently high to modify materially the near-surface ('acrotelm') drainage. In the earlier developmental stages of such systems, the detail of sub-surface topography almost certainly influenced the character of different patches of developing mire, but these have since outgrown the influence of such topographical features. Nonetheless, there is some evidence that in certain sites some surface features (such as pool systems) may continue to reflect sub-surface topography (*e.g.* Boatman, 1983; Belyea & Lancaster, 2002) and in some instances may have effectively grown up with the accumulating peat.

Where an ombrogenous deposit has developed upon a mineral base with a slight net slope, there is a greater potential for drainage to be distributed asymmetrically down the main direction of slope and for the dome of peat to be located eccentrically, in response to the effectiveness of drainage around it.

Peat accumulation in relation to water conditions

Accumulation of ombrogenous peat requires an appropriate climate to support peat formation above the water table and is especially prevalent in the wetter, cooler parts of Britain (Section 5.1). Plant material from the surface is added to the acrotelm, which is generally aerobic and where decay is relatively quick; as material accumulates and the water table rises (consequent upon a decrease in hydraulic conductivity at and near the base of the acrotelm) the decaying litter and proto-peat becomes incorporated into the top of the catotelm, which is anaerobic and where decay is much slower. Clymo (1984) has pointed out that upwards of 80% of plant material is 'lost' by decay whilst in the acrotelm, and the catotelm is the main layer in which peat *accumulates*.

Although the rate is small, decomposition of peat within the catotelm does occur and is thought to be persistent and, considered over timescales of millennia, there is a finite limit to the maximum depth of peat that can accumulate (Clymo, 1984). Morris, Baird & Belyea (2012) have modelled (using 'DigiBog') the effects of different anoxic decay rates upon ombrogenous peat accumulation, and reported that at the lowest applied anoxic decay rate (5×10^{-6} a^{-1})[1], simulated peat growth was *less* than when the decay rate was an order of magnitude higher (5×10^{-5} a^{-1}). They attributed this to feedbacks between the degree of peat decomposition and hydraulic conductivity, which in the case of the simulation with higher anoxic decomposition had resulted in peat of lower hydraulic conductivity and a reduction of water flow to the mire margin.

Rather little measured examination has been made of the relationships between rates of peat accumulation and surface wetness conditions. There has been a quite long-standing presumption that peat accumulation is greatest in wettest conditions. *Sphagnum* productivity has been reported to be particularly high in bog hollows and some shallow pools (Clymo & Reddaway, 1971) and, more conceptually, Clymo (1984) considered that in 'wet' locations "Because the water table is closer to the surface then the value of p_c [the rate at which litter and proto-peat is passed from the acrotelm into the catotelm] will be greater and so peat accumulation (and height) will be greater". However, Belyea & Clymo (2001) estimated peat accumulation rates in contrasting surface microforms, based on field measurements in a small raised bog (Ellergower Moss, see Section 5.2.9), and demonstrated a 'hump-backed' relationship between rate of peat formation and the mean water table depth ('acrotelm thickness'). The maximum rate of peat formation occurred in 'lawn' microforms, though there was considerable variance in the estimated rates[2]. In wetter conditions (hollows), vegetation productivity was smaller whilst in drier conditions (hummocks) "as acrotelm thickness increased, increases in productivity were offset by increases in cumulative decay." It is not known to what extent these results are valid for other ombrogenous mires, especially those in different bioclimatic regions, and Belyea & Clymo did not much explore the possible implications of their results. For example, can it be concluded that overall the surfaces of 'wet' raised bogs grow more slowly than do some slightly drier ones? Or that, in a blanket bog complex, the rate of peat formation on gentle slopes may be *greater* than in wetter hollows (which often have deeper, though often older, accumulations of peat). It would be desirable to have determinations from other ombrogenous mires of the relationships between 'surface wetness' and rates of incorporation of peat into the catotelm.

5.2.8 Ombrogenous mires in upland landscapes – form and hydrodynamics

In cooler and wetter, often more upland, contexts, the dominant form of ombrogenous peatland is often described as 'blanket bog' – a rather nebulous concept that encompasses a range of gross-forms and 'habitats' (see Section 9.3). Until fairly recently, the hydraulic properties and

[1] decomposition rate was expressed as units of Mass per unit of Mass, per unit of Time (*i.e.* '$g\ g^{-1}\ a^{-1}$')

[2] 'Productivity' ranged from about 0 – 1000 and decay from about 0 – 600 'gm yr' (Belyea & Clymo (2001)

hydrodynamics of blanket bogs had been rather little investigated, and a simple conceptual model comparable with the 'groundwater mound' of raised bogs may be less appropriate, in part reflecting the topographical variability of the peatlands encompassed within the notion of 'blanket bog'.

Gross-form and water supply to upland ombrogenous mires

There is, of course, no reason to suppose that the laws of soil physics that determine the size and shape of 'raised bogs' do not apply equally in more upland situations, given a comparable topographical context. That this is the case *de facto* is illustrated by the example of Dun Moss (Perth & Kinross)), an ombrogenous site at about 360 m aOD, which has the salient features of a raised bog and was a site used by Ingram and his students to develop their ideas on the hydrological characteristics of raised bogs. It is curiously ironic that this site no longer appears to be regarded as a raised bog but instead as a 'saddle mire'[1], a category which well reflects its topographical location but at the expense of recognising its ecohydrological characteristics and its affinities to other raised mire sites. This illustrates well the limitations of a simple categorisation of upland peatlands based on their topographical location, *i.e.* based on *where* they are rather than *what* they are.

Domes of ombrogenous peat appear to be quite widespread in upland contexts, though they are often rather small. Particularly distinct examples in England include May Moss (North Yorkshire Moors), Lucas Moss (Peak District), Upper Teesdale (Turner *et al*., 1973 – now inundated by the Cow Green reservoir), and possibly Stainmore (Cumbria). They are also widespread amongst the Border Mires, e.g. Prior Lancy Moss. Apparent examples in Powys include Claerwen (Elan Valley), Gors Lwyd (Rudeforth *et al.*, 1984) and Waun Fignen Felen (Smith & Cloutman, 1988) – though in the latter any former dome seems largely to have been lost by erosion. They are usually associated with shallow basins or tracts of flattish ground that are particularly poorly drained. Some examples are clearly defined by a lagg or analogous structure; in others, where the topography is appropriate, ombrogenous peat that has formed on adjoining mineral slopes may join with the dome of peat and obscure its margins. However, where the peat surface remains domed and drained by radial water flow, it retains the hydrological features – and, very often – the vegetation characteristics of an ombrogenous dome. Drainage from this will doubtless be influenced by the hydrodynamics of any adjoining, sloping peat, but this will also be the case when it adjoins a slope of mineral ground or, somewhat differently, where a surrounding lagg-like structure within the peat provides a head of water into which the dome drains.

The doming of ombrogenous peat, in the sense discussed here, is independent of the topography of the underlying mineral ground and, as was obvious even to early workers such as Elgee (1912), can, and needs to, be distinguished from circumstances where any doming reflects the underlying topography. The traditional notion of blanket bog is that it forms an ombrogenous deposit that blankets the underlying mineral ground, and its gross-form is in large measure determined by this. On more sloping ground there may be little evidence for any peat mounding at all, except insofar as the ombrogenous peat deposit is delimited laterally by watercourses and flow tracks and is raised in some measure above them. Ombrogenous peat has been reported to form on relatively steep slopes in suitable climatic circumstances, and extensive deposits can occur across hillslopes. These constitute the typical 'hill peat' of many upland districts and are often, but by no means always, relatively shallow (< 2 m depth), depending partly on slope. Depth of peat may be greater in places where the slope flattens, and in such locations pool systems may form, and the vegetation may change. This is illustrated, for example, on a small scale at Alport Moor (southern Pennines) and, on a larger scale, at Achairn Bog (Caithness) (see Annexe 1).

An ecohydrological distinction can be made between different elements within upland ombrogenous peatlands. The topmost, flatter areas, in a watershed location, are likely primarily to be irrigated more-or-less exclusively by direct precipitation, whilst flatter areas or basins downslope are likely to have precipitation augmented, perhaps considerably, by endotelmic down-slope flow, so that flow

[1] Dun Moss SSSI citation (Reviewed in 2007)

rates there are likely to be greater and water tables possibly higher. In some circumstances, there may also be the possibility of some irrigation with telluric water derived from mineral surfaces on slopes above the peatland.

Because of the tendency of blanket peat to conform in some measure with topographical variation in the underlying mineral ground, in topographically complex situations it may sometimes line small, shallow valleyheads[1], which can provide a focus for water flow, endotelmic or otherwise, and sustain water-tracks and soakways. In some irregular terrain, rocks and ridges may protrude above the general level of ombrogenous peat and, although their run-off may contribute little to the water balance of the peat, they may provide a source of solute enrichment. Boatman (1983) drew attention to blanket bog surfaces located below crags and steep mineral slopes, which he realised might contribute a significant amount of run-off, and perhaps solutes, to ostensibly 'ombrogenous' peatlands.

Water movement in sloping ombrogenous peatlands

The acrotelm–catotelm distinction made for ombrogenous domes has also been used with reference to sloping ombrogenous surfaces, though it has not been examined rigorously in these. Morris *et al.* (2010) stated that "The diplotelmic model is … not well suited to peatland types other than raised bogs" but did not explain why they considered this to be the case. [It may depend on their particular concept of 'acrotelm' and 'catotelm', as most mires are likely to be diplotelmic, with a split between a lower zone of permanent saturation and an upper 'unsaturated' zone; *haplotelmic* (*Greek* = 'simple-mire (peat)') mires may occur but are likely to be rare.]

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), and the hydraulic characteristics of such systems may be similar to those of the rands of ombrogenous domes. However, 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. Pearsall (1950) identified the collapse of peat pipes as the beginning of gully erosion in blanket bog on Rannoch Moor in Scotland. From a review of available evidence Shepherd *et al.* (2013) concluded that gullies and peat pipes are natural features of peatlands, but that gully erosion of blanket peatlands in northern England accelerated during the late 18th/early 19th centuries, and that density and size of peat pipes increases with artificial drainage of peatlands (Holden, 2005).

Holden & Burt (2003b) noted the striking lack of knowledge about the nature of runoff generation within peat catchments, given the importance of hydrology to the understanding of peatland development and ecology. Their experimental work at Moor House National Nature Reserve in the northern Pennine hills showed that overland flow dominated the runoff response of the catchment on both vegetated and bare peat, but that infiltration-excess[2] overland flow was unlikely to be significant, with saturation-excess[3] overland flows being important. They concluded that only around 2% of runoff in blanket peat catchments is generated from peat below 5 cm depth, supporting the acrotelm–catotelm model, but they also noted that spatial variation in runoff generation is at odds with a simplistic view of the acrotelm–catotelm model. Holden & Burt (2003a) found significant variation in hydraulic conductivity between nearby peat areas with similar slope, vegetation and peat depth, indicating the inherent problems of trying to generalise catchment-scale hydraulic conductivity based on only a few measurements. Holden & Burt (2003b) also found that macropores

[1] This term is used in preference to 'gullies', which may sometimes seem more appropriate, to avoid confusion with gullies and gullying, which are used here to refer to erosional features within peatland slopes.

[2] Infiltration-excess overland flow is produced when the rainfall intensity is greater than the infiltration rate and the overland flow therefore consists of water that has not been within the soil.

[3] Saturation-excess overland flow is produced when the soil profile is completely saturated, and the water at the surface is a mixture of fresh rainwater and water that has been within the soil mass

(*i.e.* >1 mm in diameter) within peat were important runoff pathways, and that *Sphagnum*-covered peat had significantly greater macro-porosity and hydraulic conductivity than other surface cover types; generally macro-porosity declined rapidly below 5 cm depth. Macropores may also provide bypass routes for water into peat pipe networks. Peat pipes were found by them at all depths and contributed significantly to overall outflow into receptor streams (mean 10%, up to 30% of streamflow), showing rapid response times. Most of the macropore and pipe drainage paths were beneath the acrotelm, but their varying routes can link the surface with deeper layers (Figure 2). The existence of pipes and macropores may thus allow the flux of peat particles, mineral sediment and nutrients from deeper peat layers and from the mineral ground beneath the peat. In contradiction to an often-expressed view that blanket bogs act like a 'sponge', Holden & Burt (2003b) concluded that rainfall is rapidly released as runoff and baseflows are very low because of very efficient transfer of water through the near surface peat.

Gilman & Newson (1980) studied ephemeral soil pipes on shallow sloping peaty soils between plateau blanket bogs and valley floor mires in mid-Wales. They suggested that the origin of pipes was in the selective enlargement of desiccation cracks, and that in some cases sub-surface erosion could lead to slumping and gully formation. Soil pipes formed dense dendritic networks and appeared to develop rapidly (within 10–20 years) but were also short-lived due to collapse and blockage. Experiments by Holden (2005) suggested that vegetation with abundant *Calluna vulgaris* can result in increased pipe density in surface peat layers (*i.e.* the upper 30 cm).

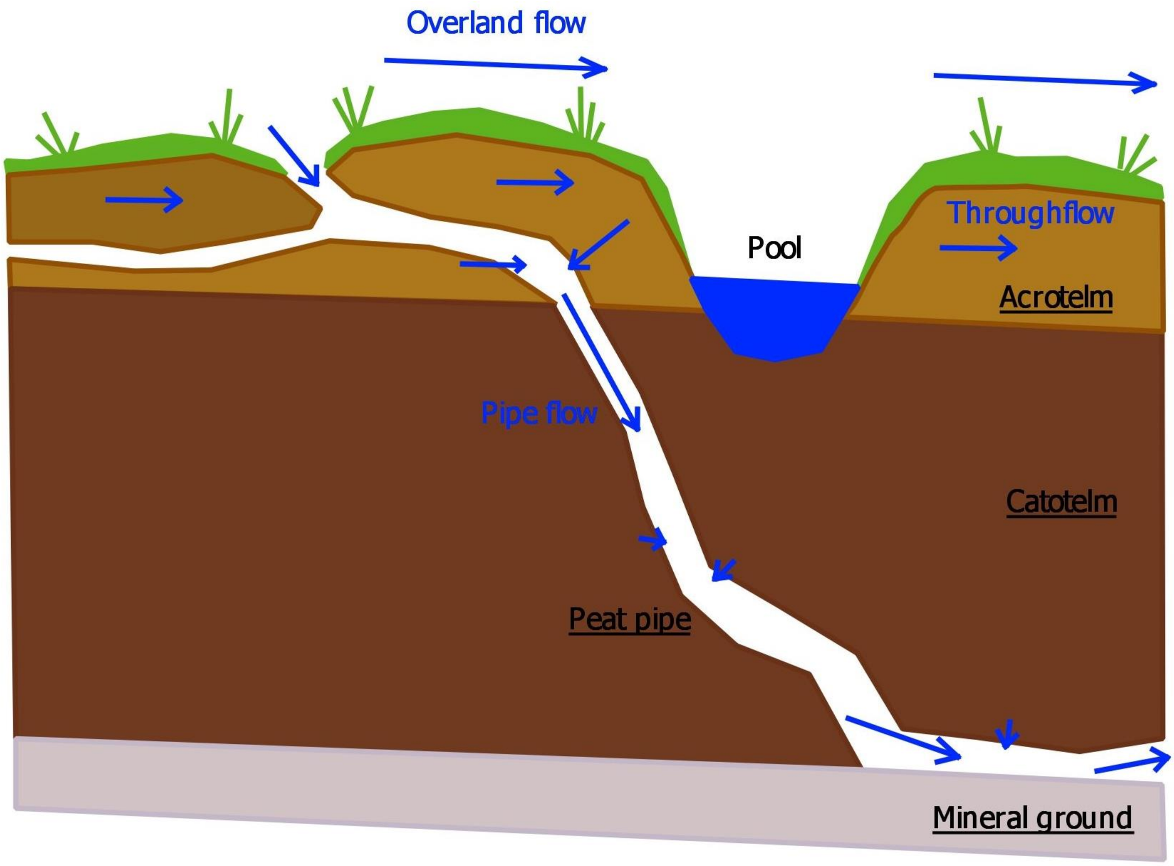


Figure 2. Conceptual diagram of possible water flow routes through peatland acrotelm, catotelm and peat pipes, at varying water table levels.

(Based on Holden & Burt, 2002).

Holden & Burt (2002), in a study of blanket bog peat up to 2.6 m deep, used ground penetrating radar (GPR) to investigate the extent and dimensions of peat pipes. They described pipes up to 150 m long with mean diameters ranging from 3 to 70 cm, and suggested that pipe networks are probably more complex than is indicated by surface surveys. They found that ephemeral and perennial pipes could be present at both shallow and deep locations in the peat profile, that pipes may connect the near-surface and deeper peat with the underlying mineral substratum, and thereby potentially provide a source of solute enrichment. Many pipe systems seemed to originate in pool–hummock complexes or surface water collecting zones and some of these drained directly into gullies. Holden & Burt (2002) also considered that peat pipes should not be thought of as simple linear channels: instead they are tortuous and frequently changing in cross-section, they can develop routes that are at variance with the surface topography, they can sometimes open up to become runnels between hummocks before becoming closed in as pipes again, and the greatest density of pipes tend to be on gentler slopes. Pipes also appear frequently to experience natural blockages from collapse, and consequently individual pipes show erratic discharge, with large amounts of sediment being produced. As a contribution to overall runoff from sloping peatlands, pipe flow is more important for smaller rainfall events, whereas during heavier rainfall, saturation-excess overland flow and near-surface acrotelm drainage becomes more significant (Holden & Burt, 2002). However, in blanket peat, compared with mineral soils, the high water table and relatively low hydraulic conductivity of the peat matrix means that saturation-excess overland flow dominates the catchment response, and piping may supply more of the very low baseflow components seen at perennial pipe outlets.

5.2.9 Ombrogenous surfaces over irregular terrain – form and hydrodynamics

The groundwater models formulated by Ingram and associates are essentially 'flat-bottomed' and include a term relating to the maximum height of the peat deposit. However, they were also applied successfully to a peat mound over irregular terrain at Ellergower Moss (SW Scotland) (Ingram, 1987; Belyea & Clymo, 2001). This is a small, roughly circular mire between Loch Dee and Black Water of Dee over an irregular surface which varied in altitude by about 5 m. The maximum height of the deposit was about 6 m above the mean altitude of the base of the peat, with a maximum thickness of about 7.2 m (Belyea & Clymo, 2001). The maximum peat altitude term adopted in this work took as its base the water level of the adjoining Loch Dee when measured in July 1986, and a good correspondence was found between the surface profile of the bog and the fitted 'water mound' ellipse.

In situations that are topographically more complex, or where there is a greater disparity in the levels and configuration of the sub-subsurface topography, simple mounds of peat do not necessarily occur and unusual, less regular, configurations of the mire surface can be found, even in 'basins' (as at Dergoals Moss (SW Scotland) and parts of Gartur Bog (central Scotland), see Annexe 1), or several small mounds may occur in separate basins, linked perhaps by shallower peat across ridges. Thus Department of Agriculture & Fisheries for Scotland (1964) regarded Anabaglish Bog (SW Scotland) as "a number of Raised Basin Bogs which have overtopped the basins in which peat formation started, resulting in the development of a continuous peat cover of variable thickness". Such bogs were termed 'ridge-raised mires', by Moore & Bellamy (1974), but this designation may obscure the actualities, either that in some complexes distinct mounds of peat can still be distinguished over individual basins, whilst in other instances, the peat that has developed across several basins has come to assume an overall elliptical profile, which is in large measure independent of the sub-surface topography, and which may well have hydraulic properties comparable to those of a 'flat-bottomed' raised bog. The first of these appears to be the case, for example, at North Rothiemurchus (northern Scotland) (Wells, 2001), while examples of the second appear to occur at Flow of Dergoals and Knock Moss (both in Wigtownshire) (see Annexe 1). In the stratigraphical section available for Knock Moss, the peat surface is 'punctured' by a protruding eminence of mineral ground, but this in itself is little different to similar features found in sites that are generally regarded as 'raised bogs', such as Malham Tarn Moss (Spiggot Hill) (Yorkshire Dales), Bowness Common and Roudsea Moss (both in Cumbria).

Coom Rigg Moss (Northumberland) (Annexe 1) is one of the best-studied examples of an ombrogenous peat deposit on particularly irregular terrain: in one part of the site the peat surface has a height difference of about 11 m over 400 m lateral distance. Ombrogenous peat formation was initiated in four fairly small hollows, where it may have formed small domes of peat (the configuration is not known). As peat accumulated, further peat development on the intervening ridges resulted in the coalescence of the original deposits, and the eventual formation of a single dome of peat over-arching much of the site. The vegetation on this was strikingly uniform, without evidence of the different modes of origin of different locations, when examined by Chapman (1964). There are, however, some deviations from the generally domed pattern, especially in some marginal locations where deposits of thinnish, sloping peat are associated with underlying steep mineral slopes. These may be better seen as local examples of 'sloping ombrogenous peat' than as especially well developed rands (though, hydraulically, any difference between the two may be small). The complex sub-surface topography at Coom Rigg has also given rise to a shallow outflow channel, apparently formed from ombrogenous peat, providing an example of a soakway fed by endotelmic flow.

In south-west Scotland, the mires of the Silver Flowe (Annexe 1) occupy a long, peat-filled valley. Seven main distinct areas of ombrogenous bog at the site have been distinguished and studied (Ratcliffe & Walker, 1958; Boatman, 1983) – these lie within a more general matrix of structurally and botanically uniform 'bog standard' ombrogenous bog (a component that has largely been ignored by researchers). The distinctive features of the seven bogs are mainly that they are, in part, somewhat domed and have patterned surfaces, which include prominent, arcuate, deep pool systems. Both Birks (1972) and Boatman (1983) pointed to the topographical and ontogenic affinities of the main patterned bog units with (the much smaller) Coom Rigg Moss (Northumberland). As at Coom Rigg, some of the rands (including the most prominent examples) in the Silver Flowe mires were associated with steep marginal mineral slopes beneath the peat, though some others were more independent of this. Also, as at Coom Rigg, the sub-surface topography was generally irregular, and although the accumulation of ombrogenous peat was in many places independent of this, the 'domes' were asymmetrically distributed within each mire unit, being somewhat tilted or bulging. Nonetheless, as in more typical ombrogenous domes elsewhere, the wettest conditions, and the patterned surfaces, were generally in the higher, least well-drained locations. The four southerly bog units are all situated near or on the valley floor, at the foot of steeply-rising hillslopes, and their subdivision into separate 'hydrological units' is associated with surface drainage from the hillslopes, which forms separating streams. A similar sub-division by watercourses is of course also found in some large raised bog complexes, such as Lochar Moss in SW Scotland and Flanders Moss in central Scotland (Annexe 1), but it appears that all of the four southerly Silver Flowe domes may have some (probably limited) connectivity with the rising hillslopes, and may receive some water inflows from outside the units, either of telmatic or telluric origin. The contribution such inflows might make to the overall hydrodynamics of the units is not known, and probably small, but is nonetheless apparently sufficient to induce a small area of minerotrophic conditions near the hillside junction in at least two examples. By contrast, the more northerly of the Silver Flowe mires (Brishie Bog and northwards) are distanced from the steep valleyside slopes and occupy a broad, flattish, south-east trending interfluve which separates two of the main tributaries (Brishie Burn and Saugh Burn) of Cooran Lane[1]. In these bog units, small minerotrophic inflows seem much less likely, but their overall features are otherwise broadly comparable with the southern examples.

Boatman (1983) held the view that the development of patterned surfaces in the Silver Flowe bogs was associated with particularly impeded drainage, and was related to an irregular sub-surface topography. He considered that hummock–hollow surfaces were generally associated with underlying ledges, and pool systems with underlying hollows, suggesting that these distinctive mire units are, in considerable measure, a legacy of sub-surface conditions. In the northern part of the

[1] the water course joining the Dungeon Lochs to Loch Dee.

system, the patterned areas of bog appear to have a distinctive vegetation, and in a vegetation survey made around 1989 (see SNH, 2020) they were classified as having 'typical' raised bog vegetation (National Vegetation Classification community M18, with or without M1 and M2 – see Section 7 for descriptions of *NVC* types), whereas the separating 'un-patterned' surfaces have generally been allocated to wet heath or blanket bog communities (M15b or M17a respectively). Unfortunately, neither surface nor sub-surface topographical data have been found for these largely unstudied tracts of mire between the main patterned areas.

Some of the 'flows' of the Flow Country bear a striking resemblance to some of the mire units in the Silver Flowe and appear also to have developed across irregular terrain. However, published topographical and sub-topographical data are generally sparse, and there also appear to be few un-published data available (or these have not been made available). Thus rather little substantiated comment can be made about these important mire systems. Examination of aerial imagery suggests that in Caithness the mires generally form mounds or domes, at varying scales in the landscapes, but as in the Silver Flowe, there is a tendency for these to vary in gross-form. Some appear to form separate domes, with radial drainage on all sides; others may be more 'attached' to adjoining hillslopes in places; some appear to form irregular domes, tilted domes, half-domes, or lobes or bulges, but without better, albeit quite simple, examination in most cases it is premature to comment on their likely hydraulic characteristics. However, Ingram (1987), referring to the measured surface profile of part of Shielton Bog (Caithness) pointed out that:

> [it] "bears an interesting resemblance to that of a raised mire; although classed as a blanket mire because of its developmental history, it seems unlikely that the hydraulic behaviour and contemporary ecology of this mire differ from those of a typical raised mire in any essential respect."

He likewise considered that the arrangement of microtopes on the mire surface was broadly comparable with their arrangement on some raised bogs. Unfortunately, he provided few details and, in particular, it is not clear what components of its developmental history he considered had resulted in its classification as blanket bog (and, because of this, whether or not they are also found in some sites generally considered to be raised bogs).

As in the Silver Flowe, there is a need to establish for the Flow Country the degree to which distinctive 'domes', 'lobes' or 'bulges' of ombrogenous peat can be related to the sub-surface topography. At Forsinard, there is evidence for the association of pools with depressions in the mineral substratum (e.g. "The pool complex is situated over a bowl…" (Belyea & Lancaster, 2002)), and Belyea (2007) reported the importance of topographical control upon the relative abundance of pools (see further, below). However, Boatman & Armstrong (1968) found no evidence that bog pools were related to variation in sub-surface topography at Richonich (north-west Sutherland), though their measurement of this may have been insufficiently extensive to reveal the wider sub-topographical trends.

5.2.10 The lagg and other ombrogenous edge conditions

The rand, if present, is an intrinsic feature of some deposits of ombrogenous peat, whereas the same is not really the case for the lagg which, although it receives drainage from the ombrogenous peat, is very often a reflection of the topography and hydrogeological characteristics of the surrounding landscape. An uncommon exception to this generalisation is where a lagg is formed from an endotelmic flow track between two (or more) ombrogenous deposits. Many ombrogenous sites do not have a noticeable lagg, except in the trivial sense that the margins of all ombrogenous deposits will have some sort of interface with minerotrophic conditions, whether of peat or mineral ground, around their margins.

