The use of historical accounts of species distribution to suggest restoration targets for UK upland mires within a 'moorland' landscape

Jonathan P. Ritson[1], Richard A. Lindsay[2]

[1] School of Environment, Education and Development, University of Manchester, UK
[2] Sustainability Research Institute, University of East London, UK

SUMMARY

Using contemporary accounts of vegetation in the South Pennine landscape of northern England from the late 18th Century to the present day, we describe the degradation and subsequent partial recovery of these upland mire systems in terms of their vegetation biodiversity. The historical sources highlight several species that were once common on these peatlands but which do not currently feature as positive indicator species in monitoring or restoration programmes. The use of archival sources may provide additional evidence that complements palaeoecological data when setting restoration targets. For example, the historical accounts support the palaeoecological timeline for the disappearance of *Sphagnum* from these landscapes. As a step toward a possible expanded set of targets for restoration works, we suggest an extended list of positive indicator species for the South Pennines which could also be applicable elsewhere in the UK. These include species such as lesser twayblade (*Neottia cordata*) and the club mosses (*Lycopodiaceae*), which were noted to be common in the 18th and 19th centuries, but which had become rare by the early 20th century. We highlight changes in land ownership and land use through the process of enclosure, as well as indirect effects from industrialisation, as the dominant interacting drivers of vegetation change.

KEY WORDS: archival research, biodiversity, indicator species, vegetation change

INTRODUCTION

Peatland restoration has attracted significant investment in recent years, although setting targets for what successful restoration would look like, and which ecosystem services should be prioritised, has proved difficult (Andersen *et al.* 2017). This is because the principle of restoration implies that a restored habitat condition-state is known and managed for, but on what basis is this knowledge obtained? Most habitats do not contain discernible records of their past states. Targets therefore tend to be based on example sites, preferably located not far from the restoration site, that are considered to display the condition-state achievable through restoration. This may or may not be an appropriate choice and there is no way to be sure. Furthermore, sites subject to restoration action may already be on a particular trajectory which can only be discerned through access to historical context. Changes attributed to restoration action may in fact largely result from established long-term trends rather than being a response to the immediate restoration actions, or unexpected failure to achieve the expected target may occur because underlying long-term trends override the effect of the restoration action.

Peatlands, on the other hand, differ from other habitats in one important respect, in that they preserve a record of their previous states in the form of the peat deposit itself. Taking advantage of this characteristic, one promising approach to setting peatland restoration targets has been the use of palaeoecological evidence whereby past vegetation composition preserved within the peat archive is used as a guide to the setting of targets (e.g. Davies & Bunting 2010, Blundell & Holden 2015, McCarroll *et al.* 2015).

Such an approach can be used to highlight species that have been important in peat formation and thereby assess how current conditions may differ from some chosen historical baseline. This is still somewhat fraught, however, because shifts in climate over the millennia have given rise to a variety of vegetation assemblages preserved within the peat archive (Barber 1981, Mauquoy *et al.* 2004, 2008), while anthropogenic influence on these landscapes in the UK also extends back at least to the Iron Age (Woodhead 1929) if not as far back as Neolithic times or even to the Mesolithic (5,000 to 15,000 years BP) (Tallis 1995). Consequently, the process of defining a meaningful baseline can be challenging. Furthermore, by definition, palaeoecological studies use remnants of plants which persist in the peat profile, thus potentially biasing the outcomes towards plants which produce material recalcitrant to decay, such as *Sphagnum* spp. Palaeoecological studies also commonly rely on a small number of cores, so while they can detect dominant species in an area, many more species may be missed simply because of their lower original abundance and the attendant low likelihood of their remains being found within a peat core.

Fortunately, archival records of peatland species and vegetation assemblages provide an additional and potentially valuable source of information capable of complementing evidence obtained from palaeoecological work. Proulx (2022) identifies the long-term value of such archives through their capacity to document changes in local floristic assemblages over time. Some of the earliest documentary records provide valuable insights into the nature and diversity of such assemblages as they existed at a time when anthropogenic influence was much lower than today. Furthermore, archival sources may provide information about the occurrence of species that were only ever a small component of total vegetation cover, or which decompose rapidly, and are therefore likely to be missed by palaeoecological studies. Such low-frequency species may not play a major role in characterising vegetation assemblages but nonetheless contribute to the overall biodiversity of a habitat. More significantly for target setting, such low-frequency species may be important indicators of particular condition-states although little attention is often given to rarer species in ecological monitoring studies where, for valid statistical reasons, species which only occur once are often removed from the analysis (e.g. Alday *et al.* 2021).

Archival records are also valuable because they can help to re-set perceptions. Current distributions of species and habitats are all too often taken to indicate the natural range and level of abundance, whereas archival records can challenge this assumption. With each new generation of researcher, conservation practitioner or policy maker, there is a danger that the status of habitats or species observed by that generation becomes the 'new normal'. Archival records permit comparisons to be made with previous 'normal' states dating farther back in time than living memory and help to re-align perceptions of current status while also opening up hitherto unexplored possibilities for target setting.