The classic concept of a lagg, as expressed for example by Godwin & Conway (1939), is that of a wet minerotrophic moat surrounding all or part of a deposit of ombrogenous peat within some sort of basin or trough, and it was seen as being a particular feature of a raised bog. As described by early workers, the lagg represented fen vegetation which had become increasingly confined to the margins of the basin by the radial spread outwards of ombrogenous peat, often restricted to a wet trough around the margin of the mire, contained by the adjoining 'upland', and maintained against further expansion of ombrogenous peat by a supply of telluric water. This process – which has undoubtedly occurred in some sites – sees the lagg as having been created, at least in part, by the spread of ombrogenous peat and the diversion of telluric water around its edges, and carries with it the implication that at a younger developmental stage any so-called 'lagg' would have been difficult to distinguish from the (potentially expansive) minerotrophic surface upon which the bog had been initiated. Water supply to this type of lagg is likely to be derived in part from the raised ombrogenous surface, but also from surface water runoff from the surrounding land, or groundwater discharge from (sometimes strongly-flowing) springs.

In other situations, it is clear that rather than telluric flow being diverted within the wetland site by the expansion of ombrotrophic peat, the lateral expansion of such peat was itself limited by powerful streams or rivers. A strip of minerotrophic conditions between bog and stream is likely to develop in this situation also, and is also sometimes referred to as a lagg, even when the ombrogenous deposits are not regarded as 'raised bog' (Radcliffe & Walker, 1958; Boatman, 1983). Ratcliffe (1964) provided a perceptive account of variation in the character of the lagg in some Scottish mires.

In some contexts, the topography of the land around a bog site can preclude the formation of a moat-like lagg along some or all margins. This is, for example, the case where a stream or river has eroded into an ombrogenous deposit, to create a cliff-like edge, with little space for minerotrophic mire to develop between this and the watercourse (Boatman, 1983). It can also be the case where ombrogenous peat has developed across a gently sloping convex landform, which may or may not have minerotrophic mire further downslope.

Hulme (1980) suggested a simple tripartite classification of Scottish peatlands based on the character of their margin:

> "For Scottish peatlands the three classes can be defined as follows. A confined mire develops within a topographic basin contained on all sides by mineral ground. Where the ground is impermeable, it develops through the colonisation of a lake by peat-forming plants. An unconfined mire blankets the mineral terrain regardless of topography and is 'checked only by major breaks in slope' (Radforth, 1977), the actual angle varying from just a few degrees to over 20° according to climate and geology. A partly-confined mire has features common to both confined and unconfined mire, being intermediate in character, and is generally located in valleys, on terraces, between ridges and drumlins, *etc*. Partly-confined mires can contain elements of basin mires which have spread beyond their original confines. "

Whilst simple in outline, and generally easy to apply, this system is essentially determined by edge conditions, but it represents a curious amalgam of these with other aspects of the mires. For example, there seems to be no reason why a confined mire should develop from a lake, rather than just from a badly-drained basin, nor why an unconfined mire should necessarily take on the characteristics of blanket peat: it is quite possible, at least in principle, for an ombrogenous deposit with attributes of a 'raised bog' to be perched upon an unconfined surface. If disambiguated from such extraneous considerations, Hulme's approach provides a useful means of considering the landscape context within which ombrogenous mires can occur, though ultimately it represents a classification of the peat deposit based on its surroundings, rather than on its intrinsic features.

5.2.11 Surface patterning and pools

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 this the different vertical zones found on bog surfaces have been rationalised into terrestrial (T) and aquatic (A) zones relative to the average water table (Lindsay, 1995; Thom *et al*., 2019), in which the vertical range is typically no more than 50–75 cm (Thom *et al*., 2019) (see Table 7).

In little-damaged bog habitats, the amplitude of the observed microtopography is strongly related to climate, and different patterns are broadly associated with different parts of Britain (Lindsay *et al*. 1988; Lindsay, 1995). Aquatic zones A3 and A4 are generally found only on bogs in northern and western Scotland, where they are a distinctive component of these mires. In many instances the pools occur on gentle slopes and form crescentic structures aligned across the slopes and are a component part of what is often referred to as a 'ridge and pool' surface.

In England and Wales surface patterning, when present, is mostly represented by a hummock–hollow micro-topography (zones T2–A2). 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). Hummock–hollow complexes also occur in many Scottish mires, including examples with ridge–pool patterning, and the relationship between the two pattern types has been examined in some detail at the Silver Flowe. Here Boatman (1983) reported that:

> "The fringes of most of the patterned mires, where gradients are somewhat higher than in the centre, generally consist of hummock–hollow pattern. It seems that pools reach the edge of a patterned area only where there is a considerable increase of surface gradient over a short distance. However, areas of hummock–hollow pattern are not necessarily associated with gradients steeper than those occupied by ridges and pools."

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 appears essentially to represent the high ridge zone T2. In some situations it can constitute a degraded form of a more

Table 7. Bog microforms (based on Lindsay *et al.* 1985; Lindsay 1995; Lindsay, 2010).

T4 and TA2 (highlighted rows) are microforms resulting from erosion, often found on damaged sites. The relationship between these microforms and bog vegetation types is shown in Figure 9.

Zone	Description	Summary description	England	Wales	Scotland
T4	Peat erosion hagg associated with erosion, >75 cm above water table	Heathland species, maybe some bog species.	✓	✓	✓
T3	Tall hummocks, >25–100 cm above the water table	Hummock made up of *Sphagnum* mosses with dwarf shrubs.	✓	✓	✓
T2	High ridge, 15–25 cm above water table	*Sphagnum capillifolium* with dwarf shrubs and graminoids. Firm surface.	✓	✓	✓
T1	Low ridge, up to 15 cm above water table	*Sphagnum magellanicum* and *S. papillosum* 'lawns'. Spongy surface.	✓	✓	✓
A1	Hollow, 0–10 cm below water table	*Sphagnum cuspidatum* and *S. denticulatum* 'carpets'; *Rhynchospora* and *Eleocharis* species can be distinctive. Cannot be walked on.	✓	✓	✓
A2	Hollow, with solid peat base 5–20 cm below water table	Shallow pools, base is firm enough to stand on. Sparse vegetation. Some aquatic *Sphagna.*		✓	✓
A3	Drought sensitive pool, up to 20–50 cm below water table	*Menyanthes trifoliata, Utricularia* spp. maybe some *Sphagnum*.	[✓]	[✓]	✓
A4	Permanent pool, water 1–4 m deep	Pools extend almost to mineral base; vertical sides. May have *Sphagnum* and *Menyanthes*.			✓
TA2	Erosion gullies	Resembling mud bottom hollows with flowing water	✓	✓	✓

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). Examples in the southern Pennines include Ringinglow Bog, Lucas Moss and the (confusingly named) Leash Fen on the Eastern Peak District Moors, Derbyshire (see Annexe 1). These sites support extensive areas of the more *Sphagnum*-rich vegetation with scattered pools and with extensive patches of *Molinia caerulea* dominating zones of water movement.

Growth dynamics of patterned surfaces

The origin and growth dynamics of surface patterning in ombrogenous mires has been investigated to some considerable degree, but mainly with regard to the surfaces of raised bogs. An early idea of 'cyclical regeneration', in which an ontogenic sequence was supposed in which hollows were successively replaced by hummocks, and hummocks by hollows (Tansley, 1939) has largely been discredited in favour of recognition of the long-term persistence of established microforms (*e.g.* Barber, 1981). These may continue to occupy more-or-less the same place on the bog surface for very long periods, during which time they may show some changes in lateral extent, or slight shifts in position, probably consequent upon physical and hydrological interactions, some of which may have been induced by changing climates (Belyea & Clymo, 2001). Recent work using peat cores at Cors Fochno (Ceredigion) (Baird *et al.*, 2015) has provided evidence for the long-term persistence of hollows and hummocks (for at least around one and half millennia, and probably much longer), but also for alternations between microforms in other places, though in these instances it can be difficult to be certain (from peat core data) whether the observed alternations reflect lateral changes in the extent or position of established, persistent, microforms, or the establishment *de novo* of a different microform on the site of another. Baird *et al.* also measured strong differences in hydraulic conductivity amongst the surface microforms, with a maximum difference of about two orders of magnitude between a hummock and hollow at 0.5 m depth (highest values were associated with hollows). There was some evidence for a similar trend between microforms at 0.9 m depth, but this was more subdued and differences between microforms in hydraulic conductivity may disappear, or become much reduced, deeper into the peat column.

Belyea & Clymo (2001) reported variation in rates of peat formation associated with different microforms at Ellergower Moss (Dumfries and Galloway) (see Section 5.2.7: Peat accumulation in relation to water conditions). Highest formation rates were associated with 'lawns'. Decay rate increased with 'acrotelm thickness' (height above the water table), and the balance between this and vegetation productivity helps to determine the height of the 'hummock' surface. "In the short term, an individual microform expands or contracts vertically in response to trends in dry-year effective precipitation...In the long term, both the dominant microform and the rate of peat formation may shift to compensate for changes in the rate of water storage" (Belyea & Clymo, 2001).

Whilst such considerations help to explain the persistence and growth of a patterned surface, the initiation of this is generally less clear and it is notable that some ombrogenous surfaces show limited evidence of surface patterning, even though this may be well developed in nearby mires. At Hummell Knowe Moss (Northumberland) (Annexe 1), Clymo (1980) commented that the "central area is wet, but with little open water, and is surprisingly free of the hummock and hollow topography, on a scale of about 5 m, which is usually characteristic of such areas. (There are a few hummocks on the moss, not associated with pools, and these may turn out to be of unusual interest)". He did not, however, suggest an explanation for this.

Bog pool complexes

Natural open-water pools are a common feature of many peatlands, and in the UK they are particularly frequent on the blanket bogs of Scotland, but relatively little is known about their ecohydrological functioning (Holden *et al.,* 2018). There is evidence that pools can be important sources of methane emissions, may have a strong influence on concentrations of dissolved and particulate organic carbon (DOC and POC), and can irrigate downslope areas (Waddington & Roulet, 1996; Turner *et al*., 2016; Holden *et al.*, 2018).

Investigations into the development of a pool complex at Forsinard in northern Scotland by Belyea & Lancaster (2002) showed that it was situated over a hollow in the undulating mineral substratum, and the largest pool overlies a deep depression where water may have collected early in the peatland's history. The present-day arrangement of pools with successively smaller and shallower pools further from the centre of the complex suggests that it has gradually spread outwards from its initial focus, leading to a gradual lateral expansion of the bog plateau, accompanied by a decrease in hydraulic gradient and hydraulic conductivity of the peat, and an increased water surplus.

Water chemistry, vegetation, and physical characteristics have the potential to exert strong controls on carbon cycling in pools. A comparative study of pool systems in Scotland and Ireland by Turner *et al.* (2016) found significant variations in pool depths, pool vegetation type, and pool water chemistry, leading to differences in pool concentrations of methane and dissolved organic carbon between these regions.

Studies of pool water-level dynamics at Cross Lochs in northern Scotland (Holden *et al.*, 2018) showed a considerable disconnect between the water dynamics in pools and adjacent areas of peat, "Pool levels and pool-level fluctuations were not the same as those of the local water tables in the adjacent peat. Pool-level time series were much smoother, with more damped rainfall or recession responses than those for peat water tables. There were strong hydraulic gradients between the peat and pools, with absolute water tables often being 20–30 cm higher or lower than water levels in pools only 1–4 m away." Peat hydraulic conductivity at 30 and 50 cm depth was generally very low, and very little flow of water between pools occurred below about 30 cm depth, connectivity between the pools being greatest within a few centimetres of the peat surface. This emphasises the role of heavy rainfall events for water flow between pools and flushing out from pools the carbon and other nutrients that may have been processed within them. Overall, they concluded that there was a striking long-term difference between pool levels and peat water-table heights, and this, they considered, was "an important finding, as it shows that the hydrological function of pools, even small artificial ones, is quite different from the hydrological function of the peat mass."

5.2.12 Vegetation

Although vegetation is a key component of all mires, it is questionable whether it should be included in their characterisation. This is partly because if vegetation is used as a partial defining feature of peatland units, it is no longer readily possible to examine the relationship between the type of vegetation present and the independent 'habitat' characteristics of the units. In the Wetland Framework project for lowland England and Wales (Wheeler *et al.*, 2009, see Section 4.4.2), it was found that a particular water-supply type (WETMEC) could be associated with a range of different vegetation types, depending, amongst other things, on the base-richness and fertility of the substratum, and bioclimatic location. Thus, in East Anglia a base-rich, oligotrophic seepage slope was characteristically occupied by M13 *Schoenus nigricans–Juncus subnodulosus* vegetation; in northern England the same combination of habitat conditions were more typically occupied by M10 *Carex dioica–Pinguicula vulgaris* vegetation. There is no reason to suppose that in upland areas examples of ombrogenous and related vegetation are restricted to a particular WETMEC or that several relevant WETMECs do not exist[1].

The vegetation types commonly found in blanket mire landscapes in the uplands are represented by various National Vegetation Classification (*NVC*) communities, shown in Table 8.

Note that many scientific names have been changed since the publication of the *NVC* accounts (Rodwell 1991 *etc*), so revised community names have been provided here to account for this and to make the community names more accessible to workers who are more familiar with common names.

The main known ombrogenous types of intact upland vegetation can be related to the *NVC* communities M1, M2, M17, M18, M19 and M20. Their characteristics are summarised elsewhere in Section 7 (Table 9). M17 is generally a community of the north and west, whereas M18 generally occurs to the south-east of this, especially in central and eastern Scotland and in parts of England and Wales (Rodwell, 1991). However, there is considerable geographical and altitudinal overlap between M17 and M18 and their habitats are not sharply separated: within stretches of erstwhile blanket mire, local areas can have something of the character of raised bog, as on watershed saddles or over deeper, drift lined basins, and some raised mires are so extensive as to be locally like blanket bogs (Ratcliffe & Walker, 1958; McVean & Ratcliffe, 1962 and Ratcliffe, 1977). Ill-defined patches of M18 occur embedded within tracts of blanket bog where the peat mantle deepens over saddles or sub-surface hollows. M17 is usually the surrounding context at lower altitudes; towards the Pennines and at higher altitudes this tends to be replaced by M19. In the Border Mires of northern England, there appears to be a fairly clear segregation of M17 and M18 vegetation that relates broadly to the land-form character of the different areas of mire (see section 7.1.1), though individual samples of the two communities can be difficult to separate floristically. In Wales some hummock–hollow vegetation with *Andromeda polifolia* (which represents *NVC* community M18a) has been recorded on domed surfaces within blanket mire complexes, which otherwise largely support more uniform bog vegetation (M19) on thinner peat over steeper slopes. In some circumstances such M18 patches can preserve some topographical features more usually associated with raised bogs, such as a shallow rand or lagg.

Further, more detailed, consideration of *NVC* vegetation types relevant to upland peatlands, in relation to habitat conditions, is provided in Section 7 and some further comment is made in Section 9.4.

[1] It may also be noted that in the development of the wetland framework one trial included the analysis of vegetation data together with environmental data. The resulting clusters were nebulous and un-interpretable.

Table 8. National Vegetation Classification communities commonly found in blanket bog landscapes in upland Britain.

(Based on feature types described in Upland Common Standards Monitoring Guidelines (JNCC 2009); http://data.jncc.gov.uk/data/78aaef0b-00ef-461d-ba71-cf81a8c28fe3/CSM-UplandHabitats-2009.pdf)

Many species scientific names have changed since the publication of British Plant Communities (Rodwell 1991). The revised names shown here use common names for most vascular plants to increase accessibility. Updated scientific names are used in the text and in Table 9.

***NVC* community code and name (Rodwell 1991)**	***NVC* community code and revised names**
Blanket bogs: bog pools	
M1 *Sphagnum auriculatum* bog pool	M1 *Sphagnum denticulatum* community
M2 *Sphagnum cuspidatum / recurvum* bog pool	M2 *Sphagnum cuspidatum / Sphagnum fallax* community
M3 *Eriophorum angustifolium* bog pool	M3 common cotton-grass dominated community
Short sedge acidic fen	
M4 *Carex rostrata–Sphagnum recurvum* mire	M4 bottle sedge–*Sphagnum fallax* community
M6 *Carex echinata–Sphagnum auriculatum / recurvum* mire	M6 star sedge–*Sphagnum* community
Blanket bog	
M17 *Scirpus cespitosus–Eriophorum vaginatum* blanket mire	M17 deergrass–hair's-tail cottongrass community
M18 *Erica tetralix–Sphagnum papillosum* raised and blanket mire	M18 cross-leaved heath–*Sphagnum papillosum* community
M19 *Calluna vulgaris–Eriophorum vaginatum* blanket mire	M19 heather–hare's-tail cottongrass community
M20 *Eriophorum vaginatum* blanket mire	M20 hare's-tail cotton grass community
M21 *Narthecium ossifragum–Sphagnum papillosum* valley mire	M21 bog asphodel–*Sphagnum papillosum* community
Degraded blanket bog (peat > 0.5m deep)	
M15 *Scirpus cespitosus–Erica tetralix* wet heath	M15 deergrass–cross-leaved heath community
M16 *Erica tetralix–Sphagnum compactum* wet heath	M16 cross-leaved heath–*Sphagnum compactum* community
M25 *Molinia caerulea–Potentilla erecta* mire	*Molinia* dominated community
H9 *Calluna vulgaris–Deschampsia flexuosa* heath and H12 *Calluna vulgaris–Vaccinium myrtillus* heath	Heather dominated community

6. Other mire types associated with ombrogenous peatlands

6.1 Endotelmic flows

6.1.1 Background

The importance of lateral water flow to both the typology and local differentiation of peatlands has long been recognised (*e.g.* Ingram, 1967) (see also 4.1.3), but usually at a rather casual, qualitative level. This is partly due to the difficulties of easily quantifying water flow rates in the low-flow environment of most peatlands.

Kulczyński (1949) had used flow as the basis for much of his characterisation of the mires of the Pripet Marshes – which at that time was a huge mire complex which largely occupied the headwaters of the Pripyat River east of Brest, in what is now the borderland of Ukraine and Belarus. In Britain, his approach was championed by Bellamy (1968), who recognised the three categories of *ombrophilous, transition* and *rheophilous (=* 'flow-loving')*,* which were, for practical purposes, more-or-less synonymous with ombrotrophic bog, poor fen and rich fen. A conceptual constraint upon Bellamy's approach was that in many mires, in Britain at least[1], areas of stronger lateral water flow may receive water from different sources (at least proportionately) to adjoining surfaces, and their different floristic and ecohydrological characteristics may reflect these different water provenances as much as, or more than, just differences in flow rate. This complication can be difficult to disentangle, especially in sites where the hydrological characteristics of underlying mineral strata are very variable or poorly characterised.

Wheeler *et al.* (2009), mainly considering minerotrophic mires in lowland England and Wales, referred generically to paths of localised lateral water flow as *flow tracks.* These were subdivided into examples with much water at the surface (*water tracks*) and those with little or no visible water (*soakways*). In these last locations, water flow is usually not visible but can be inferred from the topography and (often) vegetation contrasts. The potential ecohydrological significance of lateral water flow is that it can increase nutrient availability (as in a hydroponic system) (Ingram, 1967) and that it can increase the oxidation status of the soil and help remove (or immobilise) potential reduced phytotoxins (Armstrong & Boatman, 1967). Ingram (1967) also pointed out that vegetational differences between flow tracks and adjoining mire surfaces can also reflect differences in water level and vertical fluctuations.

6.1.2 Flow tracks in ombrogenous mires

Endotelmic ('within peat') flow tracks, of one sort or another, are quite widespread in ombrogenous mires, but they appear to be a more prominent feature of examples in wetter parts of Britain, and may be more pronounced (or obvious) on some of the less 'flat' examples. It seems likely that in many parts of England (at least) artificial drainage has caused the loss of natural flow tracks, and disturbance around the margins of many sloping ombrogenous mires may serve to disguise their former presence.

Some apparent 'endotelmic' examples are clearly fed by telluric water sourced outwith the mire. This is the case, for example, at Malham Tarn Moss which is crossed by several base-rich soakways

[1] Ingram (1967) stated that in the Pripet Marshes the areas of fen, which were downslope or downstream of the areas of bog, were fed entirely by their own rainwater and by drainage from the raised bogs and concluded "It therefore follows that the fens were able to support eutrophic vegetation entirely through movement of their ground water". This seems to have been considered to have been derived entirely from drainage from the bogs, and the possible additional contribution of telluric water seems to have been ignored.

emanating from groundwater outflow at Spiggot Hill, a small, upstanding deposit of glaciofluvial material rich in limestone clasts and rock debris that protrudes above the level of the peat.

With regard to Scotland, Ingram (1967) commented that "The most characteristic vegetation of the water tracks of Scottish blanket bogs tends to be dominated physiognomically by *Eriophorum* spp., by *Molinia caerulea* or by *Juncus* spp… *Eriophorum* and *Molinia* water tracks occur chiefly in the north and west of the Scottish Highlands. The *Juncus* water tracks are more characteristic of the Southern and Eastern Highlands". It is not, however, clear to what extent these are all strictly endotelmic.

More subtle indications of endotelmic flows within ombrogenous mires can be provided by an increased contribution of *Sphagnum* species (especially *S. auriculatum, S. fallax* and *S. magellanicum*), and of *Eriophorum angustifolium,* to the vegetation, coupled with a reduction in some of the 'drier' species of the ombrotrophic surfaces, to form a vegetation which may be referable to various vegetation types (*NVC* communities M1, M2 or M21 – see Table 8 and Table 9 for details). Examples of M21 have been much under-recorded in Scotland, probably partly because they are sometimes difficult to distinguish from (perhaps adjoining) surfaces of M18, but doubtless also because surveyors have been reluctant to recognise from Scotland a unit which the maps of Rodwell (1991) show only in the southern parts of England and Wales. Endotelmic flows with M1 or M2 can usually be distinguished from examples of these communities in pools by the gentle slope and often sinuous form of the flow track.

In the English Borders, O'Reilly (2019) recognised what he described as 'runnels' and 'flow tracks' in the wetter parts of some ombrogenous domes. These had a distinctive form of M18 vegetation, marked by an abundance of *Narthecium ossifragum* and *Eriophorum angustifolium* and a general sparsity of bog-building *Sphagnum* species. It also had more frequent *S. cuspidatum* and, rather curiously, more *Andromeda polifolia* than the more typical M18 surfaces, but an apparent absence of *Molinia.* These 'runnels' are unambiguously referable to a form of M18 (O'Reilly proposed the bespoke unit of M18-n) (Figure 3 and Figure 4) but their details and ecohydrological characteristics are uncertain.

Fig 3. Border Mires: DCA Ordination of M17 - M20 samples

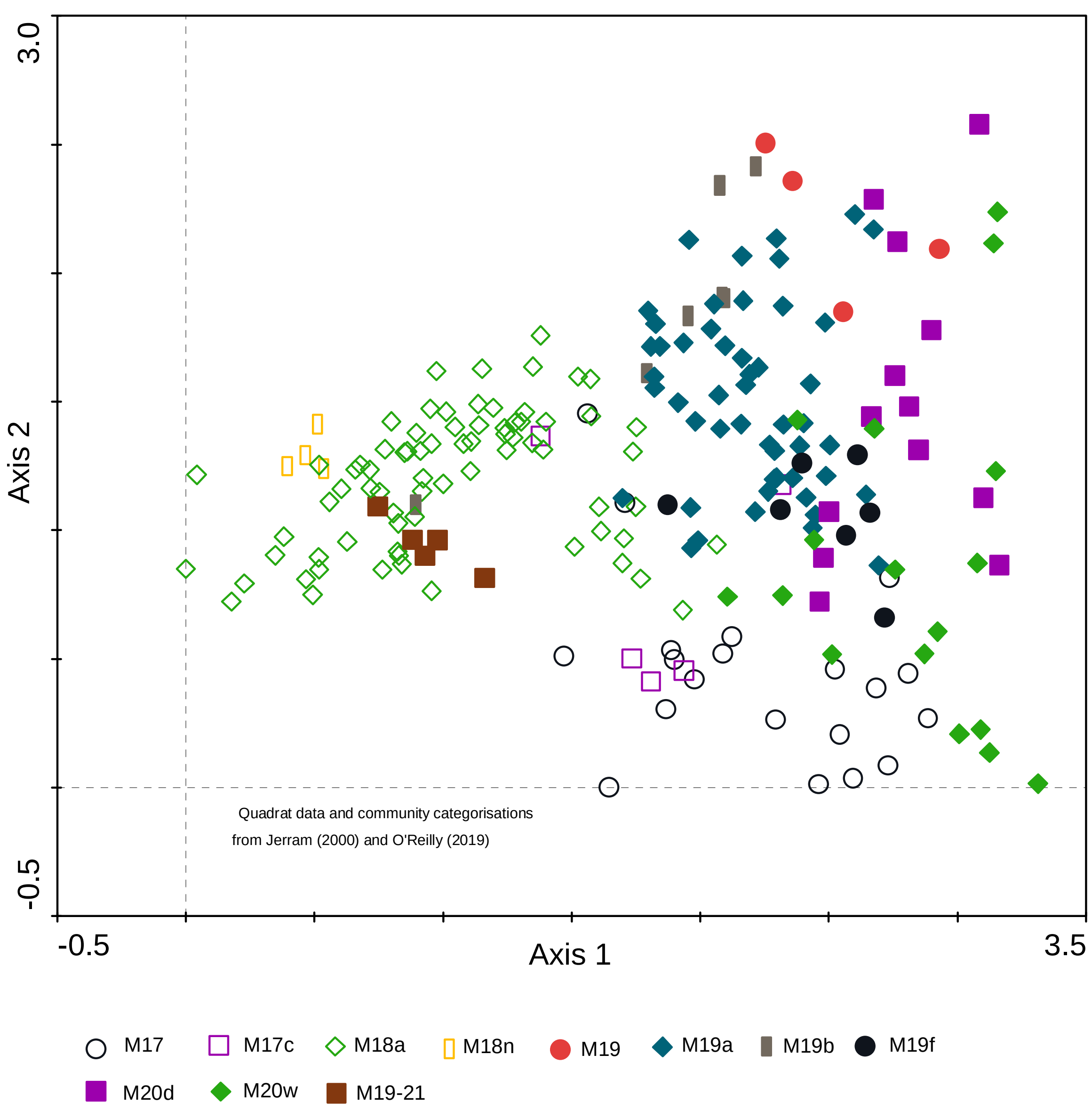
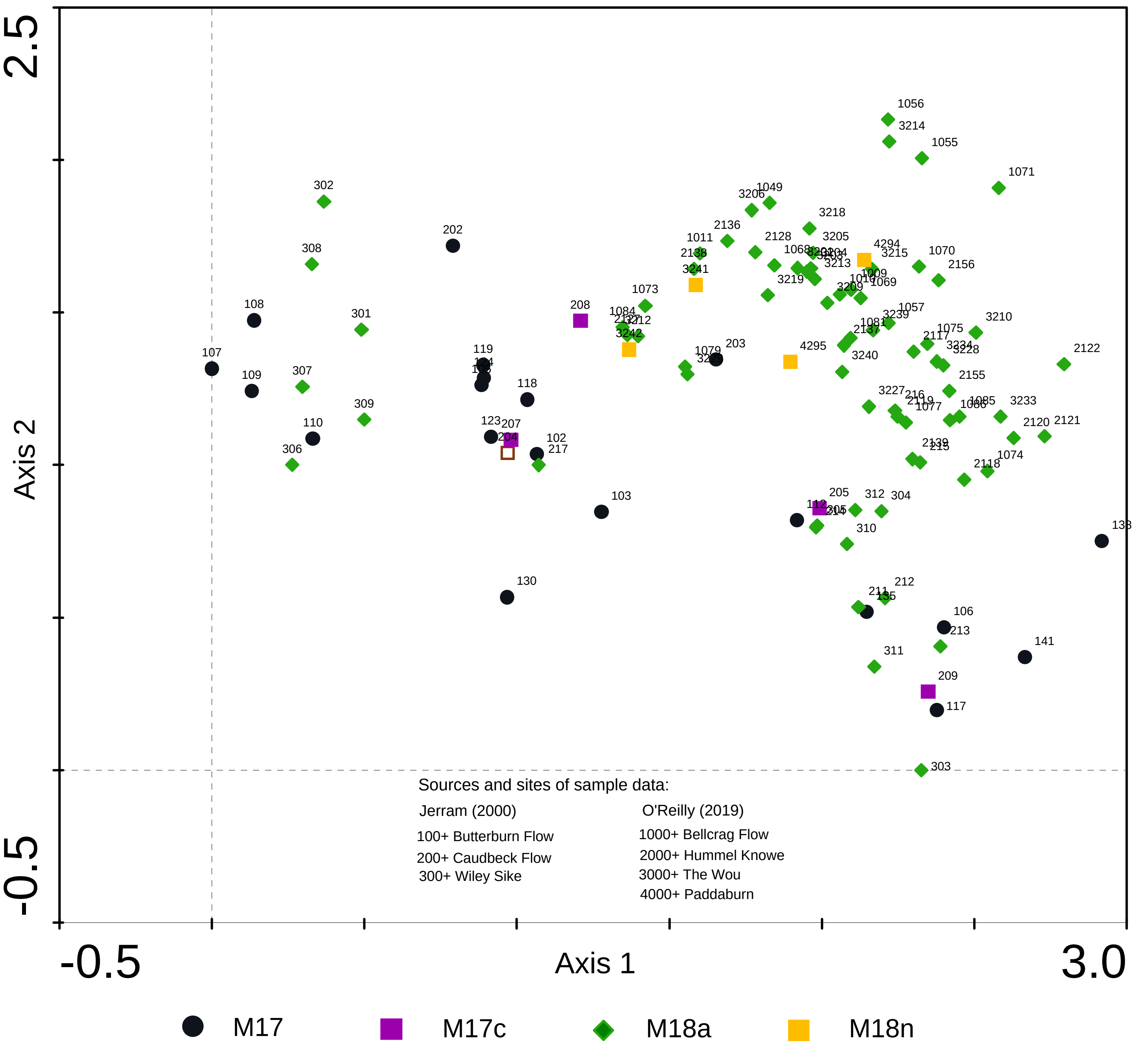


Fig. 4. Border Mires: DCA ordination of M17 and M18 samples



6.2 Minerotrophic mires

Minerotrophic mires often form a distinctive component of upland moorland or ombrogenous habitats, but for conservation purposes are sometimes subsumed within the dominant habitat and may be essentially unrecognised and un-regarded. However, in instances where detailed vegetation surveys have been carried out, the occurrence of such habitats, and their significance for biodiversity, has become readily apparent as, for example, in the Forest of Bowland (Jerram, 2014). In Jerram's survey, examples were recorded of the *NVC* communities M4, M6, M10, M21, M23, M32 and M37, together with M17, M18, M19 or M20.

Broadly, minerotrophic mires can occur in two reasonably distinct (though intergrading) circumstances with regard to more widespread ombrogenous habitats in the 'uplands': they may be largely peripheral to them or largely embedded within them. A third loose category can also be recognised: mires that are essentially mixtures of ombrotrophic and minerotrophic surfaces.

6.2.1 Mire units peripheral to ombrogenous surfaces

Examples of peripheral minerotrophic mires are perhaps most obvious in parts of England where upland ombrogenous units are localised upon the higher areas of moorland and the flatter slopes. In this circumstance, a variety of minerotrophic units can occur around the margins of ombrogenous areas, often on steeper slopes below them. Sometimes this can give rise to some unusual habitat juxtapositions, especially on Carboniferous strata where rocks of contrasting lithologies are exposed downslope of the ombrogenous cap. For example, in the Peak District numerous examples of minerotrophic habitat, usually flushes or seepages, occur downslope of the ombrogenous surfaces of the High Peak massifs (Tratt, Parnell & Eades, 2014); many of these are generally base-poor or sub-neutral in character, but a few examples are surprisingly basicolous (such as at The Roych on the south-east slope of Brown Knoll). In the North Yorkshire Moors, examples of M10 *Carex dioica–Pinguicula vulgaris* vegetation can occur on Jurassic strata downslope of ombrogenous peat on the Jurassic plateau, as can be seen well at Arden Great Moor (Hambleton Hills). Examples such as these are probably little influenced by the proximity of an extensive ombrogenous surface and are, in principle, little different ecohydrologically from their more lowland analogues (though not all of these latter have been characterised well, if at all).

6.2.2 Minerotrophic units embedded within ombrogenous contexts

Minerotrophic mires also occur embedded within dominantly ombrogenous contexts. One of the most widespread and characteristic examples of this is where streams, flanked by (often narrow) strips of minerotrophic mire, subdivide ombrogenous surfaces (see Section 5.2.10). 'Laggs', surrounding, and sometimes subdividing, ombrogenous units are well known (though not always well represented) in lowland contexts, such as Cors Caron (Ceredigion). In more upland areas, similar features have been described, for example from the Silver Flowe (Galloway) by Ratcliffe & Walker (1958) and Boatman (1983), who again labelled them as 'laggs'. It is a moot point to what extent these streams, which often originate on higher ground upslope of the mires in question, have effectively determined the lateral extent of the individual ombrogenous units, or have had their courses modified by the accumulations of ombrogenous peat; both circumstances are possible.

Another widespread form of enrichment with telluric water occurs, as is quite widely the case in some Scottish sites, where rocky knolls or similar structures protrude above the peat level and introduce some (often mild) solute enrichment to the adjoining peat. Unless the surface water catchment provided by the outcrops is proportionately large, the impact of any such run-off upon the 'ombrotrophic surfaces' may be limited, but the frequent difficulty of separating weakly minerotrophic from ombrotrophic conditions (see section 4.2.3) can make this difficult to assess. Such enrichment does not depend necessarily on the bog surface being in a depression or trough, because the effect is created by a rock outcrop around which the bog has formed. However, when the 'bog' surface is in a significant depression or trough, with rock outcrops on the ground above, the potential for some telluric enrichment is correspondingly greater. On the island of Lewis, Goode & Lindsay (1979) recognised a type of 'blanket mire' on steep slopes, and referred to it as 'sloping mire', but Boatman (1983) pointed out that "the sloping mires of Goode & Lindsay must receive an input of water from the laterally-placed rock outcrops".

A range of other minerotrophic features can occur within ombrogenous landscapes. In some locations, issues of minerotrophic water, possibly groundwater outflows, are associated with localised patches of fen vegetation, sometimes quite base rich. Some examples of these, in parts of Scotland have a scalariform pool and ridge system and were labelled as 'ladder fens' by Lindsay *et al.* (1988), though they are not comparable in size, nor probably in their hydrological character, with the ladder fens of eastern Canada or the aapa mires of Scandinavia, and Charman (1995) has since referred to them as 'patterned fens'. They are nonetheless distinctive features. Some examples in the Flow Country in NE Scotland have been described by Charman (1990 *et seq.*) (see Annexe 1), but they are more widespread than this; for example, a similar feature has been noted at Neipeval (Isle of Lewis) in peat at least 1.5 m deep (Shaw & Wheeler, 1990), possibly as part of one of the 'sloping mires' of Goode & Lindsay (1979). Daniels (1985) has also pointed out that "In a number of the valley mires of Dorset and the New Forest there are distinct pools with their elongated axes lying along the contours of the peat deposit and with lawns of *Sphagnum* and hummocks between them", but the relationship between these and the scalariform fens of northern Scotland remains to be clarified.

Other features may be embedded within a dominantly ombrogenous context but are not necessarily much related to it. These can include pools and lochans associated with mineral strata (as opposed to endotelmic pools). Numerous examples of these exist, and other mire types can occur too. A good example is provided at Little Loch Roag (Lewis), where what may have been a former lochan basin has largely terrestrialised to produce a clearly zoned mire. The wettest locations consist of a skin of vegetation and proto-peat, some 50 cm thick, over gelatinous organic muds, rich in sedge rootlets, and apparently indicative of a former swamp or limnic environment. An axial water track (with much *Eleocharis multicaulis, Schoenus nigricans* and *Sphagnum auriculatum* and with a highest MATCH coefficient to M1 bog pool vegetation) is flanked successively by a *Sphagnum*-dominated surface with greater affinity to M21 mire vegetation, a wet heathy, flushed slope (M15a vegetation) and thence ombrogenous mire (Wheeler & Shaw, 1989). The zonation of this site is strongly reminiscent of some of the valleyhead mires of the New Forest and, like them, can be considered to be an example of a Percolation Trough (WETMEC 18) (of Wheeler *et al.*, 2009), but unlike most of them it has developed its percolation surface over a swampy basin and is embedded in a landscape of ombrogenous mire rather than within heath.

One widespread cause of the occurrence of minerotrophic conditions in some ombrotrophic peatlands has been past domestic peat digging. These can create minerotrophic surfaces, either by the exposure of underlying minerotrophic peat or by lowering surface levels so that inflow of telluric water from the surroundings can take place. A good example of this is provided by Great Ludderburn Moss, a partly cut-over ombrogenous peatland on a saddle-like watershed east of Lake Windermere (Wheeler *et al.*, 2009). In this case, and in many others, its cutover status is obvious by residual baulks and blocks of (part-drained) ombrogenous peat, but in other locations there is much less surface evidence of past peat removal, and it can be difficult to assess their 'natural status'. This can be the case particularly on sloping peat surfaces, where the peat cover may naturally have been rather thin. In some instances, place names can provide suggestive clues of former turbary (*e.g.* Glan-y-Fawnog, Llyn-y-Fawnog, Ty'n-fawnog[1]) when surface evidence is lacking, sparse, or difficult to interpret.

[1] Fawnog (or Mawnog): Welsh for peat bog.

6.2.3 Mixed ombrotrophic and minerotrophic surfaces

The main difference between this category and the preceding one relates to the proportion of ombrotrophic surface. In this category, the proportion of minerotrophic peat is relatively large and sometimes dominant. The ombrotrophic peat may also be relatively thin, occasionally embryonic or vestigial, and sometimes just forms ombrogenous patches. The significance here of this category is mainly to emphasise the prevalence, and importance to biodiversity, of minerotrophic surfaces within sites often labelled uncritically as 'blanket peat'.

One apparent upland exemplar of this category is provided by the great Moor of Rannoch (central Highlands), which has extensive minerotrophic surfaces, in a range of topographical contexts, such as valleyheads, basins and troughs, as well as flattish areas. It had been hoped to include this important area of mire as a Reference Site for this project, but there appears to be a dearth of available relevant data; it has not yet been possible to gain access to the Ph.D. Thesis of A. Coupar (Coupar, 1983), which may well have contained useable information.

Some sites on the island of Lewis have apparently high proportions of minerotrophic surfaces. Cnoc Arnish (near Stornoway, Isle of Lewis) consists of an irregular north-east–facing slope with a number of smaller valleyheads and troughs, curving downslope amongst rocky knolls. The higher slopes support a form of *Trichophorum–Eriophorum* bog, but much of the peat surface appears to be minerotrophic and a sub-neutral water track (pH: 5.7; HCO_3^-: 78.5 mg l^{-1}) supported in part an example of M14 vegetation (Wheeler & Shaw, 1989). The flanking mire generally becomes progressively less base rich away from the flow track, except where there are soligenous flushes.

The Cnoc Arnish site is broadly reminiscent of Stable Harvey Moss and certain other sites in the remarkable series of mires in Furness (between Coniston Water and Broughton-in-Furness, Cumbria), though in these locations probable ombrotrophic surfaces (both M17 and M18 have been recorded) are much more sparse and poorly-developed than in Lewis. Some of the Subberthwaite and Blawith examples here consist broadly of base-rich axial flow-tracks flanked by troughs of poor fen (typically M21), and in places then by marginal narrow strips of apparently ombrotrophic character. These sites generally have been little studied, but it is likely that in some at least the vegetation zonations are determined primarily by the influence and pattern of water through-flow, and may be fairly stable. In other instances, such as Stable Harvey Moss, there is a more complex basin structure and vegetation pattern. Small spreads of thin, apparently-ombrogenous peat occur in various places on the slopes, typically marked by *Trichophorum germanicum* and *Eriophorum vaginatum* (Wheeler *et al.*, 2009) and stands with affinities to both M17 or M18 have been recorded. In this site it is possible that much of the present pattern and composition of the vegetation may be residual from past turbary and drainage, in which case the natural character of the site, or of likely ongoing re-vegetation pathways, is difficult even to guess.

In some, especially wet basin, contexts, a mix of minerotrophic and ombrotrophic surfaces is a consequence of the (fairly) recent eruption of ombrotrophic nuclei within fen as part of terrestrialisation processes. Ombrotrophic surfaces can often be found as a late-seral stage in some revegetating, flooded peat workings, from which ombrogenous peat has been removed to expose underlying, more base-rich conditions, but they also occur widely naturally. In England, a good example is provided at Tarn Moss NNR, a semi-upland site in Cumbria, which has three large patches and numerous small nuclei of apparently ombrotrophic surface developed within a matrix of wet poor fen, itself associated with a former tarn. This mire provides an example of a 'buoyant bog' (WETMEC 2 of Wheeler *et al.*, 2009) and the areas of possible ombrotrophic peat are superficial and thin (about 20–50 cm deep), suggestive of recent origin. It may be expected that these areas will coalesce and develop into a more substantial domed ombrogenous surface, and there is some evidence of a peripheral proto-lagg around the site. However, the two main areas of 'ombrotrophic' surface are split by a swathe of minerotrophic vegetation which subtends a stream that enters the south-west corner of the basin and crosses the mire to its outlet in the north-east corner. This stream originates on the lower slopes of the adjoining Great Mell Fell and appears now to receive forestry drainage. There is a silt delta where it issues into the mire basin, and it seems likely that peak flows from the stream may be sufficient to maintain a minerotrophic flow track across the mire, splitting the two main areas of ombrogenous development. This site illustrates the individuality of mire systems, and counsels against the uncritical application of generic conservation strategies, or ecohydrological assumptions, to them.

7. Vegetation types and habitat conditions

7.1 Vegetation associated with blanket mire landscapes

7.1.1 NVC communities

[See also Section 9.4: 'Use of vegetation in the categorisation of ombrotrophic surfaces']

Blanket mire landscapes support mainly ombrotrophic and weakly minerotrophic vegetation types, represented by a range of National Vegetation Classification (*NVC*) communities (Rodwell 1991 *etc*). These are outlined in Table 9, while Figure 5 illustrates the relationship between the main bog vegetation types.

Many of these plant communities support a similar suite of species and can sometimes be rather difficult to separate floristically (Table 10), especially when the vegetation is floristically impoverished (e.g. Jerram, 2000; O'Reilly, 2019; Fojt, 1994) (see Section 7.1.2). In montane areas, mainly in the Scottish Highlands, distinctive plant communities can occur due to the presence of alpine species which are particularly restricted in occurrence (e.g. *Betula nana* (dwarf birch), *Arctostaphylos uva-ursi* (bear-berry)). Vegetation that appears very different in structure (often due to different dominant species) can be similar in floristic composition, and many of the plant communities that occur on blanket peat can appear to be variations on a theme – particularly when they are degraded and species-poor. In various studies of upland vegetation, generalist species such as *Molinia caerulea* (purple moor grass), *Trichophorum germanicum* (deergrass) and *Nardus stricta* (mat grass) have increased in abundance and frequency in many upland vegetation types, and specialist differential species, for example *Sphagnum* spp., have been lost, leading to biotic homogenisation (Ross *et al.,* 2012; Smart *et al.,* 2006). The strength of vegetation classifications based on floristic composition rather than dominance is that they can differentiate between plant communities that appear structurally similar (because they are dominated by one or a few species) but that support a suite of different associated species, which gives the vegetation a distinctive character, and may be related to environmental factors.

The published *NVC* community names sometimes carry specific habitat suffixes that can be a cause of confusion, for example M18 *Erica tetralix–Sphagnum papillosum* **raised and blanket mire** and M19 *Calluna vulgaris–Eriophorum vaginatum* **blanket mire**. These suffixes imply that M19 is not a vegetation type that should be present on raised bogs, but it has been recorded on some important examples of this habitat, for example Tarn Moss at Malham Tarn (Yorkshire Dales) (Cooper & Proctor, 1998). Here it may represent a degraded form of bog vegetation in some areas, but it may also represent a natural type of vegetation on the drier edges of the bog habitat. As a more general principle, habitat suffixes have no real place in a floristic classification and should be discouraged (though in the case of *NVC* they seem to apply only to the labels, not to the descriptions).

NVC surveys require the mapping of stands of visually uniform vegetation, and the recording of plant species and their abundance within representative quadrat samples. This creates a dataset which can be analysed and related to existing data, allowing the sampled vegetation to be categorised as a particular community or sub-community. With advances in GPS technology, quadrat records can also serve as a baseline for future monitoring, though they can be surprisingly difficult to re-locate exactly, even with good GPS co-ordinates. As the dataset increases, there are, in principle, opportunities for re-analysis and the recognition of new vegetation categories, and the redefinition of existing ones, although to date this has only been achieved to a limited extent with the *NVC*.

NVC surveys have not always been carried out during site surveys because they are sometimes perceived as complicated, time consuming and requiring more specialist skills compared with broader 'habitat' surveys (e.g. UK Habitat Classification Working Group, 2018), some of which can be done by interpreting aerial photography or satellite imagery, or by rapid site visits. The categories identified and used by broader 'habitat' schemes tend to be based on a mixture of features, particularly the physiognomic character of the vegetation and on topographical features. In consequence, they are neither vegetation nor 'habitat' units but informal composite entities based on a variable and selective mix of features of vegetation and surface topography. Their conceptual basis appears to be much the same as the 'habitat' units used in Phase 1 Habitat Surveys (NCC, 1990), *viz.* a rough-and-ready preliminary assessment. As in the uplands a significant amount of time is often required to access a site on the ground, it could be argued that, once there, the amount of information gathered during a field visit should be maximised.

'Habitat' categories tend to be broad and linked to dominant species which can lead to ambiguity and confusion. For example, in the UK all minerotrophic wetland habitats above the moorland line have been classified in the statutory lists of UK Priority Habitats as "Upland Fens Flushes and Swamps" (UFFS), whereas below the moorland line they are classified either as "Lowland Fen" or "Purple Moor Grass and Rush Pasture". Therefore, the same vegetation could be included in UFFS, Lowland Fen, or Purple Moor Grass and Rush Pasture, depending on altitude and farming classification. This makes resource assessment difficult; the *NVC* is not perfect (Section 7.1.2), but it is a good starting point for characterising the vegetation component of an area or habitat.

Habitat categories derived from imagery can be rather informal and localised. Although they sometimes can be related to *NVC* communities with some success (for example in the Peak District, the category of cottongrass bog can be related to M20, and heather–cottongrass-dominated bog can be related to M19), detail is often not present, so areas of *Sphagnum*-rich vegetation or hummock–hollow areas are often not recognised, mapped or categorised as separate units (Tratt & Eades, 2012). However, the recent development and widespread use of GIS technology has allowed combinations of geographical habitat conditions to be mapped (altitude, slope, climate), and using these technologies it should be possible in targeted areas to accurately map and record quadrat samples in areas of intact vegetation, in combination with peat stratigraphy and water table. Increasing the quadrat size for *NVC* surveys to 10m x 10m may allow the better linking of satellite data to ground-truthed quadrat data / drone surveys. It would be extremely useful to create a UK-wide GIS catalogue of *NVC* surveys, peat depth surveys, and hydrological monitoring, so that the overlaps and gaps can be seen clearly.

7.1.2 Floristic distinctions between vegetation types of upland ombrogenous mires (M17–M21)

The main vegetation types of upland ombrogenous mires are all relatively species poor and share a number of species. This can sometimes hamper diagnosis of the syntaxonomic identity of mire surfaces and the recognition of their 'habitat preferences'. Some of the inter-relationships amongst individual communities are discussed below, based partly on an analysis of some local data sets. A more comprehensive analysis, based on wider data sets would be desirable.

An illustration of the similarities and differences between M17, M18, M19, M20 and M21, in terms of plant species, surface features, and gradient, is provided in Figure 6.

Figure 5. Bog vegetation types

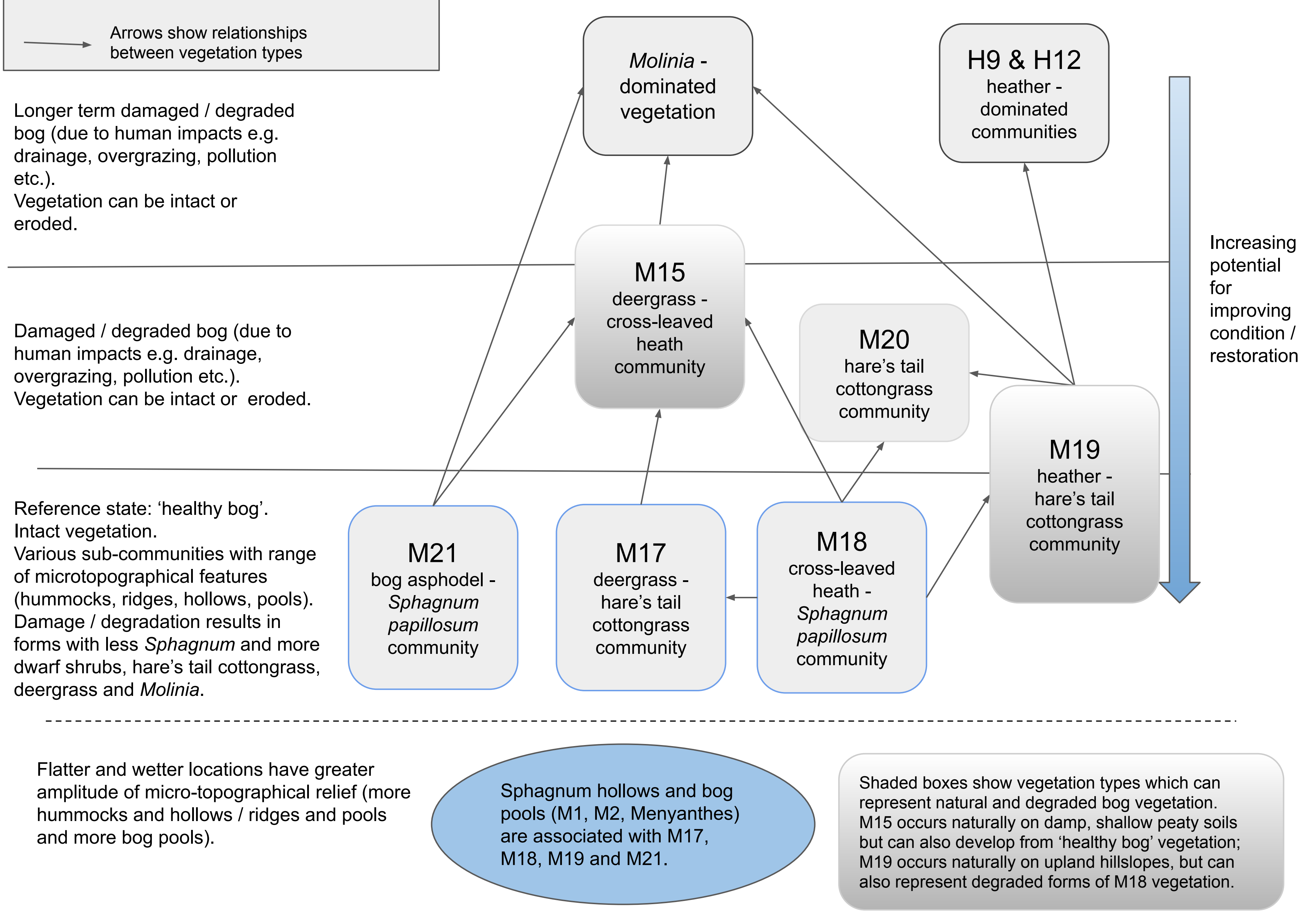
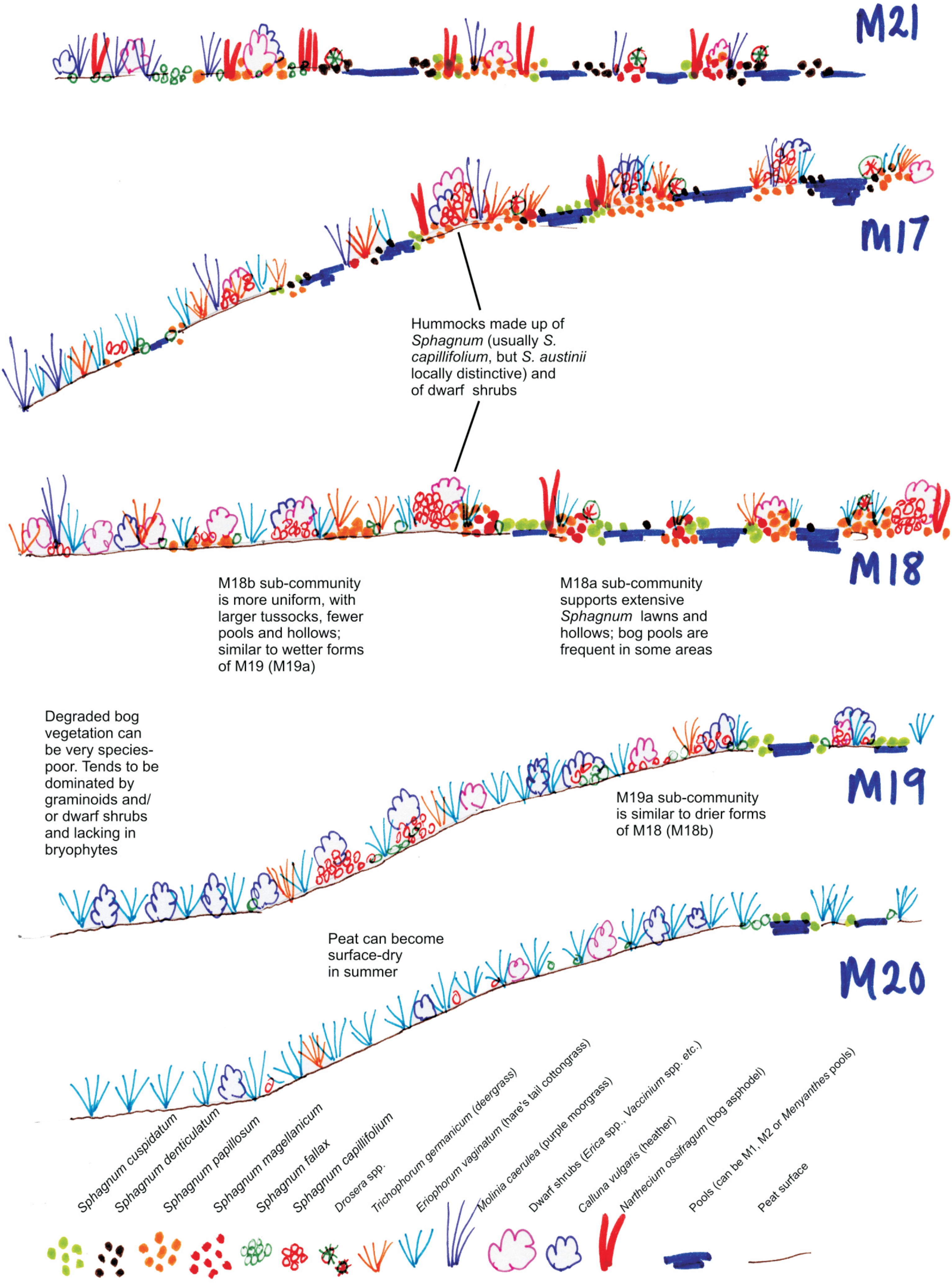


Fig. 6. Bog vegetation: sketch representations of *NVC* communities
[Based on descriptions in Rodwell (1991)].

Degraded variants of communities are shown on the left hand side; hummock-hollow complexes are shown on the right-hand side, but degraded vegetation can occur in all topographical situations, not just on slopes and at the bottom of slopes. Pools and wet hollows occur frequently in the wettest areas; when these features are large they are usually classified separately.

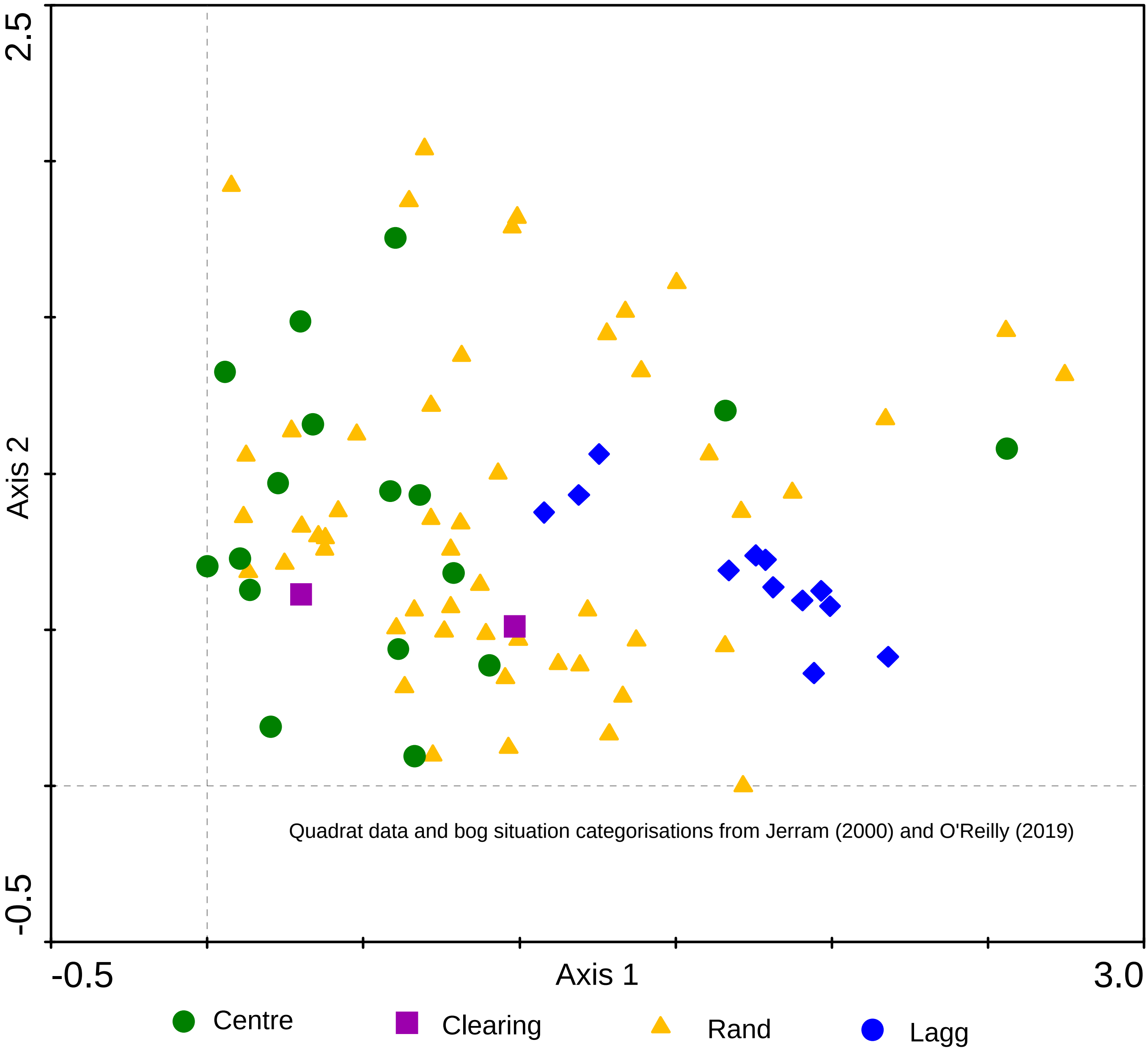


M17 and M18

There is considerable geographical and altitudinal overlap between M17 and M18, and floristic intergradation between them, especially at the southern end of the range of M17. For example, both units occur in the Border Mires of Northumberland and Cumbria, where M18 (with M2) is mainly associated with domed peat surfaces whilst M17 is particularly associated with hill peats. Vegetation with much *Trichophorum* (deergrass) may occur on the steep slopes (rands) of some of the domed peat surfaces and is sometimes then considered to represent a band of M17, but in general it appears to represent a *Trichophorum*-rich facies of M18. In general, *Trichophorum* can grow in situations which are drier than those normally occupied by many plant species of ombrogenous mires, as is shown by its prevalence in the deergrass–cross-leaved heath community (M15). [M15 has essentially the same distribution pattern as M17 within Britain but occupies better drained situations.]

The relationship between M17 and M18 in the Northumberland and Cumbrian Border Mires has been explored by Detrended Correspondence Analysis (DCA) ordinations as part of this project, based on quadrat data of Jerram (2000) and O'Reilly (2019) and using the allocation to *NVC* units proposed by these authors. When data for all of the ombrogenous community-types are analysed together there is a reasonably clear segregation of the communities, and to some extent the sub-communities, and M17 occupies a distinct ordination position between M18 and M20 (and, to some extent also, M19) (Figure 3). However, when only M17 and M18 samples are ordinated together there is much more intermixing of the two communities (Figure 7). It should be appreciated that the location of samples on an ordination is essentially an optimised compromise, based on their floristic affinities with all of the other samples present, and of theirs with one another. Thus the reason for the difference between the two ordinations is because when all of the ombrogenous community-types are considered together, the position of the M17 samples on the first ordination diagram is determined by their floristic affinities with M19 and M20 as well as with M18, whereas on the second ordination their position is determined only by their floristic affinities to M18 examples. Thus the first ordination helps to substantiate the validity of M17 as a discrete vegetation unit, in the round of all the other ombrogenous types represented, whereas the second ordination indicates that it may be difficult to distinguish between some individual samples of M17 and M18, at least in the Border Mires sites. [It should be noted that these samples were all from the southern end of the range of M17 and it is likely that differences from M18 would have been greater if samples had been included from further north and west; but the analyses provided do indicate the relationships within a small(-ish) area with similar climatic conditions.]

Fig. 7. Border Mires: DCA ordination of bog vegetation samples categorised by situation



Relationships to surface topography

Natural zonations from M18 to other vegetation types are often related to the degree of drainage of the peat. M18 is most characteristically a community of wetter, flattish and (possibly) more stagnant surfaces, and can be replaced by communities such as M15b, M19 and, sometimes M17, on steeper, more marginal, slopes (see Figure 6). This has been illustrated by Rodwell (1991) with regard to the zonation of a raised bog, where there may be a more steeply sloping rand of sometimes considerable width. M18 typically occupies the flatter, wetter and often more central areas, whilst *Molinia* can become abundant in the more freely draining marginal locations. Some *Molinia* communities on bog rands are referable to M15b (cf. 'intermediate bog' of Ratcliffe & Walker, 1958), whilst others are referable to M25a.

The relationship between vegetation composition and position within ombrogenous mires in the Border Mires of Cumbria and Northumberland have been analysed by DCA (Figure 7), using the quadrat samples of Jerram (2000) and O'Reilly (2019), which their authors had labelled by their reported locations (centre, rand and lagg) (samples for which these authors did not specify locations were excluded). In the ordination, samples from the lagg formed a fairly discrete group, but samples from the centre and the rand were much more intermixed, suggesting that vegetation with essentially the same species composition can occur in both situations, at least in these example sites. Boatman (1983) made a similar point with regard to the Silver Flowe: he noted that although there were clear quantitative differences in species abundance between the wetter, flatter surfaces and the rand, in some cases there was very little qualitative compositional difference.

M18, M19 and M20

M18 has been recorded extensively on raised bogs so it is often regarded as being synonymous with the BAP habitat Lowland Raised Bog (JNCC, 2011). However, this habitat type / plant community connection may cause confusion for surveyors when M18 vegetation is encountered in upland situations, for example at Shackleborough Moss on Cotherstone Moor SSSI (Teesdale) (Pearsall, 1941). The citation for this site states:

> "Cotherstone Moor supports a range of upland vegetation types including extensive blanket bog, part of which is an unusual bog type transitional in character between northern upland and lowland bogs. (Natural England, 1993). "

It is possible that M18 is under-recorded in upland areas, having been subsumed into the larger peatland units in which it is embedded for survey and monitoring purposes, or it may have been damaged and lost due to drainage, grazing and burning management. If the extent of these areas of deeper peat supporting structurally and floristically diverse vegetation is not known, then they are particularly vulnerable to damage and destruction. Common Standards Monitoring protocols for blanket bog are carried out at the scale of the site unit (often several hundred hectares) and they are not as demanding as the criteria for lowland raised bog, so localised areas of M18 located within extensive areas of upland blanket peatland may be overlooked by assessors, or assessed as favourable even if they are declining in floristic and structural quality and extent (JNCC, 2009).

It is possible that the *Erica tetralix* (cross-leaved heath) sub-community of M19 (M19a) may occur in upland landscapes as part of a zonation towards the margin of a domed ombrogenous surface. Rodwell (1991) showed a zonation from M18a in the wettest, central part of a domed surface grading into M18b (a slightly drier community) lacking the hummock–hollow microtopography of the flat, wetter areas, and then to less *Sphagnum*-rich forms of M15 wet heath on the steeper slopes at the edges. Where *Trichophorum germanicum* (deergrass) is not present in the vegetation, and where *Calluna* and *Eriophorum* are co-dominant over a patchy layer of *Sphagnum* and pleurocarpous mosses, this M19 vegetation may represent a relatively natural bog community, or possibly a degraded form of M18. For example, at Lucas Moss (southern Pennines), a domed ombrogenous area that is developed over a hollow, M19a vegetation occurs over the whole bog, with M2 pools in the central, wettest part of the dome. The pools are not present at the edges, and the M19 vegetation grades into a lagg zone dominated by *Molinia caerulea*. This type of vegetation is also present on other domed areas of deep peat in the Eastern Peak District Moors SSSI (Leash Fen and Totley Moss). These sites were referred to as 'saddle mires' in a recent survey (Penny Anderson Associates, 2010) (in much the same way as Dun Moss, which provided Ingram and his colleagues with material for the formulation of his GWM hypothesis for 'raised bogs' has been since called a 'saddle mire' (see Section 5.2.8)). A similar pattern is seen at Malham Tarn Moss, a 'raised bog' adjacent to Malham Tarn (Yorkshire Dales), where wetter areas of M18 with hummocks, hollows and pools in the wettest, highest parts of the bog, grade into drier, 'smoother' bog vegetation (M19a) towards the edges, and then into a lagg zone with *Molinia caerulea* and various fen vegetation types. The published *NVC* accounts describe M18b as a drier version of M18 on raised mires and M19a as the more *Sphagnum*-rich community of blanket mires, but there is considerable overlap in the species composition and description of these sub-communities. More sampling and analysis is required to investigate the nature of their distinction.

Over much of the Pennines, and elsewhere, more typical M19 vegetation occurs on peat-covered hillslopes managed by rotational burning, and in many places the vegetation is very impoverished and may lack completely a bryophyte layer. In areas where M19 vegetation is abundant (for example, the Berwyns in mid-Wales and the Pennines of northern England), flatter areas on hill tops, ridges, and saddles have more frequent pools and erosion channels, and these tend to support more *Sphagnum*, in some places developing a hummock–hollow appearance (Eddy, Welch & Rawes, 1969; Tallis, 1969). In such locations M18-type vegetation has sometimes been recorded (e.g. Pearsall, 1941), but where drainage, burning and grazing pressures have been intense, these areas appear to have been 'converted' to M19 or M20. Averis *et al.* (2004) mapped locations of M18 in the uplands of Scotland and noted that many examples are remote and surrounded by other types of mire, but that these areas are vulnerable to damage by heavy grazing and burning and, of course, afforestation. Remnant patches of *Andromeda polifolia* (bog rosemary) occurring within M19 vegetation in the Pennines may mark out former areas of M18 vegetation (see Annexe 1).

M20 mire is a very species-poor community dominated by *Eriophorum vaginatum* (hare's tail cottongrass), which appears to be a degraded form of M19. It has also been recorded forming a marginal zone around the edges of ombrogenous bogs, sometimes with *Molinia caerulea* (purple moor grass) and *Trichophorum germanicum* (deergrass) (O'Reilly, 2019).

M18 and M21

Wheeler *et al.* (2009) used DCA to examine the floristic relationships between M18, M21 and M2 amongst their vegetation samples from mires in lowland England and Wales. This showed that M18 was well segregated from M21 but that, whilst M2 samples occupied a fairly discrete sector of the ordination, some of them were intermixed both with M18 and M21. In that data set the examples of M21 were all from minerotrophic locations but generally had somewhat lower fertility than the M18 samples. For the present project, a DCA ordination has been made of samples of M2 and M15–21, all from semi-upland locations in Cumbria (Figure 8). Most of these samples were not from distinct ombrogenous 'types', such as raised bog or blanket bog, but from ombrotrophic (or apparently ombrotrophic) surfaces mixed with minerotrophic surfaces, in valleyhead, trough or hillslope contexts. This ordination showed that samples referred to M2, M17 and M18 (by MATCH) were quite well intermixed, but that M21 samples formed a coherent grouping that was separate from them. Unlike the samples of M2, M17 and M18, the samples of M21 were mostly from surfaces that were unambiguously minerotrophic.

M18 can be generally separated from M21 by the presence of *Andromeda polifolia* (bog rosemary), *Eriophorum vaginatum* (hare's-tail cottongrass) and, less reliably, *Trichophorum germanicum* (deergrass) (Rodwell, 1991. O'Reilly (2019) argued, partly on this basis, that his 'aberrant' samples of 'M18-n runnels' should be regarded as a variant of M18 rather than as M21. In this instance, his assessment is almost certainly correct (see Figure 3), but it should be noted that, in terms of their diagnostic value for distinguishing M18 from M21, *Andromeda* is absent from many parts of Britain whilst *E. vaginatum* occurs quite frequently in samples that appear to be referable to M21 (it was found in about 20% of the M21 samples from England and Wales on our own database). M21 has generally been under-recorded in Scotland. This may be because the samples available to Rodwell in the *NVC* had no Scottish records for M21 and thus showed it essentially to be a 'southern' community, but also because the floristic distinction between M21 and M18 may be less obvious in Scotland than in England, on account of the absence of *Andromeda* from the north and west and a (putative) wider habitat range of *E. vaginatum.* Wheeler & Shaw (1989) sampled what they considered to be M21 vegetation in Scotland, with their syntaxonomic diagnosis in some cases supported by MATCH coefficients. It is possible, based on existing information, that stands of M21 may be marked partly by a prominence of *Sphagnum auriculatum, S. fallax* and *S. magellanicum* coupled with a scarcity or absence of some of the 'drier' species from M18 surfaces (such as *Calluna vulgaris*), but a more detailed examination of sample data from Scotland is required to help substantiate this proposition. It also seems possible, perhaps likely, that, in some of these more 'upland' locations, M21 may not be specifically associated with minerotrophic conditions, but may also occupy endotelmic flow tracks without telluric water sources, in much the same way as does M1 and, to some extent, M2. However, in the case of the four samples of the 'M18-n runnels' recorded by O'Reilly (2019) in the English Borders, MATCH coefficients with M21 were consistently second-highest to M18.

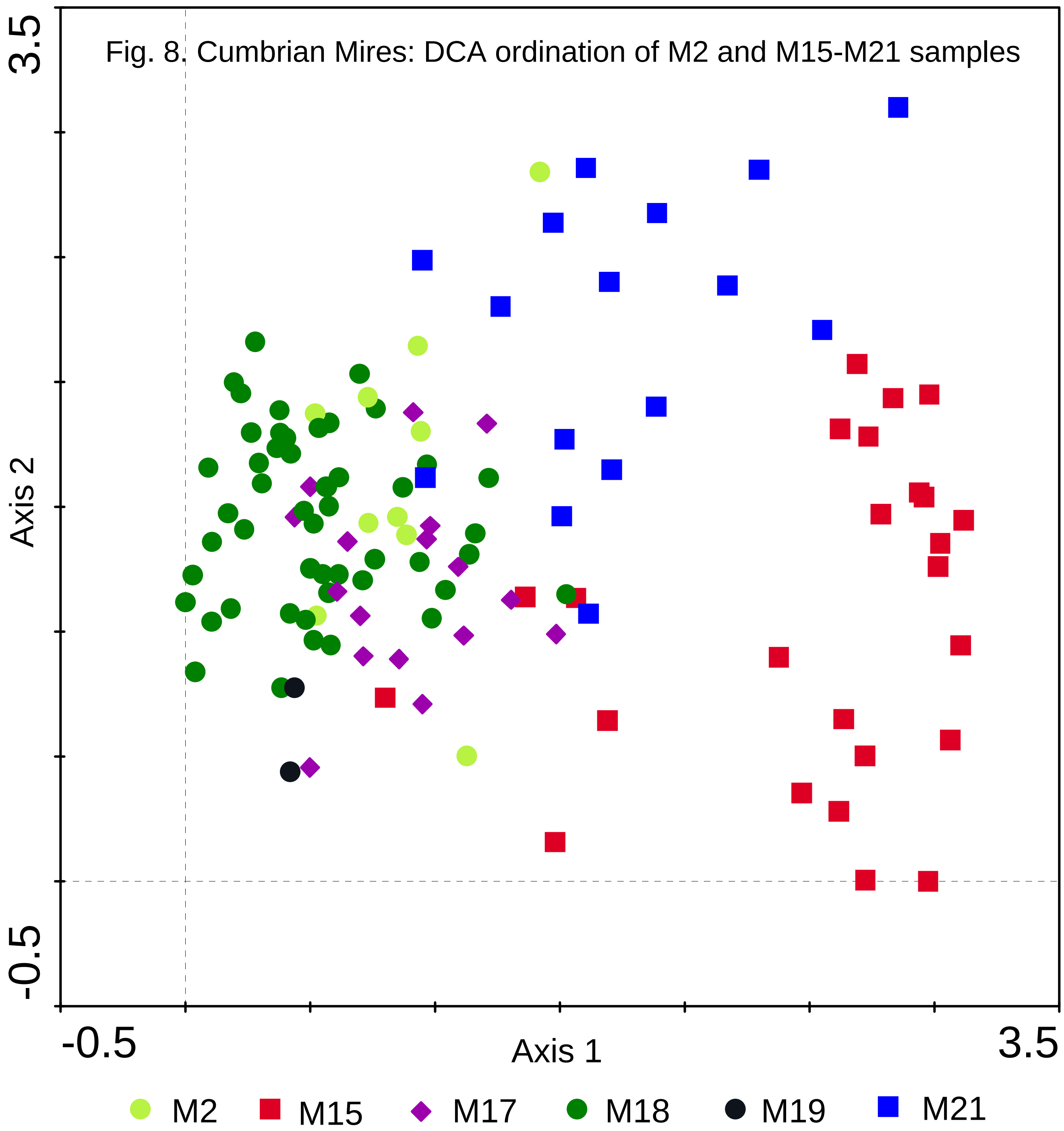


Fig. 8. Cumbrian Mires: DCA ordination of M2 and M15-M21 samples
3.5
-0.5
Axis 2
-0.5
Axis 1
3.5
M2
M15
M17
M18
M19
M21

Table 9. *NVC* vegetation & blanket bog landscapes (based on Rodwell, 1991; Rodwell *et al.,* 2000; JNCC, 2011; see Annexe 1 Reference sites). Scientific names have been updated, see Table 8 for original community names.

NVC code	*NVC* revised name	Description	Situation / conditions	Key examples
Vegetation of stagnant, acid and dystrophic waters in the pools of Sphagnion bogs on deep peats				
M1	M1 *Sphagnum denticulatum* community	Mixtures of *Sphagnum denticulatum* and *S. cuspidatum* in pools with sparse *Menyanthes trifoliata* (bog bean), *Utricularia* spp. (bladderworts) and *Potamogeton polygonifolius* (bog pondweed) in open areas of water. *Rhynchospora alba* (white beak sedge) frequently forms a marginal fringe. With M17 and M21, in hummock–hollow / ridge–pool complexes.	Flat or very gentle slopes Very wet pools and wet hollows.	Highlands: Trichophoreto-Eriophoretum pool component
M2	M2 *Sphagnum cuspidatum / fallax* community	*Sphagnum cuspidatum* and/or *S. fallax* forming extensive carpets in hollows and pools. With M18, in hummock–hollow complexes.	Flat or very gentle slopes Very wet pools and wet hollows.	Border Mires: runnels & laggs; fen complexes.
M2a	*Rhynchospora alba* sub-community	*Rhynchospora alba* (white beak sedge) very frequent with *Andromeda polifolia* (bog rosemary) and *Drosera* spp. (sundews).	Flat or very gentle slopes Very wet	
M2b	*Sphagnum fallax* sub-community	*Sphagnum fallax* abundant with frequent *Vaccinium oxycoccos*.	Flat or very gentle slopes Very wet	
M3	M3 *Eriophorum angustifolium* community	Patchy *Eriophorum angustifolium* (common cottongrass). Bryophytes form sparse patches – mainly *Drepanocladus fluitans*, or tufts of *Sphagnum cuspidatum*.	Flat or very gentle slopes, erosion channels	With M19 and M20 in erosion complexes, particularly in the Pennines.
New swamp sub-community	*Menyanthes trifoliata* bog pool community	Peaty pools with sparsely vegetated open water. *Menyanthes trifoliata* (bog bean), *Potentilla palustris* (marsh cinquefoil) and *Utricularia* spp. (bladderwort) are present at low cover.	Peaty pools with water 30–100cm deep.	Only found in Scotland – particularly characteristic of the Flow Country.
M4	M4 Bottle sedge (*Carex rostrata)*–*Sphagnum fallax* community	Extensive patches of aquatic *Sphagnum* spp. with patchy and open cover of sedges most frequently *Carex rostrata* (bottle sedge), but *C. curta* (white sedge), *C. limosa* (bog sedge), *C. lasiocarpa* (slender sedge) locally	Flat or very gentle slopes, pools and water flow tracks	Border Mires: fen complexes; laggs Moorhouse: Sphagneto-Juncetum effusi, *Carex rostrata* facies

NVC code	*NVC* revised name	Description	Situation / conditions	Key examples
Small-sedge poor-fen vegetation of acid, oligotrophic flushes and soligenous mires on peats or peaty mineral soils				
M6	M6 Star sedge (*Carex echinata)–Sphagnum fallax / denticulatum* mire	Sparse cover of mixed sedges and rushes over a wet layer of *Sphagnum fallax* and *S. denticulatum* with sometimes prominent *Polytrichum commune*.	Base-poor groundwater outflow; water flow tracks. Slopes mean 5° (0–28°); acidic, pH 3.3–6.0)	Border Mires: laggs
M6a	*Carex echinata* sub-community	Very variable flush vegetation. *Carex echinata* (star sedge) generally the most abundant sedge.		Highlands: Sphagneto-Cariecetum subalpinum Wales: *Sphagnum–Carex nigra* mire
M6b	Common sedge *(Carex nigra)*–mat grass *(Nardus stricta)* sub-community	Rather more grassy vegetation with frequent *Nardus stricta* (mat grass) and *Juncus squarrosus* (heath rush) and with more *Carex panicea* (carnation sedge) and *C. nigra* (common sedge) in the sward.		Highlands: Sphagneto-Cariecetum subalpinum
M6c/d	Sharp flowered rush / soft rush *(Juncus acutiflorus /effusus)* sub-communities	Rather species-poor vegetation dominated by rushes and often forming patchworks with rush pasture (M23 *Juncus acutiflorus/effusus–Galium palustre* community).		Berwyn: *Juncus actiflorus/J effusus* flush bog Highlands & Moorhouse: Sphagneto-Juncetum effusi
New community [M6/M10]	Common sedge (*Carex nigra)*–lesser spearwort *(Ranunculus flammula)* community	New community which includes vegetation transitional to more base-rich flushes. Sometimes referred to as neutral or sub-neutral flush.		Wales, other locations in moorland fringes

NVC code	*NVC* revised name	Description	Situation / conditions	Key examples
[OXYCOCCO-SPHAGNETEA Br.-Bl. et Tüxen ex Westhoff *et al*. 1946]				
Wet heath and bog vegetation of acid, oligotrophic peats, permanently or winter-waterlogged in raised, blanket or valley mires and their surrounds				
Wet heath vegetation on drying deeper peats or winter-waterlogged peaty intergrades				
M15	M15 *deer grass (Trichohorum germanicaum)–cross-leaved heath (Erica tetralix)* community	Very variable community. *Molinia caerulea* (purple moor grass), *Trichophorum germanicum* (deer grass), *Erica tetralix* (cross leaved heath) and *Calluna vulgaris* (heather) are frequent throughout but their proportions can be very variable as well as the range of associates. A wide range of bryophytes form a patchy layer.	Occurs at a range of altitudes in cool and wet northern and western areas mean slope 8º (0–42°); mean annual precipitation >1200mm; at least 180 wet days or on areas of impeded drainage. peat depth <2m Better drained than M17	
M15a	Carnation sedge *(Carex panicea)* sub-community	Flushed heath and water flow tracks within wet heath. Rather variable vegetation. Some samples may represent forms of M6/M10, M10a or M14 embedded within heath, classified here due to inclusion of surrounding wet heath vegetation in samples.	Areas of water flow / flushing embedded within wet heath vegetation. pH recorded here can be quite high (up to pH7.4), suggesting telluric influence.	Samples from Devon, Shropshire, Cumbria, North York Moors are associated with water flow tracks channelling more base-rich water and are referable to other communities (with affinities to M6, M10 and M14).
M15b	Typical sub-community	This type is transitional to M17 and M18 *Sphagnum capillifolium* can be patchy within this community.	Deeper peats Moderately high water table	
M15c	Bilberry *(Vaccinium myrtillus)* sub-community	Dominated by mixtures of *Calluna vulgaris* (heather) and *Molinia caerulea* (purple moor grass) with small tussocks of *Nardus stricta* (mat grass), *Deschampsia flexuosa* (wavy hair grass) and other grasses. Pleurocarpous mosses become more frequent, and Sphagnum spp. less.		
Molinia dominated, species-poor vegetation	Basal community (Rodwell 2000).	Very species poor *Molinia* dominated vegetation.		Border Mires: rand, often mixtures of tussocky *Molinia* and *Eriophorum vaginatum*. Scotland: *Molinia–Myrica* mire of McVean and Ratcliffe.

NVC code	*NVC* revised name	Description	Situation / conditions	Key examples
M16	M16 cross-leaved heath (*Erica tetralix)–Sphagnum compactum* community	Very variable vegetation mainly occurring in east and south, generally on thinner peaty soils (wet heath vegetation).		
M16d	Heath rush (*Juncus squarrosus*) – *Dicranum scoparium* sub-community	Mainly in the north and east of Britain. *Erica tetralix* (cross-leaved heath), and *Trichophorum germanicum* (deer grass) are prominent in this sub-community. *Sphagnum compactum* and *S. tenellum* can be frequent together with a range of pleurocarpous mosses.		North & East; North York Moors – forms bulk of vegetation with H9, grades into M19 on Winter Hill peat soils
Bog vegetation on deeper, wetter peats in raised, blanket and valley mires				
M17	M17 deergrass–hare's tail cottongrass *(Eriophorum vaginatum)* community	Vegetation is dominated by mixtures of *Trichophorum germanicum* (deergrass)*, Molinia caerulea* (purple moor grass) and dwarf shrubs over a *Sphagnum*-rich ground layer. Can form a ridge / hummock component to *Rhynchosporion* hollows (M1 / M2). *Sphagnum papillosum* is a major dominant at water level. *E vaginatum* (hare's tail cottongrass) is not a dominant component of this community despite being in the *NVC* name.	Flat or gentle slopes (mean 4°, range 0–25°). Below 500m altitude (mean 300m). Mean annual precipitation >2000 mm; >160 wet days (180–200) Peat depth 2–4m High, stagnant water table Oligotrophic, pH 4	Border Mires: some 'flow' sites show similarities Wales: *Erica tetralix–Sphagnum* papillosum mire Devon & Cornwall: Dartmoor and Bodmin
M17a	Sundew (*Drosera rotundifolia*) – *Sphagnum* spp. sub-community	Extensive carpets of *Sphagnum* spp. particularly *S. papillosum*, with *Drosera* spp. (sundews). Areas with soligenous influence can include butterwort and black bog rush. The distinctive liverwort *Pleurozia purpurea* is strongly preferential. Ridge–pool and hummock–hollow patterns are frequently found in this type of vegetation.		Highlands: Trichophoreto-Eriophoretum typicum

NVC code	*NVC* revised name	Description	Situation / conditions	Key examples
M17b	*Cladonia* sub-community	*Calluna vulgaris* (heather) and *Trichophorum germanicum* (deergrass) tend to co-dominate. *Erica cinerea* (bell heather) can be prominent. *Sphagnum* layer is rather patchy and there is little development of hummock–hollow transitions. *Racomitrium lanuginosum* (woolly hair moss) is often prominent with frequent *Hypnum jutlandicum* (plait moss) and conspicuous lichens (*Cladonia* spp.)	Tops of hummocks – drier locations	Highlands: Trichophoreto-Eriophoretum typicum – Racomitrium-rich type
M17c	Heath rush *(Juncus squarrosus)*–*Rhytidiadelphus* sub-community	Transition to M19 – *Calluna vulgaris* (heather) and *Trichophorum* (deergrass) are dominant accompanied by a range of other dwarf shrubs *Vaccinium myrtillus* (bilberry), *V. vitis-idea* (cowberry) and *Empetrum nigrum* (crowberry). *Eriophorum vaginatum* (hare's tail cottongrass), *Juncus squarrosus* (heath rush) are also more abundant and grasses can be prominent, particularly *Nardus stricta* (mat grass) and *Deschampsia flexuosa* (wavy hair grass). Pleurocarpous mosses are conspicuous in the ground layer. *Sphagnum papillosum*, *S. capillifolium* and *S. subnitens* are patchy.	Higher altitude than other sub-communities; drier	Further east in Scotland: *Juncus squarrosus* bog
M18	Cross-leaved heath (*Erica tetralix)*–*Sphagnum papillosum* community	*Sphagnum* spp. are dominant with vascular plants forming a less prominent component of the vegetation (*Calluna vulgaris (heather), Erica tetralix (cross-leaved heath), Eriophorum angustifolium (common cottongrass)* and *E. vaginatum* (hare's tail cottongrass) are most common). Pronounced hummock–hollow complexes can occur in this type of vegetation. More extensive pool features can be assigned to bog pool communities.	Generally flat or slightly domed 0–2° Deep peat up to 10m or more Altitude, generally below 550m Mean annual precipitation 800–1200mm; 140–180 wet days Waterlogged, high, stagnant water table, pH 4	Border Mires, Scotland and Wales: central and rand parts of domed bogs Present in Pennines blanket mire landscapes as localised features (e.g. Ringinglow Bog in Peak District and Shackleborough Moss on Cotherstone Moor.)
M18a	*Sphagnum magellanicum*–bog rosemary *(Andromeda polifolia)* sub-community	Most distinct sub-community. Extensive areas of *Sphagnum papillosum* and *Sphagnum magellanicum*. *Andromeda polifolia* (bog rosemary) and *Vaccinium oxycoccos* (cranberry) are distinctive where they occur.	Domed ombrogenous surfaces – wettest areas; vegetation rafts Wetter conditions	Border Mires: several types in central parts of domed bogs Silver Flowe: Flat communities

***NVC* code**	***NVC* revised name**	**Description**	**Situation / conditions**	**Key examples**
M18b	Crowberry (*Empetrum nigrum*)–*Cladonia* spp. sub-community	*Sphagnum capillifolium* dominant with *S. papillosum* still frequent but not forming extensive areas. Vascular species have higher cover. Lichens (*Cladonia* spp.) can be abundant. May be analogous to M19b.	Domed ombrogenous surfaces drier areas – hummocks, towards rand Drier conditions (edges and erosion features)	Silver Flowe: medium & tall hummocks Moorhouse: Trichophoreto-Eriophoretum: Typical facies
M19	M19 heather (*Calluna vulgaris)*–cottongrass *(Eriophorum vaginatum)* community	Vegetation dominated by mixtures of *Calluna vulgaris* (heather) and *Eriophorum vaginatum* (hare's tail cottongrass). Only rarely shows the development of hummock hollow structure, but does often support a well-developed bryophyte flora. *Sphagnum* element not so rich or luxuriant as in M17 and M18, but the M19a sub-community is transitional in composition. Large areas have typically managed by rotational burning and sheep grazing. Erosion of the peat is common.	Found on flat or gently sloping (mean slope 4°, range 0–10°) ground at altitudes above 300m (mean altitude 550m): "high level plateaux and broad watersheds"; "occurs on broadly convex summits and slopes which shed water quite readily" Mean annual precipitation 1200–2000 mm; 160–200 wet days. Well humified peat, depth usually >2 m Can be surface-dry or oxidised in the summer. Surface often not water-logged. Oligotrophic pH<4	Border Mires: Extensive on hill slopes, and in degraded domed bogs Pennines (north and south) – extensive Berwyns – extensive
M19a	Cross-leaved heath (*Erica tetralix)* sub-community	Transitional to wetter bogs (e.g. M18). *Erica tetralix* (cross-leaved heath) can be abundant. May support 'lawn' species e.g. *Narthecium ossifragum* (bog asphodel), *Drosera rotundifolia* (round-leaved sundew). *Sphagnum* spp. are abundant in the ground layer – *Sphagnum capillifolium* and *S. papillosum* are most characteristic.	More western distribution; extends over flat or concave areas of relief where a high water table can be maintained. Mean altitude 400m. High water table	Berwyns: *Erica tetralix*–*Vaccinium oxycoccos* series, *Plagiothecium*–*Hylocomium* and *Racomitrium*–*Cladonia* noda. Moorhouse: Trichophoro-Eriophoretum
M19b	Crowberry (*Empetrum nigrum)* sub-community	*Rubus chamaemorus* (cloudberry) is characteristic in this sub-community together with *Empetrum nigrum* (crowberry) and *Vaccinium myrtillus* (bilberry).	Extensive in Pennines Mean altitude 600m	Moorhouse: Calluneto-Eriophoretum

***NVC* code**	***NVC* revised name**	**Description**	**Situation / conditions**	**Key examples**
M19c	Cowberry (*Vaccinium vitis-idea)–Hylocomium splendens* sub-community	Montane bog with many variants	Montane areas in Scottish highlands with outliers in Pennines, Cheviot and parts of Wales. Mean altitude 700m	Berwyns: *Juncus–Deschampsia* series Moorhouse & Scottish Highlands: Empetro-Eriophoretum
M20	M20 hare's tail cottongrass (*Eriophorum vaginatum)* community	Species-poor, impoverished vegetation dominated by tussocks of *Eriophorum vaginatum* (hare's tail cottongrass). Result of management treatment – grazing, burning, aerial pollution, draining.	Degraded forms of bog vegetation? Gentle slopes 0–10° 500–700m 1200–1600mm 160–200 wet days	Border Mires: recognised a dry and wet form in rand and lagg areas.
M20a	Species-poor sub-community	Very species poor.		South Pennines: widespread – derived from M19
M20b	Heather *(Calluna vulgaris)–Cladonia* spp. sub-community	Transitional to M19 with scattered dwarf shrubs		South Pennines: widespread – derived from M19
M21	M21 bog asphodel (*Narthecium ossifragum)–Sphagnum papillosum* community	Vegetation is dominated by areas of *Sphagnum* spp with scattered herbs and dwarf shrubs. Low amplitude relief (microtopography) compared to M17 and M18 – ridge–pool patterning is not a feature, but there are hummocks and hollows. Similar to M17 but *Eriophorum vaginatum* (hare's tail cottongrass) and *Trichophorum germanicum* (deergrass) are more scarce; *Andromeda polifolia* (bog rosemary) not generally present in this community.	Valley mires; peat depth 20–150cm Mostly <200m altitude, but can occur on higher ground in Dartmoor & Exmoor Mean precipitation <1200mm <160 wet days; Saturated surface pH3.5–4.5	Important sites in New Forest, Dorset, Cumbria. Probably under-recorded in blanket bog complexes in Scotland (Averis *et al*, 2004).
M21a	White beak sedge *(Rhynchospora alba)–Sphagnum denticulatum* sub-community	Very mixed mosaic of *Sphagnum* patches with *Rhynchospora alba* (white beak sedge) frequent. Liverworts are abundant.		

NVC code	*NVC* revised name	Description	Situation / conditions	Key examples
M21b	Cranberry *(Vaccinium oxycoccos)* – *Sphagnum fallax* sub-community	*Sphagnum papillosum* is more patchy in occurrence, with *S. fallax* more prominent. *Rhynchospora alba* (white beak sedge) is scarce and *Vaccinium oxycoccos* (cranberry) is more abundant in this sub-community.		
Dry heath				
H9	*Heather (Calluna vulgaris)–Wavy hair grass (Deschampsia flexuosa)* community	Dominated by *Calluna vulgaris*; usually managed by rotational burning and sheep grazing.	Low to moderate altitudes; acid and impoverished free-draining soils, including drained deep peat which has been subjected to drainage and grazing.	Pennines
H12	*Heather (Calluna vulgaris)–bilberry (Vaccinium myrtillus)* heath	Similar to H9, but more varied shrub layer including frequent *Vaccinium myrtillus* (bilberry).	Sub-montane zone 200–600m altitude. Moist, acidic free-draining soils.	Pennines

Table 10. Constant species of *NVC* mire and heathland plant communities.

(Dark grey = constant; light grey = additional sub-community constant species. Based on Rodwell, 1991). Community names are given in Table 9.

		NVC Community code														
NVC constant species and naming species		M1	M2	M3	M4	M6	M15	M16d	M17	M18	M19	M20	M21	M25	H9	H12
Species name	Common name															
Dwarf shrubs																
Andromeda polifolia	bog rosemary		▒							▒						
Calluna vulgaris	heather						■	■	■	■	■	▒	■		■	■
Empetrum nigrum	crowberry									▒	▒					
Erica tetralix	Cross-leaved heath		■					■	■	■	▒		■			
Vaccinium myrtillus	bilberry						■									■
Vaccinium oxycoccos	cranberry															
Vaccinium vitis-idea	cowberry										▒					
Other vascular plants																
Agrostis canina	bent grass					■										
Carex echinata	star sedge					■										
Carex nigra	common sedge					▒										
Carex rostrata	bottle sedge				■											
Deschampsia flexuosa	wavy hair grass														■	■
Drosera rotundifolia	round-leaved sundew		■						▒				■			
Eriophorum angustifolium	common cotton grass	■	■	■					■	■	■	■	■			
Eriophorum vaginatum	hare's tail cottongrass								■	■	■	■				
Juncus acutiflorus	sharp-flowered rush					▒										
Juncus effusus	soft rush					▒										
Juncus squarrosus	heath rush							▒	▒							
Menyanthes trifoliata	bogbean	■														
Molinia caerulea	purple moor grass						■	■	■				■	■		
Nardus stricta	mat grass					▒										
Narthecium ossifragum	bog asphodel								■				■			

		NVC Community code														
NVC constant species and naming species		M1	M2	M3	M4	M6	M15	M16d	M17	M18	M19	M20	M21	M25	H9	H12
Species name	Common name															
Potentilla erecta	tormentil															
Rhynchospora alba	white beak sedge															
Rubus chamaemorus	cloudberry															
Trichophorum germanicum	deergrass															
Bryophytes and lichens																
Dicranum scoparium																
Hypnum jutlandicum																
Pleurozium schreberi																
Polytrichum commune																
Rhytidiadelphus loreus																
Sphagnum auriculatum																
Sphagnum capillifolium																
Sphagnum compactum																
Sphagnum cuspidatum																
Sphagnum recurvum																
Sphagnum magellanicum																
Sphagnum papillosum																
Sphagnum tenellum																
Cladonia spp.																

7.1.3 Additional or modified NVC units

According to Rodwell (1991), the intention of the *National Vegetation Classification* was not that it should be seen as an *ex cathedra* statement, set in tablets of stone, but that it should be open to modification. However, as the tablets provided were both rather expensive and quite difficult to digest, there has been a tendency to 'leave well alone', even though various workers have recognised deficiencies (for example, in minerotrophic mires in lowland England and Wales (Wheeler *et al.*, 2009)).

Rodwell *et al.* (2000) and JNCC (2011) have proposed some possible amendments to the *NVC* scheme, including some that are relevant to upland peatlands. Other modifications could also be suggested and a need for a better updating mechanism for *NVC* can be identified, though it is recognised that this should only be done carefully, cautiously and in a well-controlled manner.

Menyanthes trifoliata *bog pools*

Some pools in apparently ombrotrophic mires can have much emergent *Menyanthes trifoliata* forming what could be regarded as either aquatic vegetation or a very open swamp. Other plant species are scarce, consisting mainly of small amounts of aquatic *Sphagnum cuspidatum* and *S. denticulatum*. This vegetation does not really fit any existing *NVC* category. The pools in question are often some 5–100 square metres in area, with water 30–100 cm deep, sometimes deeper, and are thus usually larger and deeper than pools with M1 and M2 vegetation. They are locally frequent in some of the bogs in north and west Scotland and are identified among the 'Drought-sensitive pools' (A3) and 'Permanent pools' (A4) in the Aquatic (A) part of the classification of bog microtopes and vegetation types of Lindsay (1995). 11 relevés of such vegetation are available from north-west Sutherland (A.B.G. Averis, unpublished data) (Rodwell 2000). Boatman (1983) and others have speculated on possible reasons for the absence of abundant *Sphagnum* in such pools.

Species-poor stands of Molinia caerulea

In both ombrotrophic and minerotrophic situations, there can be a tendency for swards of *Molinietalia* vegetation to become strongly dominated by dense, tussocky *Molinia caerulea*, especially where former grazing or mowing has been abandoned or where there has been eutrophication of ground waters, atmospheric N deposition or drying of the peats. Such vegetation is hard to place within the *NVC* scheme because of the increasingly poor representation of smaller associates and it could be regarded as what in Continental Europe might be called a 'basal community' of the Order (Rodwell *et al.*, 2000).

Wheeler (1980) had previously described this type of vegetation as a dominance-type based on *Molinia* and, following the notation of Tansley (1939) (who recognised units based on dominance rather than overall floristics), referred to it as a '*Molinia* sociation'. Just as the lineage of patches of species-poor *Molinieta* is various and variable, so too are the habitat conditions associated with them and they are difficult to characterise – whilst extreme *Molinia* dominance is often associated with drying surfaces, it can also occur in surprisingly 'wet' conditions. A similar comment can also be made of the (related) M25 community, which is a broad and unwieldy unit which occupies a wide range of habitat conditions. Any attempt to characterise the conditions of M25 better should be based upon a re-examination and re-analysis of the character and composition of vegetation currently encompassed within it.

Carex nigra–Ranunculus flammula *mire*

In this type of minerotrophic mire vegetation, a variety of small sedges are abundant to dominant, with a low cover of associates such as *Ranunculus flammula* (lesser spearwort), *R. acris* (meadow buttercup), *Potentilla erecta* (tormentil), *Viola palustris* (marsh violet), *Juncus articulatus* (jointed rush), *J. bulbosus* (bulbous rush), *Molinia caerulea* (purple moor grass), *Dactylorhiza maculata* (heath spotted orchid), *Succisa pratensis* (devil's-bit scabious), *Holcus lanatus* (Yorkshire fog), *Anthoxanthum odoratum* (sweet vernal grass), and the bryophytes *Calliergon cuspidatum and Pellia epiphylla*, whilst

Sphagnum warnstorfii, S. contortum and *S. teres* are locally prominent. Some stands are strongly dominated by a dense sward of *Carex nigra* (common sedge) 30–40 cm tall. Other stands have a more open cover of small sedges, with mixtures of *Carex nigra, C. panicea* (carnation sedge), *C. demissa* (common yellow sedge) and *C. echinata* (star sedge). There is a superficial resemblance to both M6 *Carex–Sphagnum* and M10 *Carex–Pinguicula* mire communities and, in terms of the associated species, the vegetation is somewhat intermediate between these two. Some examples also have affinities to M26 (*Molinia caerulea–Crepis paludosa* mire). This type of vegetation typically occupies small, damp, soligenous depressions among grassland and heath at low altitudes in western parts of Britain, becoming frequent in the western Highlands. It is usually grazed at medium to high intensity, and most stands appear to be grazed derivatives of M15 *Scirpus–Erica* wet heath or M25 *Molinia–Potentilla* mire. Relevés are available from Scotland (Averis & Averis 1995, 1996 and recent unpublished data; Cooper & Mackintosh, 1996 (in Rodwell, 2000) and Wales (M. Yeo, unpublished data). Similar vegetation in Ireland has been described as a Carici nigrae–Juncetum articulati Br.-Bl. & Tx. 1952, sometimes placed in the Caricion nigrae, sometimes (Ó Críodáin & Doyle 1994) in the Caricion davallianae (Rodwell et al. 2000). Jones (1973) had previously described what appears to be this same vegetation type in Upper Teesdale as part of her Violo-Epilobietum palustrii, and gave detailed consideration of its syntaxonomy and to the occurrence of related vegetation elsewhere in Britain.

7.1.4 Surface patterning and microtopographical zonation

Whilst examples of bog vegetation are often rather similar floristically, its appearance can be visually quite varied due to a localised pre-dominance of particular species in the vegetation, for example dwarf shrubs (e.g. *Calluna vulgaris, Erica tetralix*), sedges and grasses (e.g. *Eriophorum vaginatum, Trichophorum germanicum, Molinia caerulea*) and bryophytes (e.g. *Sphagnum* spp. *Racomitrium lanuginosum*). Such vegetation can be rather uniform structurally, but in some situations the presence of various hydrotopographical and microtopographical features can much alter its appearance and pools, water flow tracks, ridges and hummocks can lead to very distinctive small scale patterning (Lindsay, 1995). Eroded areas are also sometimes distinctive features with various patterns of haggs, pans and gullies present on some sites (Tallis, 1985 and 1998).

Plant species show a variable range of specificity of association with particular habitat conditions such as wetness, though this is sometimes context-dependent. Some are quite tightly associated with particular conditions and can be useful proxy indicators of these (Wheeler & Shaw, 1995c; Bellamy *et al.,* 2012). Several studies on *Sphagnum* have demonstrated the ecological range of particular species: for example *Sphagnum capillifolium* is able to tolerate relatively dry conditions because its shoots retain more water, and this species can be associated with conditions where the vegetation surface is frequently unsaturated. Other species e.g. *Sphagnum cuspidatum*, 'prefer' more frequent waterlogging, though they may still be able to tolerate considerable episodes of dehydration (Hayward & Clymo, 1983). In vegetation with pools, ridges, hollows and hummocks, this niche separation can lead to the formation of vegetation mosaics at various scales, and such structural diversity provides a range of habitat niches for other species in bog ecosystems, particularly invertebrates and birds (Thom *et al*., 2019).

Two main types of surface patterning have been identified in bogs: ridge–pool systems and hummock–hollow complexes (Figure 9). Ridge–pool systems are largely restricted to the north and west of Scotland, where they can occur together with hummock–hollow complexes. On the Silver Flowe (Galloway) both types were associated with the 'wetter' and 'flatter' parts of the mires where, according to Boatman (1983), both were encompassed within the *Trichophoreto-Eriophoretum* vegetation of McVean & Ratcliffe, (1962) (now part of the M17 community). In other parts of Scotland, and in England and Wales, only hummock–hollow complexes occur, associated again with the wetter, flatter parts of mires, sometimes within topographical hollows. These generally occur within examples of M18 and M19 vegetation.

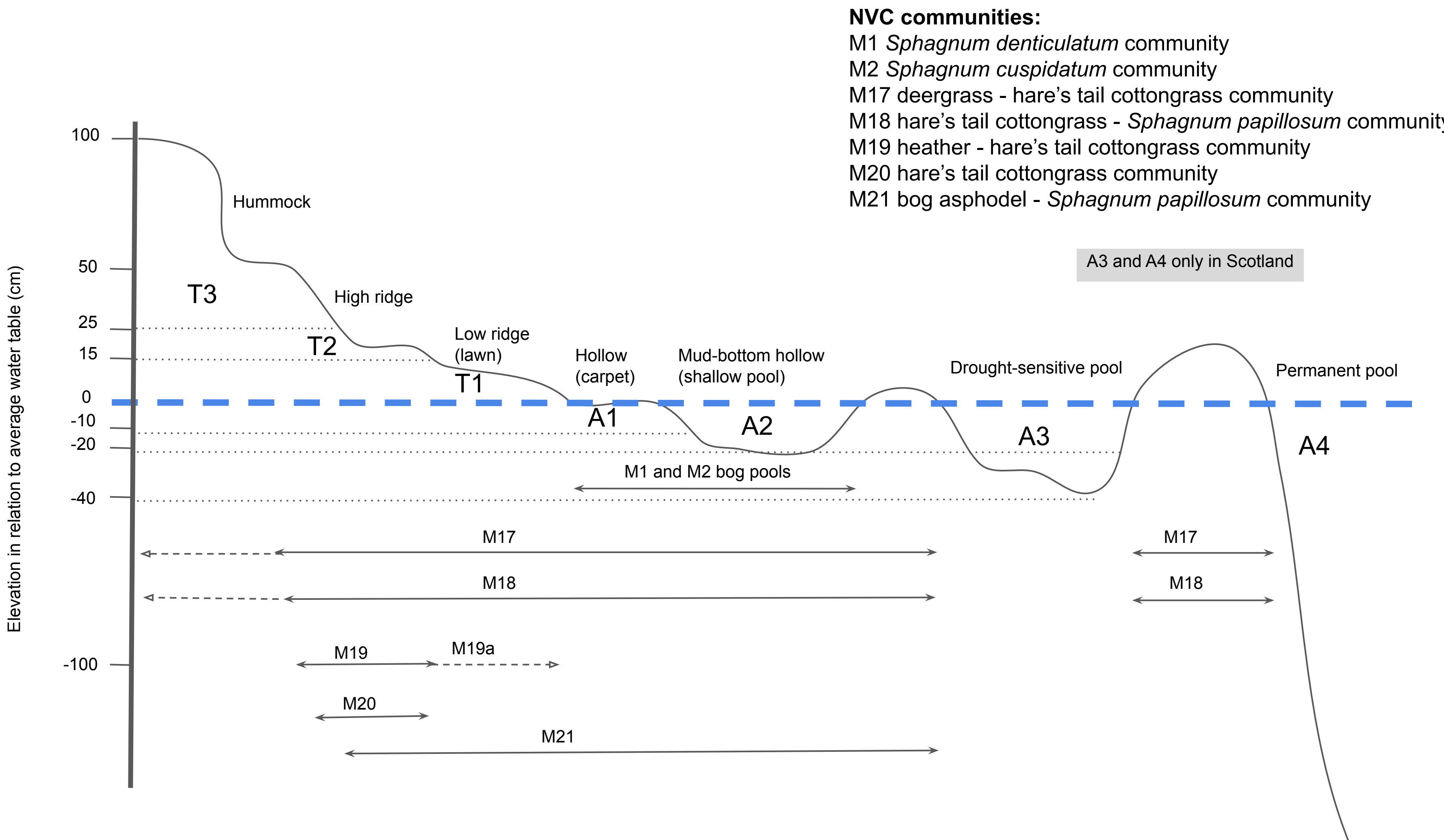


Figure 9. Bog habitat microforms and their relationship to NVC communities.
Microforms present on bog vegetation surfaces are shown as terrestrial (T) and aquatic (A) zones relative to the average water table (based on Lindsay 2010), and related to National Vegetation Classification (NVC) plant communities (based on descriptions in Rodwell 1991 and Averis *et al.* 2004). Solid lines show main zones present in different NVC communities; dashed lines show more extreme variants. The deeper pools (A3 and A4) are found only in Scotland, are often sparsely vegetated and were not represented in the published NVC accounts. A new NVC community (Menyanthes pool) has been suggested for the distinctive vegetation supported by these pools (Rodwell 2011).

Sampling 'Patterned Surfaces'

In addition to ridge–pool and hummock–hollow complexes, vegetation mosaics of other kinds occur widely in mires, associated with various surface tumps and tussocks of vegetation. They present a conceptual question to the stand-based sampling techniques associated with *NVC* surveys, for it can often be observed that individual components of vegetation mosaics sometimes correspond to different *NVC* communities which, if they were of greater surface extent, would almost certainly be sampled separately. It may be tempting therefore, to suggest that the different components of a mosaic, such as a hummock–hollow complex, should be sampled separately. The main difficulty with this is that the identification of the limits of the components within an intimate mosaic is often difficult and arbitrary, and in some instances may be tantamount to sampling a hummock of a single species. Moreover, unlike those vegetation mosaics which reflect an underlying mosaic of contrasting conditions (such as a patterned limestone surface), vegetation patterns on mires are generally part of the same surface, from which they have all developed. From this perspective the vertical microtopography of a mire surface is conceptually more akin to the vertical structure of a woodland, in which a number of stratal layers can be identified, all of which have originated from essentially the same soil surface.

The general approach adopted by *NVC* surveyors to sampling surface-patterned mires (which includes, for example, *Schoenus nigricans* (black bog-rush) fens as well as hummock–hollow complexes) has been to recognise the difficulty of subdividing them into their different components and to sample them as a composite unit (with annotations concerning its structure if required). This does not preclude the separate sampling of component elements of the mosaic where they form suitably large and uniform surfaces, and there is no reason why such samples cannot be analysed together with those from a mosaic in the identification of vegetation units. A benefit of this approach is that it avoids, or at least reduces, the difficulties of making a largely arbitrary and subjective separation of intimately linked components within a mosaic. Another benefit of sampling, say, a hummock–hollow complex as a single unit is that it reflects better the known communality of the various microtopographical components of the surface, their physical interactions, linked ontogenies and ecohydrological feedbacks (Barber, 1981; Belyea & Clymo, 2001).

Perhaps the main difficulty in dealing with mosaics is not that of describing them using the standard techniques of *NVC* survey, but of relating their surface to environmental conditions, as the surfaces of the different microtopographical components are likely to be at different levels relative to the 'water table'. Of course, the actual level of the water table (and associated capillary fringe) may also vary in response to its microtopographical context. This can mean that every small-scale component may each have different 'optimal' and actual water levels, and this can provide a particular constraint to those who wish to identify appropriate 'water levels' to conserve or model such systems. In addition, the capacity of many vascular plants to root at a wide range of depths means that the relationship between their occurrence across different levels of a mosaic and the position of the water table may itself be complicated and uncertain.

Lindsay *et al.* (1988) have used a detailed sampling protocol to characterise variation in the microtopographical characteristics of mires, and where detailed information on these is required specifically it is appropriate. However, in our view, just as with the sampling of separate layers within woodland, this synusial approach is best seen as an adjunct to a 'standard' *NVC* sampling of mire surfaces, not as an alternative.

7.1.5 'Biogeographical' units

Four broad categories of bog vegetation were described by Thom *et al.* (2019, p26), which relate to the EUNIS classification of mire habitats (Section 7.1.6): Western Blanket Bog, High level / Eastern Blanket Bog, Lowland Bog and Damaged Bog (Table 11). The first three of these are essentially biogeographical units; the fourth relates to surfaces that have been to some extent modified ('damaged') and is inconsistent with the others, as 'damaged' units can occur in each of the other three, and with different vegetational expressions. The term 'lowland' in this typology is also misleading.

This tripartite subdivision is simple to apply, but is also coarse and has limited information content, particularly when compared with the units of communities and sub-communities of the *NVC.* It is unlikely to provide a satisfactory basis for understanding the composition and ecohydrological properties and processes within upland peatlands and their vegetation units, but it does indicate the broad geographical distribution of the three identified types.

Table 11. Broad vegetation categories found on UK blanket bogs (based on Thom *et al*., 2019).

(The apparent *NVC* units contained within each category have been suggested by us.)

Vegetation category	Description and suggested *NVC* communities	Environment	Location / human impacts
Western Blanket Bog	Networks of ridges and pools. Ridges are characterised by a sward of *Trichophorum germanicum* (deergrass) and *Molinia caerulea* over ground layer of *Sphagnum capillifolium* and *S. papillosum* with scattered dwarf shrubs. Wetter areas have *Narthecium ossifragum* (bog asphodel) and there can be trails of *Schoenus nigricans* (black bog rush) in western-most locations. M17, M1, M2, deep pools [M21?]	Hyper-oceanic Rainfall >2000mm Wet days >200 Altitude <500m	
High level / Eastern Blanket Bog	*Calluna vulgaris* (heather)–*Eriophorum vaginatum* (hare's tail cottongrass) co-dominant. M19, M20, M2, M3	Higher altitudes Rainfall 1200–2000mm Wet days 160–200	Often managed by rotational burning and grazing.
Lowland Bog	Carpets of *Sphagnum* with *Erica tetralix*, *Eriophorum* spp. *Trichophorum germanicum* and pools with *S. cuspidatum.* M18, M2	Flat areas / domed surfaces	Found on extensive raised bog systems, and over saddles and deep depressions. Not necessarily 'lowland'
Damaged Bog	Various heath and wet heath communities are found over deep peat deposits. H9, M15, M25, Bare peat Erosion features e.g. gullying	Lowered water tables Bare peat	Drainage, burning, peat cutting, afforestation, atmospheric pollution.

7.1.6 European classifications and designations

Because of their globally restricted distribution and conservation importance, all types of blanket bogs supporting 'active' bog vegetation are recognised as habitats of international importance and are included in the list of EC Annex 1 habitats – H7130 Blanket Bogs[1]. The term 'active' is unfortunate and ambiguous, as workers have attached different meanings to it (Tallis, 1998). However, in the JNCC habitat description 'Active' is defined as:

> "Supporting a significant area of vegetation that is normally peat-forming. Typical species include the important peat-forming species, such as bog-mosses Sphagnum spp. and cotton-grasses Eriophorum spp., or purple moor-grass Molinia caerulea in certain

[1] https://sac.jncc.gov.uk/habitat/H7130/distribution

> circumstances, together with heather Calluna vulgaris and other ericaceous species. Thus sites, particularly those at higher altitude, characterised by extensive erosion features, may still be classed as 'active' if they otherwise support extensive areas of typical bog vegetation, and especially if the erosion gullies show signs of recolonisation." (JNCC *https://sac.jncc.gov.uk/habitat/H7130/*).

The incorporation into this definition of the criterion "normally peat forming" is questionable, as the measurement of actual net or gross peat 'formation' is usually difficult to achieve in the short term, but the statement provided suggests that the 'real' definition is actually vegetational, based on the occurrence of 'typical bog vegetation', even in erosional contexts. What constitutes 'typical bog vegetation' or, perhaps more pertinently what does not, is not made clear and it is therefore not evident how an area of 'active blanket bog' is to be distinguished from any other sort of (presumably 'inactive'?) blanket bog which also supports 'typical bog vegetation' (see Section 7.1.1).

Blanket bog complexes or landscapes are likely also to support some other EC Annex 1 habitats, nested within the main broad habitat. These include dystrophic pools – particularly in some Scottish examples – and Rhynchosporion hollows.

In the EUNIS classification of European 'habitats' (Davies *et al*, 2004), four main sub-categories of blanket bog are recognised: eroded bogs, boreal bogs and two 'intact' types that are found in the UK – hyper-oceanic low altitude blanket bogs and montane blanket bogs. Within these two latter sub-categories there are several sub-types that are common to both, for example the sub-components D1.216 (of hyperoceanic bogs) and D1.227 (of montane bogs) are both complexes with hollows and pools, and the descriptions are identical except for the qualifier that pools and hollows are less prominent in montane blanket bogs than in the hyper-oceanic blanket bogs. These sub-types and component features can be related to some *NVC* communities and sub-communities and to features such as hummock–hollow pool (T3–A2) complexes.

It should be noted that the EUNIS classification is not so much an identification of specific, discrete 'habitats' as a melange of variable and partly overlapping units that are differently based on a range of criteria. These include landscape topography and vegetation physiognomy, and many of the units consist essentially of bundles of different types of vegetation than may grow together in the same broad situation. The nature of the 'habitats' that they occupy is often not identified except in the broadest of terms, and some of the units identified appear to encompass a considerable actual habitat range. Although European in scope, the lack of poor characterisation of many of the units, their overlapping character and the top-down nature of the classification, means that it is often difficult to identify the affinities between different units, and particularly the affinities between what appear to be parallel units inserted into different sectors of the classification. Overall, it is difficult to see what real value this scheme has in the examination and description of British mires, particularly in the development of any understanding of their ecohydrological processes and regimes, and the 'tolerances' of distinctive vegetation-types. The EUNIS classification shares and reflects many of the incongruities and inadequacies of the CORINE system that has been used for the identification of 'EC Habitats'. We understand that, in an attempt to resolve these difficulties, for their effective use in Britain the 'EC Habitats' categories were transposed, in some instances rather uncomfortably, into *NVC* communities. It seems likely that a similar transposition would be needed for the EUNIS units, in which case, despite its limitations, the *National Vegetation Classification* would be better, and more simply, used directly.

7.2 Mire habitat conditions

The investigations in the current project suggest that environmental data, particularly data that can be linked to vegetation types, is generally sparse for upland peatland habitats.

In some early surveys of peatland vegetation, the range of linked environmental data reported was generally small. In Scotland, McVean & Ratcliffe (1962) and Birks (1973) provided slope, aspect and altitude data for their vegetation samples. Birse & Robertson (1976) also provided some soil data (including soil pH) for some of their samples, though these were primarily lowland. More recently, some *NVC* surveys have reported pH and conductivity data for their samples (*e.g.* O'Reilly, 2019), while others have not, probably depending upon the terms of their contracts. Jerram (2014) apparently recorded pH and conductivity for each of his mire samples from the Forest of Bowland, but these data are not presented in his report.

Over the period 1985–1989 BD Wheeler and SC Shaw made a comparative survey of a wide range of habitat conditions related to specific plant community-types in lowland minerotrophic mires in Britain (Shaw & Wheeler, 1991). This was subsequently supplemented with additional data, especially from lowland ombrogenous mires, and in conjunction with some hydrogeological assessments formed the basis for the Wetland Framework project (Wheeler *et al*., 2009) and for the relevant part of the Ecohydrological Guidelines (Wheeler *et al.*, 2004). These investigations were restricted to lowland mires and were of limited relevance to upland mires, especially in England and Wales where the segregation of 'lowland' from 'upland' is usually clear, except perhaps insofar as it is possible to extrapolate from lowland data to upland examples of the same community. The subsequent Wetland Framework project was restricted to England and Wales, but the original Habitat Conditions project also included a number of Scottish sites, including some from (minerotrophic) examples from north and north-west Scotland, where there is some tendency for 'upland' habitats to occur in 'lowland' contexts.

As far as is known, there is no readily available dataset for habitat conditions in upland mires, particularly ombrogenous examples, comparable to that which was available for the Wetland Framework project. In addition, although there are a number of published studies on various hydrological aspects of upland mires, the information they provide is often highly processed, and it is not possible to extract from them underlying base-line data such as would be relevant to determining 'water conditions' relevant to the vegetation, though such data may well exist in unpublished form. A number of sets of little-processed hydrological data are available from various studies, but these have not necessarily been related to the vegetation represented at the site of dipwells etc (e.g. water level data from Waun Figen Felen in the Brecon Beacons, and water level data from Scottish peatland restoration projects).

Some lowland Scottish samples included within Wheeler & Shaw's original Habitat Conditions project, all apparently minerotrophic in character but possibly relevant to the present project, have been tabulated (See Annexe 5). Several caveats should be noted:

1. The table does not include all of the Scottish sites for which data are available, only those which seem likely to be most relevant to the habitats considered in this project.
2. The site names given are just labels, adopted in landscapes in which very often other named features are lacking. In particular, samples labelled after a loch were not necessarily recorded from the loch or even its close vicinity. For example, the mire referred to as 'Little Loch Roag' occupies a shallow trough separated by some 350 m distance and 40 m altitude from the eponymous loch.
3. In some instances, the *NVC* communities to which the samples relate are questionable. Two sets of community codes are given: one is the community to which Wheeler & Shaw considered the vegetation most closely to correspond *at the time of investigation* (which was before publication of the relevant *NVC* volume and was based partly on an independent TWINSPAN analysis of the data set). The other is the highest MATCH value of the sub-communities, which was derived and applied subsequently. In some instances there is a considerable mis-match between these two assessments. This may be attributed, at least in part, to the poor representation of Scottish examples of some of these vegetation types in the *NVC* analyses, but also to the rather idiosyncratic character of some of them. It should be noted in particular that both Wheeler & Shaw and MATCH assessed some samples as belonging to M14 and M21, neither of which had been mapped in Scotland on the distribution maps provided for these communities by Rodwell (1991) (and which in probable consequence may have been under-recorded in this region, or ignored, by subsequent surveyors).

It is important to recognise that where the identities of some communities are hard to characterise and delimit, there may be little point in trying to attach estimates of meaningful habitat conditions to them, except as broad assessments.

8. Restoration potential of damaged blanket bogs

8.1 Perceptions and causes of 'damage'

A large proportion of the blanket bog resource in Britain has been damaged in one way or another, and as a consequence the cover of bog vegetation has in many places become degraded. Drainage, burning, atmospheric pollution, over-grazing and afforestation can significantly affect the vegetation of bogs, and many peatland sites have been subjected to combinations of these (e.g. Tallis *et al.*, 1997). The general effects of such activities have been to reduce the microtopographical variation present on the bog surface and to reduce floristic diversity, with sensitive species such as bryophytes being particularly affected. Blanket bog that has been little affected by drainage and that has a more or less continuous cover of 'blanket bog vegetation', even if it is dominated by very species-poor vegetation (e.g. M19 and M20), is often referred to as 'intact' bog (e.g. Shepherd *et al.*, 2013).

The flattest and wettest parts of 'undamaged' bogs often support hummock–hollow microforms and structurally diverse vegetation types (including M17, M18 plant communities). In some regions, particularly in the north and west of Scotland, extensive pool and ridge–pool complexes are also very often present. Damage to such surfaces can have a profound effect upon their vegetation, generally causing a reduction in the extent of *Sphagnum*-filled hollows and an increase in vascular species, particularly dwarf shrubs, cotton-grasses, and purple moor-grass.

On peat-covered hill slopes the vegetation is often more uniform structurally, with vascular species (particularly dwarf shrubs, cotton-grasses and deergrass) more prominent and a more scattered bryophyte component, and with species characteristic of drier micro-habitats (*e.g*. *Sphagnum capillifolium*) more abundant, than is the case on flatter, wetter surfaces. Such vegetation (typically M19 and M20 plant communities) may be indicative of damage to the bog surface (*e.g.* through burning and drainage) and change from former examples of M17 or M18, but it can also be a natural constituent of little-damaged bogs. The same can be true, for example, of wet heath vegetation (usually M15), especially on very shallow peats. *Molinia caerulea* (purple moor-grass) is a typical component of M15, M17, M18 and M21 but can become overwhelmingly dominant on some 'damaged' bog surfaces; *Eriophorum vaginatum* (hare's-tail cottongrass) likewise is a characteristic component of M18 and M19 but can become dominant in response to 'damage' (leading to the development of M20 vegetation). In areas where the surface peat has dried out extensively, species-poor, heather-dominated vegetation (e.g. H9 and H12) can be abundant, sometimes with dense stands of bracken. The relationships between vegetation types found on healthy and degraded bogs are summarised in Figure 5.

Table 12 lists plant species regarded as being characteristic of 'undamaged' bog surfaces ('bog species'), and those used as indicator species in generic favourable condition tables.

Erosion features are commonly found in blanket bog landscapes; a review of available evidence by Shepherd *et al.* (2013) concluded that gullies are natural features of undamaged peatlands, but that gully erosion of blanket peatlands in northern England accelerated during the late 18th and early 19th centuries. Several studies have shown that bogs are dynamic systems with phases of erosion and re-deposition (e.g. Crowe, Evans & Allott, 2008). Erosion features are generally classified into gully erosion and micro-erosion, and most monitoring protocols require workers to locate areas of re-growth of bog species in eroded areas and actively eroding areas, and then assess the balance of erosion and spontaneous re-vegetation (IUCN 2014, *et seq.*). Ombrogenous peatlands are potentially an important carbon sink and the prevention of carbon loss from peatlands, and the identification of ecohydrological conditions that are most appropriate for carbon storage, is seen as a major conservation priority, as is the reduction of runoff and peak flow rates, which are believed to have an impact upon downstream flood risk (e.g. Alderson *et al.*, 2019). Restoration of 'intact' bog vegetation upon eroded and drained sites, through programmes of grip and gully blocking and re-vegetation, is the aim of several catchment scale programmes in England (e.g. United Utilities 'Sustainable Catchment Management Programme'). Several studies of restoration areas have shown that carbon loss (in the form of sediment loss and water colour) from upland peatlands is reduced, and in storm conditions lag times are increased, in restored sub-catchments compared to un-restored sub-catchments (Shepherd *et al*., 2013).

Holden *et al.* (2013) examined the effects of managed burning and wildfires upon near-surface hydraulic conductivity and macropore flow, and found evidence that burning reduces the role of macropores in water flow in the upper peat layers, and reduces the hydraulic conductivity of the peat, which could increase leaching of dissolved organic carbon into watercourses. These effects may be the result of drying, causing consolidation of the bare peat, and fine sediment, mobilised by overland flow after fires, blocking macropore entrances. Their data suggested there was little difference between managed burns and wildfires, and that recovery from these effects increased with time since burning, such that there were no significant differences in hydraulic conductivity and macropore flow between unburned sites and areas burned more than about 20 years before.

8.2 Potential for restoration of damaged blanket bog

Much work has been done in recent years to assess the potential for restoration or rehabilitation of damaged blanket bog. For example, monitoring the effects of deforestation on blanket peatland in Ireland, Murphy (2008) found that, after felling, younger plantations (13–20 years old) had ground flora with more similarity to intact bog than did older plantations (25–35 years old). Similarly, a 4-year study of forestry plantations felled at different ages in Kintyre, Scotland (Sheridan, 2008) found that younger Sitka spruce plantations had ground layer vegetation that was more similar to the M19 blanket bog community than beneath older plantations. A catchment scale monitoring study (Anderson *et al.*, 2011) noted that grip blocking, grazing reductions and control of burning was followed by increases in *Sphagnum* abundance in a Forest of Bowland catchment. A comparison of rates of runoff across different upland vegetation types in the North Pennines (Holden *et al.*, 2008) found that overland flow was consistently and significantly higher over bare peat than over vegetated surfaces, and flow over *Sphagnum*-dominated vegetation was significantly lower than for other vegetation types.

Recent work by Alderson *et al*. (2019) on five restoration areas in the southern Pennines over a 15-year period found that proportion of vegetation cover, runoff, and sediment yield responded very rapidly to restoration, and that establishment of vegetation led to an increase in surface 'roughness' which was linked to reductions in runoff and concentrations of particulate organic carbon.

Several long-term monitoring studies of water tables in restoration areas have shown a recovery of water table where ditches have been blocked and where bare peat has been revegetated (e.g. Wallage & Holden, 2011), and of increases in indicator species of wet *Sphagnum* bog (Bellamy *et al.,* 2012), although recovery of species is generally slow (in the order of decades). However, a five-year study by Green *et al.* (2017) at a blanket bog site in the Migneint region of north Wales found no evidence that blocking shallow ditches led to an increase in water table levels in the peat between the ditches, nor a change in abundance of cotton-grasses or *Sphagnum* species, though this may have been the result of previous peat subsidence around the ditches altering the surface configuration of the peatland.

Studies such as Holden *et al.* (2008), which have shown that increased cover of *Sphagnum* bog-mosses can increase surface 'roughness' and reduce rates of runoff, have led to a focus of restoration work on increasing the cover and abundance of *Sphagnum* on blanket bogs. Many recent projects have attempted to plug-plant *Sphagnum* or inoculate bare peat surfaces with *Sphagnum* 'beads', but the establishment of transplanted *Sphagnum* has often not been very successful, possibly because it is reliant on suitably high and constant moisture content of the peat surface. It also seems likely that in some instances, in the drive to 'restore' a *Sphagnum* surface, little consideration has been given to the appropriateness of particular topographical locations and starting conditions to the likely success of achieving this objective. Some ombrogenous surfaces subject to '*Sphagnum* restoration' initiatives may not naturally have supported much, or any, significant *Sphagnum* cover.

8.3 Investigating and monitoring blanket bog restoration

Many hydrological studies have focused on degraded blanket bog sites with the aim of using restoration to prevent loss of peat and to regulate flow in downstream water courses. Investigations into dissolved organic carbon, surface roughness, overland flow *etc*. have often been related to informal land-cover units, which sometimes, but do not always, correspond to *NVC* plant communities, or have focussed upon particular species mixtures. Information linking simple stand-level observations of water table to the vegetation present at each sampling point may well exist, but are not usually reproduced in published accounts.

Permanent quadrats are sometimes used for monitoring bog restoration, but this is not always the case, and if vegetation is recorded it is often limited to dominant species e.g. *Calluna vulgaris, Eriophorum vaginatum*, or to dominant species groups such as dwarf shrubs, graminoids, *Sphagnum, etc.* If not already part of a monitoring protocol, it is recommended that an *NVC*-compatible quadrat[1] is recorded next to water level monitoring points as part of ongoing bog restoration projects. This would help to improve both understanding of the vegetation types currently present on degraded bogs and the effects of the restoration processes upon bog vegetation.

The availability of linked environmental data and vegetation data from specific sites, both from undamaged blanket mires and degraded sites undergoing restoration, is critical to better understand how restoration of hydrological and hydrochemical processes influence vegetation restoration.

[1] For example a 2m x 2m quadrat recording all plant species and their % cover, with additional records of species present within the surrounding 10m x 10m, recorded as 'plusses'.

Table 12. Plant species that are characteristic of intact, healthy bog, and generic thresholds for favourable condition.

CSM: Common Standards Monitoring (JNCC, 2009).

Bog species	Species particularly characteristic of undamaged raised bog in UK (Wheeler & Shaw 1995a) (‘bog species’)	CSM lowland raised bog ✓ at least one present ✓✓at least two present combined cover >20% ✓✓✓ at least three present combined cover <80% No single species >50%cover	CSM upland blanket bog ✓ 6 or more present Dwarf shrubs, cottongrass, deergrass <75% cover >50% of stand must be made up of at least 3 indicator species
Higher plants			
Andromeda polifolia (bog rosemary)	✓	✓	✓
Arctostaphylos uva-ursi (bearberry)			✓
Betula nana (dwarf birch)			✓
Carex bigelowii (stiff sedge)			✓
Carex limosa (bog sedge)	✓		
Calluna vulgaris (heather)		✓✓✓	✓
Carex magellanica (tall bog sedge)	✓		
Cornus suecica (dwarf cornel)			✓
Drosera longifolia (great sundew)	✓		✓
Drosera intermedia (oblong leaved sundew)	✓		✓
Drosera rotundifolia (round-leaved sundew)	✓	✓	✓
Empetrum nigrum (crowberry)	✓	✓	✓
Erica tetralix (cross-leaved heath)	✓	✓✓✓	✓
Eriophorum angustifolium (common cottongrass)	✓		✓
Eriophorum vaginatum (hare’s tail cottongrass)	✓	✓✓✓	✓
Menyanthes trifoliata (bog bean)	✓		✓
Molinia caerulea (purple moor grass)	✓		
Myrica gale (bog myrtle)_	✓		✓
Narthecium ossifragum (bog asphodel)	✓	✓	✓
Osmunda regalis (royal fern)	✓		
Rhynchospora alba (white beak sedge)	✓		✓
Rhynchospora fusca (brown beak sedge)	✓		
Rubus chamaemorus (cloudberry)	✓		✓
Trichophorum germanicum (deergrass)	✓	✓✓✓	✓
Vaccinium oxycoccos (cranberry)	✓	✓	✓

Bog species	Species particularly characteristic of undamaged raised bog in UK (Wheeler & Shaw 1995a) ('bog species')	CSM lowland raised bog ✓ at least one present ✓✓at least two present combined cover >20% ✓✓✓ at least three present combined cover <80% No single species >50%cover	CSM upland blanket bog ✓ 6 or more present Dwarf shrubs, cottongrass, deergrass <75% cover >50% of stand must be made up of at least 3 indicator species
Vaccinium myrtillus (bilberry)			✓
Vaccinium uliginosum (northern bilberry)	✓		✓
Vaccinium vitis-idea (cowberry)			✓
Bryophytes			
Aulacomnium palustre	✓		
Calliergon stramineum	✓		
Calypogeia spp.	✓		
Cephalozia spp.	✓		
Cephaloziella spp.	✓		
Cladopodiella spp.	✓		
Dicranum undulatum	✓		
Drepanocladus fluitans	✓		
Kurzia pauciflora	✓		
Mylia anomala	✓		
Odontoschisma sphagnii	✓		
Pleurozium purpurea	✓		
Polytrichum alpestre	✓		
Sphagnum capillifolium	✓	✓✓	✓
Sphagnum cuspidatum	✓	✓✓	✓
Sphagnum denticulatum	✓		✓
Sphagnum fimbriatum	✓		✓
Sphagnum fuscum	✓		✓
Sphagnum imbricatum	✓		✓
Sphagnum magellanicum	✓	✓✓	✓
Sphagnum papillosum	✓	✓✓	✓
Sphagnum pulchrum	✓	✓✓	✓
Sphagnum fallax	✓		(✓)
Sphagnum subnitens	✓		✓
Sphagnum tenellum	✓	✓✓	✓

9. An assessment of some existing categorisations of ombrogenous peatlands in Britain

9.1 Categories of ombrogenous peatlands and surfaces

In his summary review of the ecohydrology of Scottish peatlands, Ingram (1987) noted that there were essentially two types of ombrogenous peatlands: those that develop a domed surface and are a particular feature of basins, and those which have developed over "the mineral substrate of hill slopes and plateaux". This view corresponds essentially with that of the Scottish Peat Surveys (see Annexe 1), which distinguished 'Basin Raised Peat' from 'Hill Peat'. These two categories have long been recognised widely, if informally, by British ecologists, as 'raised bog' and 'blanket bog'. For the most part, the exact distinction between the two seems to have been regarded as being of little consequence or concern. In essence, the distinction is between ombrogenous deposits that have developed in some sort of 'basin' (which tend to be water-collecting and often particularly poorly drained) and those that have developed on some sort of 'slope' (which tend to be water-shedding and somewhat better drained, though are not necessarily that much 'drier' at the surface than the other). However, some ombrogenous deposits have developed in circumstances that are neither one nor the other of these, or are over an irregular topography which contains both basins and slopes. In these cases, the ombrogenous surfaces may have features that are transitional in character between 'raised bog' and 'blanket bog'. In some instances they may represent a merging of the two types; in others, they form complexes in which both 'basin' peat surfaces and 'sloping' peat surfaces can be distinguished in juxtaposition. Both of these situations seem to have been encompassed in a category of 'Intermediate Bog' that was proposed by Ratcliffe (1964), but they are different in character, and their components, especially in the complexes, may have rather different ecohydrological characteristics and conservational requirements. It should be recognised that the category of 'Intermediate Bog', whether 'merged' or 'complex', is primarily conceptual, *viz.* it is a unit that is intermediate in concept between the *concept* of raised bog and the *concept* of blanket bog. It is possible that, in the case of some peatland complexes, the concept could also be applied to the 'real' transition between an area of raised bog and an area of blanket bog in the field, but we have no knowledge of where, or if, this is the case (not least because these broad categorisations are usually applied to a 'whole site', not to parts of it).

JNCC (1994) have recognised several sub-types of ombrogenous mires, which form a basis for the selection of Bog SSSIs. They are:

Raised Bog: *Flood-plain raised bog. Estuarine raised mire. Basin raised bog. Damaged raised bog*

Blanket Bog: *Watershed mire. Valleyside mire. Spur Mire. Saddle Mire. Eccentric Mire.*

Most of these sub-units, with the exception of 'damaged raised bog' and 'eccentric mire' are based on their position in the landscape. They are derivative from similar categories outlined as 'mesotopes' (Box 2) by Lindsay *et al.* (1988) and Lindsay (1995), though Lindsay also included the additional categories of 'watershed-valleyside mire' and 'unconfined raised bog'.

JNCC (1994) also noted the category of 'Intermediate mires' but, for the purposes of SSSI selection considered that apparent examples of this should be classified either as raised mire or blanket mire, depending upon their particular characteristics and affinities.

Wheeler & Shaw (1995b) examined the sub-types of blanket bog that had then been proposed and concluded that "As their characteristics have not been clearly or comprehensively described, their true relationships remain obscure. We therefore hold the view that whilst it is highly likely that some meaningful sub-types of hill bog may be recognised, the present degree of comparative information available to us would make their identification a haphazard exercise."

Since then, not much has changed. The categories proposed then have (mostly) been perpetuated and, presumably, used, and there is not a great deal of additional relevant data available to help inform the typology. But there have been some additional studies, and the data assembled for the current project permit some further consideration of the sub-types of blanket bog and their suitability for SSSI selection and other conservation activities.

Box 2. Mesotopes and WETMECs

The term 'mesotope' was introduced by Soviet telmatologists and became accessible to British workers mainly through the English translation of the work of K.E. Ivanov (Ivanov, 1981), though it is suspected that for many the meaning and significance of the term remains rather elusive. The definition given in Ivanov (1981) is essentially that it is a "mire massif developed from one original centre and possessing at each stage of their development a pattern of microtope distribution that conforms to clearly defined principles". Lindsay *et al.* (1988) subsequently suggested that "The mesotope is equivalent to the mire massif or mire unit, being a body of peat which has developed as a single hydrological entity. Thus a single raised mire or a valleyside mire would represent a mire mesotope, the surface of which may contain a range of microtopes". More recently, Lindsay (2010), has adopted a somewhat different position, in which a 'mesotope' seemingly can be either a landscape unit or a hydrological unit: "The mesotope represents the individual, identifiable peatland unit. In blanket mires these are largely described in terms of their landscape position, such as saddle mire, or watershed mire, but the generally-smaller fen mesotopes are described in terms of their hydrology – *e.g*. spring fen, basin fen". Very little detail or description has been provided, but diagrams show units that are based essentially on landscape topography and putative surface water flow lines (Lindsay, 2010). The peatland units (mesotopes) recognised by Lindsay (2010) in upland landscapes appear to correspond to separate surface water flow units – essentially individual water-shedding areas which can (presumably), be formed by the configuration of the mineral ground or by the accumulation of peat (or both). However, it seems likely that such flow-based subdivisions of the landscape may well be incongruent with the existing JNCC sub-types (which are also apparently 'mesotopes' (see Section 9.3)). An understanding of Lindsay's approach is hampered by a sparsity of clear, illustrative examples, and at least one of the (few) examples named by Lindsay (2010) as a 'mesotope' (Alport Moor, southern Pennines) occupies more than one surface water divide. Of perhaps greater ecohydrological consequence, the surface of a single, broad surface-water flow unit (such as part of Alport Moor) can contain several rather different ecohydrological types, sometimes including examples of minerotrophic mires along with ombrotrophic examples.

It appears that the term 'mesotope' has been understood and used by different workers in different, and not clearly specified, ways; one is left with the impression that, rather like the concept of an 'ecosystem', the concept of a 'mesotope' is largely what a particular worker happens to be thinking about at the time. It was partly confusions and contradictions of this type that led Wheeler *et al.* (2009) to adopt the term WETMEC (see Section 4.4.2) to refer to wetland surfaces with distinctive water-supply mechanisms, though they recognised that in some circumstances these might broadly equate to a 'mesotope' (but in others almost certainly not). WETMECs make no assumptions about whether a mire (or part of a mire) has originated from one or more centres, nor whether it represents 'a single hydrological entity' (which itself can be an elusive concept). Rather, they are ecohydrological units based on the recorded character of the present-day mire surface and its interactions with topography and water supply.

9.2 A general perspective on types of peatlands

Peatland classification has been notoriously complex, partly because of different approaches and opinions, partly because a wide range of contrasting classification criteria and objectives are available. Here, we are concerned with the recognition of broad ecohydrological and landscape units of the sort used by JNCC (1994) as sub-types of raised bog and blanket bog.

Peatlands are not particularly easy objects to categorise, largely because of their variability (both within and between sites) and their individuality. However, a greater problem for peatland categorisation in Britain is the dearth of useful data available for many sites. Attempting to categorise such data-poor sites can be akin to categorising books by their content but without reading them: if it is done at all, it is usually done using superficial criteria, such as *where* it is rather than *what* it is.

One further difficulty in assessing the character and validity of blanket bog sub-types is that unlike raised bogs, for which there is an inventory available (Lindsay & Immirzi, 1996), we have not been made aware of an easily-accessible list of the sub-types to which individual sites, or parts of sites, have been assigned. Some information may be available in the descriptions of some individual SSSIs, but these need to be examined with some caution. The example of Dun Moss (Perth & Kinross) provides a salutary example. This site formed the *locus classicus* for the development of thought and theory about the hydrology of raised bogs (Ingram, 1982), and was clearly regarded as a 'raised bog', but it was classified subsequently in the *NPRI* (Lindsay & Immirzi, 1996) as an 'intermediate bog'. In its SSSI description it is notified as a 'Saddle Mire' (which is a sub-type of blanket bog) but the text states that "it is an example of an upland saddle raised bog". Although this latter does not seem to be a category recognised by JNCC, it nonetheless provides a fair assessment: the site is 'upland' (370–380 m aOD), occupies a saddle in the landscape and has features which are most comparable with those of sites that elsewhere have been regarded as 'raised bogs'. If nothing else, this example illustrates the need for a rationalisation and clarification of the typology of ombrogenous peatlands.

The Dun Moss example also illustrates that the purpose of a peatland categorisation, whether for ecohydrological or conservational purposes, is not just to provide an arbitrary pigeon-hole within which information about the site can be stored. Rather, it needs to reflect as well as possible the salient features of the mire, so that it can be compared meaningfully with examples elsewhere, to assess how similar (or different) they are. A difficulty presented by simple 'locational' classifications, whether they are based on geographical or topographical locations, is that they can over-ride or obscure real affinities between sites, or parts of sites, as assessed in terms of their intrinsic features, such as vegetation, peat characteristics and ecohydrological processes. 'Locational' classifications of peatlands are akin to categorising books on where they happen to be stored. The significance of this (for peatlands) is explored further, below.

9.3 JNCC sub-types of blanket bog

9.3.1 The suite of 'mesotopes'

The blanket bog sub-types adopted by JNCC in 1994 (see Section 9.1) are based on peatland units previously identified by Lindsay *et al.* (1988) as *mesotopes* (see Box 2). A small amount of descriptive detail has been provided by Lindsay (1995) beyond that provided by JNCC (1994). Lindsay has illustrated the various types by simple diagrams showing their position in the landscape and their schematic conformation, and by diagrammatic plans onto which have been inserted putative surface water flow lines. The field reality is, of course, a good deal more complicated than this (for example, groups of flow lines can sometimes be nested several times). Nonetheless it is readily possible to recognise areas of mire that correspond broadly to the categories that Lindsay has proposed.

However, a significant difficulty in evaluating the proposals of Lindsay, and the validity of the suggested JNCC sub-types, is that it is hard to envisage just what is meant, particularly with regard to their scope. This is a consequence of a general absence of supporting information or evidence for the proposals, including very often a lack of simple citation of the names and location of reference sites. The primary focus appears to have been upon the perhaps more 'interesting' areas of blanket bog, which tend to be those which have deeper peat, a distinctive surface conformation and, often, surface patterning. This is suggested, for example, by the flow-lines given to illustrate 'valleyside mire', which clearly conform to the presence of a bulge or mound of peat near the bottom of the valley, not just to down-slope flow. It is not clear how this unit is supposed to relate, if at all, to the widespread areas of shallower, 'undifferentiated' ombrogenous peat that occur widely, sometimes lateral to, or above, the 'valleyside mire' unit that was recognised and illustrated. As the proposed sub-types seem to have largely emerged from a study on the mires of the Flow Country (Lindsay *et al.*, 1988), they may have been influenced particularly by the characteristics of the mires in this area, rather than by more generic considerations of the blanket bog resource as a whole. Yet even within the north of Scotland, the domed, partly-domed or bulging, often patterned, ombrogenous surfaces (which form the focus of the JNCC sub-types of 'blanket bog'), are localised, and this is even more the case over much of the rest of the United Kingdom (where such surfaces are represented mainly in mires usually referred to as 'raised bog').

A significant omission from the JNCC blanket bog sub-types is the lack of any explicit accommodation in the typology for areas of structurally uniform 'bog-standard' blanket bog. Such tracts of shallow(-ish) ombrogenous peat, which are sometimes outwith the compass of SSSIs and which frequently have been considered suitable for afforestation, may perhaps be regarded as unimportant for the purposes of SSSI selection, but they occupy very large areas, constitute much of what is usually considered to be 'blanket bog' and contribute important ecosystem services. Moreover, any assessment of the character of the more 'interesting' patches of peatlands needs to take comparative account of these 'less interesting' tracts, if only to try to establish the ecohydrological (or other) basis for the differences. Some workers have found their own bespoke solutions and nomenclature to refer to such unadopted peatland surfaces. For example, O'Reilly (2019) has recently referred to them as 'blanket valleyside bogs'.

As the JNCC typology of blanket bog units is essentially based on their location in the landscape, it is quite possible in principle to allocate any area of peatland to a landscape unit, irrespective of its characteristics. But whilst such a solution might seem simple, it is also simplistic, because it takes no account of real differences in the characteristics of the different blanket bogs that may occur within the same landscape unit. And the differences that can be observed within the suggested locational sub-units are not just a consequence of broad, national geographical trends, but can also be found within some specific regions or even individual 'sites'.

A typology based essentially on landscape position imposes an arbitrary categorisation on mires and forces a typological distinction between any units that are essentially the 'same' but occur in different locational categories. It also hinders comparison of 'blanket bog units' with ombrogenous units elsewhere in Britain. Referring to the measured surface profile of part of Shielton Bog (Caithness), Ingram (1987) pointed out that it "bears an interesting resemblance to that of a raised mire; although classed as a blanket mire because of its developmental history, it seems unlikely that the hydraulic behaviour and contemporary ecology of this mire differ from those of a typical raised mire in any essential respect." There can be little doubt that such domed, partly-domed or bulging 'blanket bog units' bear greater affinities to many examples of 'raised bog' than they do to the extensive tracts of shallow, sloping ombrogenous peat that constitute so much of what is normally considered to constitute 'blanket bog'. It is curiously ironic that the 'blanket bog sub-types', as recognised and described by JNCC (1994) and Lindsay (1995), represent those patches of 'blanket bog' that are most similar to examples of 'raised bog' as recognised elsewhere.

It should also be appreciated that, although ostensibly simple, any locational categorisation may be quite difficult in practice because of the variability of the landscape. Lindsay (1995) has recognised this by his identification of a separate category of 'watershed / valleyside mires'. This appears to be a separate consideration from his observation that watershed and valleyside mires grade into one another and can then be difficult to distinguish.

These various matters are explored further below with regard to individual blanket bog sub-types.

9.3.2 Watershed-valleyside mire

This category was illustrated by Lindsay *et al.* (1988), Lindsay (1995) and Lindsay (2010), but has not been described and has not been included in the JNCC suite of blanket bog sub-types. It appears to represent a mound forming a low-level watershed. Its suggested flow paths indicate radial flow from a dome to a watercourse, and it is difficult to see how this was thought to differ conceptually, or in any significant respect, from the ombrogenous dome of a raised bog (or, if preferred, a ridge-raised bog). No reference sites were suggested. One possible example of this category might be Munsary

Dubh Lochs (Caithness) where examination of aerial imagery suggests that the main peat body is separated from adjoining mires and hillsides by surrounding watercourses and lagg-like structures, but this assessment requires validation by more direct measurement of surface topography.

9.3.3 Unconfined raised bog units

Lindsay (1995) recognised that within some areas of blanket mire there can be domes of ombrogenous peat that have developed independently of the conformation of the sub-peat topography. He provided little description of these, and no examples, and it is not clear how he considered them to differ from 'raised bogs' elsewhere, other than by their location in a 'blanket mire landscape'. Nor, within 'blanket mire landscapes' did he indicate how they differed materially from radially-draining ombrogenous domes such as can occur within 'watershed mires'. This unit was not included by JNCC (1994).

'Raised bog units', sometimes with a small and shallow dome of ombrogenous peat, sometimes larger, occur sporadically, but widely within upland 'blanket mire' landscapes. They are often associated with basins of some sort in the underlying mineral ground. They are not necessarily 'unconfined'.

9.3.4 Watershed mire

This type of mire occurs on watershed plateausor broad ridges, where the surrounding land slopes away on all sides (JNCC, 1994). This source also points out that of all the blanket bog sub-types this is the only one that can be considered with fair certainty to have a surface that is irrigated directly and exclusively by precipitation. Nonetheless, watershed locations, even peat-covered examples, range considerably in their topographical character, and include fairly sharp ridges, shallow rounded ridges, flattish surfaces and shallow basins (or irregular terrain consisting of hollows and ridges). The first three of these topographical sub-categories can be seen essentially as water-shedding surfaces, varying in their degree of shed, whilst the fourth has a greater capacity for water retention. The ombrogenous mires embraced within the 'watershed' category similarly range in their character, from undifferentiated mire surfaces, broadly comparable with those on hill slopes, to flatter surfaces with some limited patterning, to subdued domes and bulges of peat, sometimes with striking and spectacular surface patterning. Broad, national trends in this variation can occur, as intimated by JNCC, but the three types can also be found together within specific regions, such as the north of Scotland, and in some individual 'sites'.

The reason for the occurrence, in a watershed context, of particularly wet domes of ombrogenous peat, does not seem to have been established (or even investigated) with any degree of rigour. One likely possibility is that they are associated with particularly poorly-drained locations, and they may be situated over basins and irregular terrain within the watershed, but this needs to be established as a consistent trend. More clear, however, even with the current dearth of information, is that in terms of their salient characteristics they seem to have more in common with similar structures on the valley slopes than with some of the other areas of mire on watersheds, even locally. On a national scale, in England the upland analogues of the wet watershed domes of the Flow Country are not the 'watershed mires' of, say, the Kinderscout plateau in the southern Pennines, but sites such as Butterburn Flow in the Border Mires.

9.3.5 Valleyside mire and Spur mire

These two landscape units are considered together because it is difficult to make a meaningful ecohydrological distinction between them. Both occur on gently sloping ground, one on a spur, the other towards, or at, the bottom of a hillslope. JNCC (1994) stated that the distinguishing feature between the two is that 'spur mire' is terminated downslope by steepening ground, the 'valleyside mire' by a water course. It is unlikely that such a difference consistently influences much, or even any, of the character of the mire above the downslope limit. According to Lindsay (1995), most of the mire units at the Silver Flowe (Galloway) (those that are on or near the valley floor beneath a steep slope) are 'valleyside mires', whereas other mire units here that are associated with a broad interfluve, are regarded as 'spur mires'[1]. [He did not state how Brishie Bog (on the same broad interfluve but differing in that it is terminated downslope by the Cooran Lane river) was to be categorised.] Although there are differences between all of the separate patterned mire units at the Silver Flowe (see Annexe 1), those which are regarded as 'valleyside mires' do not seem consistently different in their salient characteristics from the 'spur mires', certainly in comparison with other types of blanket bog. All of them also have affinities with raised bog or ridge-raised bog surfaces, as was recognised by Birks (1972) and Boatman (1983).

As illustrated by Lindsay (1995), the 'valleyside mesotope' seems to relate particularly to a lobe of peat, thickest at the junction between the lower valley slope and the valley bottom. In our experience, such units may occur as a partial dome of peat, with some sort of 'crown', but others are more a bulge of peat, with a sloping surface and a steeper downside edge (often not dissimilar to a rand). It is not clear whether this blanket bog sub-type is also supposed to contain the (very different) shallow ombrogenous peats that blanket many valley slopes. Likewise, at the Silver Flowe, it is not known if the 'spur mesotope' is intended also to encompass the large areas of undifferentiated ombrogenous peatland that occurs between, or above, some of the patterned mires. These 'less interesting' surfaces seem largely to have been ignored by telmatologists, including Boatman (1983).

A distinctive feature of both the 'valleyside' and 'spur' mire categories as identified by Lindsay (1995), (*i.e.* those on generally deeper peat and with a distinctive topography and possibly a pattern-rich surface), is that in both situations the 'crown' of the bog is located asymmetrically and is usually closer to the upslope margin than the downslope edge. This feature (when present) provides such units with some affinities to 'eccentric bog'. The difference, according to Lindsay, is that an 'eccentric bog' has a much more intense surface patterning, but it is questionable if this provides a very valid point of distinction as it may relate more to bioclimatic differences than to distinctions in typological characteristics. In any case, some of the patterned areas of mire at Kentra Moss (Argyll) (which Lindsay cited as an example of an 'eccentric bog') are remarkably similar to those found in parts of the Silver Flowe (Galloway) (which H. Sjörs, according to Boatman (1983), considered to be similar to the eccentric mires of Sweden, but which Lindsay (1995) considered to be 'valleyside mire'). [It also should be recognised that these considerations apply only, or primarily, to areas of patterned surfaces, not to the entirety of the mires in question.]

Other undifferentiated areas of ombrogenous peat on sloping ground appear to be of quite different character to the 'valleyside mire' sub-type described by JNCC (1994) and, in our view, constitute a different type of mire to the patterned areas. These are very widespread, but it is not clear to us how JNCC consider that such areas should be characterised. No sub-types of blanket bog on valley slopes have been specified by JNCC other than the bulges and semi-domes of deeper peat referred to already. It is possible, informally, to suggest other 'types', but the identification of these requires more rigorous examination than is possible here. A general feature of many sloping blanket bog surfaces on shallow peat is an absence or relative scarcity of surface patterning and pools, such as may occur on flatter surfaces, though in some instances there are soakways and runnels aligned down the hillslope gradient, as well as gullies and small streams.

A broad distinction of surface conditions could also distinguish between hill slope peat with much *Sphagnum* and that with little or none. In some locations the occurrence of *Sphagnum*-poor slopes doubtless reflects various forms of (often quite recent) damage, but in others it may well be 'natural' (Section 8.1), and this is reflected in the different composition of peat retrieved from different sites or parts of sites. The degree of slope is one possible important control on the character of the bog peat and vegetation, but examples are known of *Sphagnum*-rich bog peat on quite steep slopes.

[1] Lindsay *et al.* (1988) considered that in the Silver Flowe "parts are clearly mesotopes of blanket bog, others of raised bog, and others intermediate between the two".

Some hill slopes consist of a mixture of sloping ground separated by flatter surfaces, often associated with sub-peat topographical variation. The flatter areas may contain some sort of patterned surface, and seem to be comparable with (usually larger) flatter areas of blanket bog in a 'watershed' location, though there may be little practical value in distinguishing them and such valleysides could be considered to have a composite 'slope and bench' topography. In other instances, undifferentiated surfaces of blanket bog on 'valley sides' may be largely indistinguishable from similar surfaces on 'watersheds', except in terms of their location, and there may be no good justification for regarding them as separate peatland types.

A better understanding of the ecohydrological reasons for variation in the abundance of *Sphagnum* on hill slope blanket bog might usefully inform current restoration initiatives on damaged surfaces by the artificial introduction of *Sphagnum* (Section 8.2). It is suspected that some such work is being undertaken indiscriminately and may sometimes involve transplanting *Sphagnum* into surfaces where it has not naturally occurred, or not much so.

A potentially important consideration for both 'valleyside' and 'spur' mires, which was identified by Lindsay (1995), is that both of these types, because of their topographical position, could potentially be influenced or fed by downslope flow of water from above, particularly into their upslope margins. This is considered in more detail below (9.3.7).

9.3.6 Saddle mire

Saddle mires are said to be similar to Spur mires but have rising slopes on two sides rather than just one (JNCC, 1994); they may spill to some degree over the lips of the saddles on their unconfined sides. The only example cited by Lindsay (1995) is at Dry Loch, at the head of the Silver Flowe, but this area was afforested and its allocation to this unit was tentative. It is presumed that there are other examples. Dun Moss is given as a 'saddle mire' on its SSSI citation, but it is not considered to be a type of blanket bog (see Section 9.2).

Like other ombrogenous mires on or below hillslopes, saddle mires are potentially susceptible to receipt of water downflow, which in some cases may be telluric in character. A number of saddle or saddle-like locations are known which support significant areas of minerotrophic vegetation in response to water downflow. In appropriate climatic regions these may also have shallow ombrogenous surfaces in locations distant from, or elevated slightly above, any such minerotrophic influence, but it is not known whether any of these are supposed to correspond with a JNCC 'bog unit'.

9.3.7 Ecohydrological differences between 'watershed mire' and 'valleyside / spur mire'

Lindsay (1995) made the valid point that a significant difference between his 'valleyside mires' (also his 'spur mires' and 'saddle mires') and his 'watershed mires' was that only the latter could be thought with certainty to be fed directly and exclusively by precipitation. The others may, at least potentially, receive water into their upslope edges by hillside downflow in addition to direct precipitation. This is potentially an important ecohydrological point in their separation and requires further examination. A number of considerations are relevant.

Lateral water movement of some sort is a feature of all, or most, deposits of ombrogenous peat. For example, in an isolated raised bog, assuming a uniform distribution of rainfall across its surface, overall water flow will generally increase from its dome to its margins because of the need to drain lateral flow from the upslope surfaces as well as local, direct precipitation input. The same will apply to the shallow 'domes' of watershed blanket bog units. In some instances, even in lowland raised bogs, flow may become concentrated into diffuse soakways or, sometimes, better defined water tracks. These may have a vegetation that is rather different from the main ombrogenous surfaces, sometimes with a prominence of *Molinia caerulea* or *Myrica gale* (Ingram, 1967) (Section 6.1).

The surface of an area of blanket bog located at or near the base of a slope may potentially be fed by downslope flow of water of telmatic or telluric origin, in addition to direct precipitation. The extent to which this occurs depends, amongst other things, on a number of local factors, including the presence of a (natural) drainage system which intercepts much or all downslope flow and diverts it from the area of mire, or the presence of a lagg-like system which diverts flow around the margins of the mire. The hydraulic connectivity of the mire to the slope above (whether mineral ground or covered by ombrogenous peat) is clearly potentially important but is often quite difficult to assess, partly on account of a sparsity or absence of simple topographical data. In the case of one of the (few) well-studied examples, the Silver Flowe, it appears that most of the individual valleyside units have a limited connection with the slope above by means of a narrow 'isthmus' of peat or mineral ground. This may potentially receive some limited surface flow from above.

When considering 'extraneous' water inflows in regard to peatland characterisation, a distinction needs to be made between inflows that generically help determine significantly the character of a large number of mires, and help thereby to determine any typology based on them, from those which relate to specific sites and which, whilst they may influence (parts of) an individual site, do not affect the overall character and categorisation of the mire *unit* as a whole. For example, and in a very different context, fen surfaces that are known generally to be fed by significant amounts of both groundwater and surface water can be categorised as a distinctive ecohydrological type based on both water sources, which can be differentiated from a type based on surfaces that are normally fed dominantly by groundwater outflow only. However, in some instances, dominantly groundwater-fed surfaces can also be fed by limited or episodic surface water inflows, which may impact locally upon its character, but in a holistic assessment such as the WETMEC analyses of Wheeler *et al.* (2009) (see Section 4.4.2), such surfaces were clustered into the 'groundwater fed' category, with any surface water inflows regarded as being incidental or subordinate to the main character of the *category*. Any categorisation is based on a simplification of the reality of the entities from which it is derived, and a distinction needs always to be made between the characteristics of an extracted, conceptual *type* from the features of the individual field sites on which it is based. It may also be noted, in addition, that some wetland sites and surfaces are highly individual, almost idiosyncratic, and cannot easily be referred to *any* unit of a generic typology!

Down-slope flow of telmatic water is integral to the hydrodynamics of most ombrogenous surfaces on valleyside slopes, just as lateral flow occurs towards the margins of raised bogs. This is how such surfaces naturally 'work'. There is little evidence to suggest, nor reason to suppose, that there is a generic, consistent material change in the character of ombrogenous valleyside surfaces downslope; such differences as do occur appear to relate mainly to local changes in the steepness of slope.

Where 'ombrogenous' surfaces on valleysides (*etc*.) occur below slopes of mineral ground, they may be potentially influenced by downflow of telluric water. This may affect a zone along the upper margin of the peat deposit or, in some cases, may penetrate into it more comprehensively. In such circumstances, some or all of the peatland area would technically be weakly minerotrophic in character, and if the effect was sufficiently significant this would likely be evident in the character of the vegetation (*i.e.* this would not be considered to be ombrogenous). If, however the vegetation of such surfaces was essentially the same as that of surfaces that are considered to be ombrogenous in less ambiguous circumstances elsewhere, and given the difficulties of separating weakly minerotrophic surfaces from ombrotrophic examples based on their measured hydrochemistry (see Section 4.2.3), there seems to be little practical point, or even possibility, of making a sensible distinction between them.

The above comments relate generically to ombrogenous surfaces on sloping ground. However, those made by Lindsay (1995) about the possibility of extraneous surface water entering and influencing the character of his 'valleyside mires' and 'spur mires' appear to relate particularly to possible effects upon downflow on individual topographically distinct units, often with patterned surfaces, rather than upon bog that blankets more generally valleyside slopes.

Any water entering a 'valleyside mire' unit by flow from upslope may potentially have at least three effects upon the mire: it augments its overall water balance, by adding to direct precipitation inputs (though not necessarily increasing water levels across much or any of the ombrogenous surface); it may modify growing conditions, at least locally, on account of greater flow and possible effects upon the oxidation–reduction status of the peat and, perhaps, supply of solutes and 'nutrients'; and, if the water is partly of telluric origin, it may induce more pervasive differences in water chemical composition, at least locally. Such considerations apply similarly to surface water inflows into the lagg of a 'raised bog', but in that case the dome of ombrogenous peat is likely to be situated largely above the level of extraneous surface water inflow, and any effects of this upon growing conditions are likely to be confined to the lagg. In the case of a 'valleyside bog', depending on its degree of slope and surface conformation, the hydraulic gradients may be such that more of the mire surface may potentially or actually be influenced directly by any surface water inflow into the unit.

There is clear evidence that some examples of 'valleyside mire' receive some water flow from the slopes above, and that this can apparently influence the vegetation at the margin, near the point of entry of water downflow into the 'valleyside mire' unit. For example, Pearsall (1956) reported that there were two clear 'seepage lines' along part of the upslope margin of Strathy Bog (Sutherland), and one of these was associated with increased local prominence of *Eriophorum vaginatum* and *Myrica gale* in the vegetation. Likewise, at Silver Flowe (Galloway) there is evidence of more *Myrica* and of *Phragmites australis* at the narrow point of connection with the adjoining mineral slope in at least three of the mire units. In these mires, this apparent influence of water inflow is not completely confined to any lagg or lagg-like features, and in some instances, *Phragmites* can occur in the marginal parts of patterned surfaces where these come close to the hillslope (Boatman, 1983). However, patterned surfaces are still present and the overall character of the mire is similar to those in which such indications of minerotrophy are absent. This suggests that, in these examples, the effect of any enhanced flow or enrichment is more by way of a local 'contaminant' than a determinant of the character of the mire, and it is questionable whether it should influence its overall categorisation in a typology. In this regard it is, perhaps, unfortunate that the 'affected' mire examples at the Silver Flowe (which is one of the few 'upland' sites to have been well investigated ecologically) are in a rather unusual topographical position, in that the closely-bordering hill slopes are particularly high and steep (and quite different, for example, from the lower, more gently-undulating terrain of parts of the Flow Country (NE Scotland). [In this regard, it should be recognised that the epithet 'valleyside mire' is something of a misnomer for the southern mires of the Silver Flowe, for they are located on undulating terrain at the foot of the steep hillsides and would better be described as occupying the foot of the hillside and the adjoining valley bottom.]

Another point of distinction between the 'valleyside' and 'watershed' mire units, as they have been conceptualised by JNCC (1994), is that the valleyside examples tend to be domed asymmetrically whereas watershed examples may have a more central crown and may drain more equally radially. This feature may provide the latter with greater affinities to 'raised bogs' than is the case with the valleyside examples, which present more usually as a partial dome set against a hillslope, or just as a bulge of peat. However, few topographical data are available for most examples (there does not appear to be Lidar coverage of the Flow Country mires), and there are even fewer usable stratigraphical data, so an assessment of the field relationships between the 'valleyside' and 'watershed' types is not really possible, other than to note that their surfaces can seem to be very similar, but the 'watershed' examples often have larger, and more isodiametric, pools near the crown of the mire.

In assessing the topographical character of the different blanket bog sub-types, it is important to recognise that the available profiles and sections usually have strongly exaggerated vertical axes. Thus, in the field, some of the mires of the Silver Flowe alongside the Cooran Lane river appear visually to be 'flat' and, in the absence of levelling measurements, one might debate not whether the 'dome' was located asymmetrically but whether there was a 'dome' there at all!

9.3.8 Hydraulic connectivity and mire landscape context

The above discussion illustrates that different components of a 'blanket peat landscape' may have hydraulic interconnections, of varying strength and significance, and Lindsay (1995) has emphasised the importance of this. However, it should be recognised that all, or nearly all, peatland units, anywhere, are likely to have some measure of hydrological connection either with other juxtaposed peatland units or with mineral surfaces, and again these may be of varying strength and significance: blanket peats are not generically exceptional in this respect. The importance of such connectivity to the characteristics of specific areas of peatland may differ from place to place, and can be subsumed by other influences on water conditions. The (limited) information available on the differentiation of blanket peat types suggests that water conditions may generally be controlled more by local topographical variation of the surface and sub-peat surface (degree of slope, small basins *etc.*) than by hydraulic interconnections between adjoining 'peatland units', though these latter may have great importance in some specific, individual circumstances. It is important to distinguish between the generic circumstances and processes that help construct an overall typology, and the detailed behaviour and characteristics of individual sites, though the two are obviously linked.

From his work in the Flow Country, Charman (1995) also formed a holistic view that blanket mire development consists of units that are hydrologically interlinked. However, whilst such units may interact with one another, they are not necessarily inter-dependent, and this is well illustrated by Charman's work on strips of scalariform fen embedded within ombrogenous mire (see Annexe 1). This showed that both fen and bog units can each occur independently, in the absence of the other (though not of course necessarily in the same unique relationship that may occur at any one individual location). For example, Charman (1995) has shown that an example of a scalariform fen at North Altnaharra occurs in the absence of the intimate relationship with adjoining ombrogenous surfaces that he found at Cross Lochs.

The rather nebulous considerations of 'hydraulic connectivity' have influenced some approaches to peatland typology. For example, both Lindsay *et al.* (1988) and Thom *et al.* (2019) made the point that there may be little merit in distinguishing raised bog elements within blanket bog as they "are hydrologically linked to each other because the peat mantle extends continuously beneath them all". Lindsay (1995) also considered that some types or areas of mire (including 'eccentric mire') should be regarded as 'blanket bog' because they occur within other areas of blanket bog – a view which contrasts with the detailed distinction and separate sampling of the microforms within patterned surfaces (see Section 7.1.4), as these are more clearly and intimately linked together, both hydraulically and physically, than is the case for different mire structures within 'blanket bog'. Nonetheless, this appears to be the reason why Lindsay *et al.* chose to re-classify Claish Moss (Argyll) as 'blanket bog' from the 'raised bog' of earlier authors (*e.g.* Ratcliffe, 1977). But such a rationale seems unfounded, and if applied to other contexts would have wide ranging and probably unwelcome consequences[1].

More recently, Thom *et al.* (2019) have pointed to practical difficulties in distinguishing 'raised bog' elements within 'blanket bog':

> "Terrestrialisation of open water bodies via hydroseral succession to bog leads to domed, apparently raised bog units within a blanket bog landscape. It is impossible to distinguish between these 'raised' domes and those caused by the morphology of the underlying mineral ground without testing the depth of the peat and establishing the morphology of the underlying mineral ground."

However, in our experience, in the first instance the detection of such units does not depend usually upon peat cores (useful though these are) but on differences in surface conditions and vegetation,

[1] For example, on this basis a wet valleyhead fen in chalk with M13 vegetation could presumably be categorised as 'chalk downland' because this is the habitat in which it is embedded, because chalk extends continuously beneath it, and because it is strongly linked hydrologically to the chalk, by chalk-water springs and seepages.

both of which are usually apparent readily on careful field inspection. [There is also little reason to suppose that 'raised bog units within a blanket bog landscape' have necessarily arisen by the terrestrialisation of open water bodies (see Section 5.2.4 and Annexe 1).]

In our view the identification and description of mire units is best achieved by an 'object-oriented' approach, based on the salient features of distinctive, individual areas of mire, not on their locations or surroundings, or their postulated 'connectivities'. A plant of *Pyrola rotundifolia* (round-leaved wintergreen) does not cease to be *Pyrola rotundifolia* when it is surrounded by plants of *Salix repens* (creeping willow), even though the two species may be linked strongly by mycorrhizae. There is no doubt that different ecohydrological types of ombrogenous mire occur juxtaposed in 'upland' landscapes, nor that often they are probably linked hydraulically and may intergrade, but it is both possible and desirable to differentiate individual and distinctive types of mire on the basis of *what* they are rather than *where* they are. However, a typology founded on this approach would differ materially in a number of respects from the scheme provided by JNCC (1994).

9.4 Use of vegetation in the categorisation of ombrotrophic surfaces

The plant species and vegetation units found growing on ombrotrophic surfaces are probably the most sensitive indicators of differences in growing conditions and ecohydrological circumstance that are readily available, and may be of use in the distinction and categorisation of these. Moreover, they are usually directly responsible for much of the character of accumulating proto-peat and recent peat; they are also, generally, relatively easy to observe and recognise. Thus, for example, the occurrence of M18 surfaces within areas otherwise assigned to M19, or sometimes M17, is often a good proxy indicator of distinctive ecohydrological conditions and, with these, perhaps a different type of mire.

The introduction of the *National Vegetation Classification* (Rodwell, 1991 *etc*), was an important milestone in British ecology, because it identified vegetation units based on the full floristic composition of the vegetation, not just on the dominant species, as had generally been favoured hitherto by Tansley (1939) and others. Although 'dominant species' may often seem easier to use in the field to describe vegetation, this is not always the case, and they are inappropriate for vegetation where there are no dominant species or where there is mixed dominance. A more fundamental limitation of dominance-based characterisations is that there can be a mis-match between dominant species and floristic composition: thus several different species can sometimes be dominant within a single floristic community, whilst a single species can sometimes be dominant across several floristic communities. This issue, which one might have thought had been put to bed with the creation of the *National Vegetation Classification*, has arisen again with the increased desire to use remote sensing approaches to 'identify' vegetation units in the field. It appears that whilst such techniques may be able remotely to identify patches of dominance in the field with some degree of success, at present they are generally less satisfactory for the recognition of floristic units.

The species that typically dominate ombrotrophic surfaces can occupy a relatively wide range of environmental conditions, and vegetation units based on species dominance are generally less sensitive and less reliable indicators of underlying environmental and ecohydrological conditions and trends than are floristic units. The latter are by no means perfect in this regard, but they can provide a sensitive first-line indication of significant ecohydrological differences (or lack thereof) which might otherwise be difficult to detect without extensive instrumentation. Moreover, consistent changes in species abundance, including changes in the dominant species, *within* a particular *NVC* unit, can often provide a good indication of ecohydrological differences in the field, between different facies of the same community. On the other hand, some *NVC* sub-communities are rather coarse, clumsy affairs which lack a very clear ecohydrological compass, and it may often be desirable for careful surveyors to note consistent patterns of variation of species composition in the field, even where they are clearly accommodated within a single *NVC* sub-community.

Detection of differences such as these can sometimes be hampered by the surveying protocols used by some surveyors: some record 'replicate' (often 5) samples of vegetation within the same community, but these may be widely scattered, sometimes in different variants of the vegetation and in separate stands. When subsequently combined in data analyses, the merging of such samples into a single constancy list can obscure real and significant differences in floristic composition amongst them. This is because they are not 'replicate' samples but independent samples of different versions of the vegetation. If 'replicate' samples are to be taken in *NVC* surveys – and in general we see no particular benefit in this, providing the sample area is sufficiently large – they need to be fairly close together, and be 'replicates' of the same, 'uniform' expression of the vegetation.

An influence of species dominance upon the perception of vegetation-type can sometimes arise in *NVC* surveys, where the presence of a particular dominant species may help sway the identification of communities. For example, it is suspected that in the English Border Mires some stands with much *Trichophorum germanicum* may as a result sometimes have been allocated to M17, though their overall floristic affinities are most strongly with M18 (the relationship between these two communities, and others, in the Border Mires is discussed elsewhere (Section 7.1.2)). Despite this, it is clear that in the Borders region those areas of mire which, on ecohydrological grounds would be regarded as 'sloping ombrogenous surfaces' (blanket bogs) generally support M17 vegetation, whilst 'domed ombrogenous surfaces' (± raised bogs) generally support M18. This suggests that the floristic identity of the vegetation itself can be used to help recognise and identify different ecohydrological units within these upland mire landscapes, at least in the first instance and within a particular bioclimatic region. This last caveat reflects the fact that the distribution of ombrogenous communities, especially M17, is influenced strongly by bioclimatic variation as well as by local ecohydrological conditions, and that in some regions general bioclimatic trends may over-ride local ecohydrological circumstances in determining the vegetation that occurs.

Of course, other factors may also influence the composition of ombrogenous vegetation, including burning and draining. There is also much evidence that industrial pollution of various types has materially changed the character of the vegetation of ombrogenous surfaces in the southern Pennines and elsewhere, and in some instances appears to have over-ridden local ecohydrological circumstances in determining the character of the present-day vegetation. In these instances, the former occurrence of *Sphagnum*-rich surfaces, some of which may once have been referable to M18, can sometimes be inferred from the pre-18th century composition of the peat. A ghost of this, and of a particular type of mire, is sometimes still evident in the persistence of (impoverished) pool–hummock complexes, and sometimes in the persistence of relict populations of species such as *Andromeda polifolia.* This is believed to be the case, for example, at Ringinglow Bog, Sheffield (Conway, 1947, 1949), a mire which is largely referable to M19, but where patches of *Andromeda polifolia* (and *Sphagnum papillosum*) mark degraded remnants of M18.

9.5 Summary conclusions

1. As a concept and category, 'blanket bog' represents an informal and variable unit that is used to encompass a range of upland types of ombrogenous peatland.
2. Variation in the character of blanket bog occurs in differences in such things as the depth and stratigraphy of peat, surface conformation and surface patterning. Areas vary also in the position they occupy in the landscape.
3. Several different sub-types of blanket bog have been recognised by JNCC (1994), based primarily on the topographical location of the mires in the landscape. They are generally ill-defined and poorly described units and their rationale and compass is not very clear.
4. The sub-types of blanket bog as described by JNCC (1994) appear mainly to represent only certain, perhaps the 'more interesting' versions of these peatlands, such as are typically associated with deeper accumulations of peat of distinctive surface conformation (which can be distinguished from the general topography of the peatland landscape in which they occur), and, often, a (sometimes striking) surface patterning. However, areas with such characteristics are

localised within the wider compass of 'blanket bog', even with the blanket mire landscapes of northern Scotland, and more so elsewhere in the UK.

5. The JNCC typology does not appear to encompass the widespread, thinner forms of blanket peat with surfaces that follow more faithfully the underlying topography of mineral ground. These constitute much of what is generally considered to be 'blanket bog' and are extensive, though many such areas have been afforested. These 'bog standard', and perhaps 'less interesting', surfaces can also be divided into a small number of sub-types, but these are not part of the JNCC typology.
6. A consequence of the foundation of the JNCC sub-types upon the landscape locations in which they occur, is that areas of peatland in one landscape unit are necessarily placed into that particular landscape sub-type without reference to their salient features. It is thus possible for very similar examples of blanket bog surfaces to be placed into different blanket bog sub-types because of their different landscape context, despite inherent similarities they may possess. Conversely, contrasting peatland units can be placed within a single locational category.
7. In the light of the information presented by JNCC (1994), and of field evidence and experience, it is difficult to make any consistent or sensible distinction between the categories of 'valleyside mire' and 'spur mire' except for the landscape location in which they occur. The category of 'watershed mire' (as described in the JNCC typology) has some obvious affinities with 'valleyside mire' (more so than with the ubiquitous sloping surfaces of shallow blanket peat), and also with lowland raised mire. However, the field characteristics of peatland areas referable to this unit seem to have been so poorly investigated and characterised that it is difficult to make informed comment on their actual affinities and inter-relationships. [Note that this comment refers only to the 'watershed mire' units as described by JNCC; it does not necessarily apply to other examples of blanket bog in watershed locations.]
8. As 'blanket bog' and 'raised bog' are the two main units of ombrogenous mire that have been widely recognised in Britain, they might be assumed to have some parity in conceptual status and range of variation encompassed, but this is not the case. Although exceptions can be found, 'raised bogs' are usually coherent entities, with limited and (often) predictable variability, and can usefully be considered as such; on the other hand 'blanket bogs' can contain a melange of contrasting hydro-physical and hydro-topographical structures and surfaces, some of which come closer in their characteristics and properties to those of lowland 'raised bogs' than to some other types regarded as 'blanket bog'.
9. It would be possible to generate a more coherent and comprehensive, and more firmly-founded, categorisation of blanket bog surfaces, taking into account the points made above, amongst others. This would require a greater trawling of the 'grey literature' than has been possible in the present project, accompanied by the acquisition of some carefully-targeted additional field data, to resolve certain specific points and issues.
10. The development of an object-oriented, ecohydrologically-based typology of ombrogenous peat within upland contexts could be of particular importance to conservationists and conservation managers, because such units are likely to have rather different hydrodynamics and vulnerabilities, particularly in comparison with more generic sloping blanket bog surfaces.
11. It seems likely that SSSI Selection criteria and Common Standards Monitoring protocols and thresholds might need to be revised and targeted to take better account of natural variability in the characteristics of a representative suite of sub-types of blanket bog, as assessed ecohydrologically, and also in the variation in the natural capacity of these to support specific conservation targets and outcomes.
12. Overall, it should be appreciated that the name 'blanket bog' is curiously apposite. It is a 'blanket term' which, as often used, can 'blanket out' real and significant ecohydrological heterogeneity in the field and mask the relationships of distinctive units therein with ombrogenous mires elsewhere. It has been used to unite a range of rather different types of wetland, generally found within landscapes of mires, mists and midges, and has hampered recognition that some of these show strong ecohydrological links with other examples, including some minerotrophic types, that occur also in more lowland and southern circumstances. That this labelling is a potential

millstone to the development of a holistic conceptual understanding of mires is illustrated by, amongst other studies, the work of Charman (1990 *et seq.*) in the Flow Country and, more recently, by Grootjans *et al.* (2016) (at Roundstone Bog, Connemara).

13. An ecohydrological approach to the categorisation of ombrogenous mires would avoid the use of nebulous concepts such as 'blanket bog', other than for broad descriptive purposes, in favour of a more penetrating, comparative analysis of the relationships of the salient features of these mires, both to other examples within 'blanket bogs' and to other mires in other landscapes.

10. Conclusions and recommendations

10.1 Conclusions

The requirement of the UK Country Agencies for the development of user-friendly ecohydrological guidelines for upland mire habitats resulted in the commissioning of this scoping study, which was aimed at reviewing information that could be used to characterise the water supply mechanisms of upland mires, and to understand how these relate to the different vegetation types of blanket mire landscapes.

A search of the available literature was undertaken, including published reports and journal articles, and unpublished work where this could be acquired. Gaps in the available information have been identified and recommendations for further work have been made. Acquisition of data has not been straightforward because of the short timescale of the project, the need for additional funds to acquire some datasets, and some sensitivity in releasing data to contractors.

An important part of the process has been the synthesis of the available information to provide a series of reference site accounts for important ombrogenous bog sites throughout the UK, and also chapters providing details about the characteristics of blanket mire landscapes, mire vegetation, hydrology, related habitat features, bog restoration, and an evaluation of existing blanket bog classification.

A broad conclusion from this work is that a more coherent and comprehensive categorisation of blanket bog surfaces would assist conservation managers in their task of determining appropriate management and restoration actions for blanket bogs. The existing set of blanket bog sub-types currently recognised by JNCC appear to be ill-defined and poorly described units that do not help conservation managers to understand their salient characteristics and ecohydrological status, or to determine appropriate conservation targets for individual sites.

An objective typology of ombrogenous upland mires based on ecohydrological data could be developed, but in order to do this it would be necessary to gain access to more linked environmental and vegetation datasets for blanket bog sites. This would require a more detailed examination of unpublished literature, as well as acquisition of additional carefully targeted field data, to facilitate a 'bottom up' approach, *i.e.* based on an objective synthesis of actual field data, as used in the original 'Wetland Framework' approach. Accumulated data could be analysed objectively and numerically, allowing the identification of different water supply mechanisms (WETMECs – see Section 4.4.2) and the recognition of distinctive ecohydrological mire types within blanket bog sites. The possibility of modelling variation in the characteristics and form of types of 'blanket bog' should also be considered (using an approach such as that of DigiBog).

Because this approach has a great degree of flexibility in application, it should help conservation managers to achieve a more in-depth understanding of blanket bog sites and their likely ecohydrological requirements.

10.2 Recommendations

In order to achieve this, it is proposed that the project should continue beyond this scoping stage, and recommendations for further work are given below. Note that it would be fruitless to attempt to progress this project if suitable datasets do not become available. Consequently, the full development of these Guidelines should be regarded as a long-term project.

1. Fund a more in-depth study and produce a more detailed discussion of blanket bog ecohydrology that includes the Flow Country of northern Scotland, additional Welsh blanket bog sites, and consideration of the upland mires of south-western England.
2. Develop a phased approach to a continuation of the project:
    - Part 1 – continued data gathering.

- Part 2 – data analysis and production of report / guideline information.

3. Consider the possibility of modelling salient issues of 'blanket bog' form and character to help the development of a typology. This could take the form of funding a Masters by a Research student to undertake a more systematic exploration of selected bog 'type' sites, using the DigiBog model that has been developed at the University of Leeds.
4. The continuation of the project should have a longer timescale (e.g. a full year) than this scoping study, to allow for the anticipated slow progress in accessing datasets, and a longer timescale would allow for research groups to open up access to additional datasets.
5. The highest priority datasets for acquisition are thought likely to be:
   - James Hutton Institute Flow Country research projects
   - Research projects of Dr R. Tipping (ex University of Stirling)
   - 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
6. Continue to develop relationships with known and potential data-holders.
7. Discover which datasets are likely to remain of restricted access and which are likely to be published soon.
8. Urgently ascertain which datasets would require payment for their collation and release, and which might be covered by existing funding agreements with the Agencies.
9. As a matter of urgency, develop agreements with data-holders for enabling data sharing.
10. Provide funding for the acquisition of relevant datasets, both in terms of payment to the data-holders (if required) and the time needed to make and manage these data requests.
11. Budget for visits to the local offices of the various Country Agencies in order to identify or access paper copies or stored pdf copies of important reports and older datasets.
12. Budget for time required to tabulate electronically older data sources that are not in spreadsheet format.
13. Budget for time and funding to undertake targeted fieldwork aimed at gathering linked vegetation and environmental data from particularly important blanket bog sites.
14. Contact should be made with Bobby Hamill of Northern Ireland Environment Agency.
15. As a general point, it would be beneficial for the various Agencies to develop protocols for sampling and encourage all research and restoration projects on blanket mire habitats to aim as standard to collect vegetation data from study areas, particularly in the vicinity of dipwells and hydrochemical monitoring points, in a way that would allow the vegetation to be assigned to an *NVC* community, even where it is not a clear 'fit' to existing *NVC* vegetation types. This would also allow the compilation of an extensive vegetation data set which could be analysed to improve understanding of the variation found across the UK resource.

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12. 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)
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).
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
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) (see Section 4.1).
Eutrophic	nutrient-enriched (not necessarily also base-rich, but often so). (see discussion in Section 4.3)
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)

Term	Definition
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.
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. (See Section 4.1)
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
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)*

Term	Definition
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 (see Section 4.1)
Microform	mire microform; relating to single surface feature, such as pool or hummock. (See also Figure 9 and 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. (see discussion in Section 4.2)
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). (see Section 4.3)
Ombrogenous	wetland developed under the exclusive influence of precipitation (see Section 4.1)
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. (see discussion in Section 4.3)
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.
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.

Term	Definition
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 (see Section 5.1.2)
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) (see Section 4.1)
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.
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.
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). (see Section 4.1)
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. (see Section 4.1)
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.

Term	**Definition**
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). (see Section 4.1)
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. (see Section 4.1)
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) (see Section 4.1)
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.
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.

Term	Definition
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 Mound' hypothesis is discussed in Section 5.2.7*)
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.

Annexes

13. Annexe 1: Reference Sites

See separate document:

Filename: SWE EcoHydro Report Annexes Aug 2020.pdf

14. Annexe 2: Classification of 'upland' peat soils

1 **SOIL SURVEY OF ENGLAND & WALES**
2 **SOIL SURVEY OF SCOTLAND**

See separate document:

Filename: SWE EcoHydro Report Annexes Aug 2020.pdf

15. Annexe 3: Literature sources

See separate spreadsheet catalogue of literature sources:

Filename: SWE Ecohydro literature 09-03-2020.xlsx

16. Annexe 4: Datasets

See separate spreadsheet catalogue of datasets:

Filename: SWE Ecohydro datasets 09-03-2020.xlsx

17. Annexe 5: Scottish lowland peatland *NVC* types.

See separate spreadsheet of Scottish peatland *NVC* plant communities, collected as part of a comparative survey of a wide range of habitat conditions related to specific plant community-types in lowland minerotrophic mires in Britain, by Wheeler and Shaw (unpublished):

Filename: ScotHabQ.xls