Archival records nevertheless bring their own challenges, not least those of nomenclature and taxonomic change. If only the common or local name is used in the archival record it is necessary then to interpret this in terms of likely scientific name, which can be difficult if local names for the same plant differ from area to area, or if the same local name is used for different species in different areas. Even if scientific nomenclature is used in the archival material, taxonomic changes over time can make it difficult to be sure of the most appropriate name to use today, especially when later taxonomy distinguishes two or more species from what was once considered a single species - a particular issue for lower plants.

In this article we trial the technique as an aid to understanding how species distributions on upland mires in the South Pennines hills (UK) have changed over time. In focusing on the mires of the South Pennines, a further challenge arises from the terminology applied almost uniquely to this type of landscape in Britain. 'Upland' in Britain refers to land above and outside enclosed cultivated ground, leading to a very general concept of upland as being synonymous with any land lying above the 300 m contour. 'Moorland', on the other hand, is a uniquely British term applied to gently rolling uncultivated ground, generally in the uplands, dominated by heather or coarse grasses (Pearsall 1950, Soffe 2003). As such, 'moorland' is a landscape concept rather than a habitat type (Simmons 2003) but has nonetheless long been, and continues to be, used as a broad habitat term. In practice, moorland is a habitat mosaic dominated by blanket mire comprising both bog and fen elements formed over variable depths of peat, together with expanses of heather-dominated (*Calluna vulgaris*) upland heath and upland grass heath formed over organo-mineral soils. All too often, archival material will simply refer to 'moorland' as the source of a plant record, meaning that the relevance of that record to peatland conservation and restoration is ambiguous. In such circumstances it is necessary to use the known habitat preferences of species as a guide to their relevance in terms of any specific moorland habitat but in the case of many species this still leaves room for considerable uncertainty.

A degree of interpretation must therefore be applied to such records when assigning them to particular moorland habitats, otherwise their use could lead to the adoption of incorrect or inappropriate recovery-target assemblages for particular habitat units. On the other hand, by acknowledging and recognising the differing habitat types present and by assigning archival records appropriately, it should be possible to generate a richer picture of moorland biodiversity than if records for moorland species were treated as belonging to a single habitat entity.

METHODS AND STUDY AREA

To assess vegetation change within the upland mires of the South Pennine moorlands over recent centuries, we have used the archives of the University of Manchester as well as local learned societies (Halifax Scientific Society and Manchester Geographical Society). These archives contain extensive accounts of flora, many of which are yet to be digitised and thus are unavailable to most restoration practitioners. Where digitised copies were available, we searched for the keywords ‘peat’, ‘moss’, ‘bog’, ‘moor’, ‘moorland’, ‘cottongrass’, ‘*Eriophorum*’ and ‘*Sphagnum*’ to identify articles suitable for inclusion. From this initial search we were then able to identify additional historical sources through the references contained within. For undigitised archives, such as the majority of records held by the Manchester Geographical Society, we manually read the article titles in each volume of the Society’s journal to ascertain whether the content was likely to be suitable for inclusion.

In addition, some care must be taken in interpreting these sources in that survey methodologies are not standardised across studies, meaning that the disappearance of a particular species may be an artefact of the survey rather than a genuine change. Still, while this might create some errors in comparing individual studies, we can still infer broad changes in species distribution as their reported abundance changes from common to rare to locally extinct.

We chose the South Pennines because they have been at the epicentre of the industrial revolution in the counties of Yorkshire, Lancashire and Derbyshire (central/northern England, UK) with significant historical and ongoing pressures from pollution, burn management, wildfires, tourism and agriculture. We believe their transition to a locally denuded state and subsequent partial recovery presents an interesting extreme case of human pressures on peatlands and the methods which can be adopted to reverse their effects. The moorland vegetation is predominantly M19 *Calluna vulgaris* - *Eriophorum vaginatum* blanket mire and M20 *Eriophorum vaginatum* blanket mire in the wetter areas, with H9 *Calluna vulgaris* - *Deschampsia flexuosa* heath and H12 *Calluna vulgaris* - *Vaccinium myrtillus* heath in the drier areas according to the British National Vegetation Classification (NVC; Rodwell 1991); see Averis *et al*. (2004) for an illustrated habitat guide. In the European Union EUNIS classification system this corresponds to blanket bog (7130) and European dry heath (4030). Treed areas, known locally as ‘clough woodland’ (see Moss 1905), also occur in steeper areas where peat formation is limited or not possible. For the purposes of this study, we have focused on the peatland areas of the moorland landscape.

For the South Pennine region, it is usual within floras to talk broadly of *Eriophorum* moors, whereas within such peatlands there is a distinct division between peat bog vegetation and the fen peatlands represented by flushes, springs and soakways. These fen components are often overlooked as distinct features when describing the peat moors but they form the hydrological margins of individual bog units and contribute significantly to the biodiversity of the peatland system as a whole and are thus an important part of interpreting early floristic records.

In terms of tracking individual species taxonomy and use of standard authorities covering the timespan considered in this study, nomenclature for higher plants has ranged from Hooker & Arnott (1855), Pratt (1855–1866), Bentham (1865 and later editions), to Clapham, Tutin & Warburg (1952 and later editions) and, most recently, Stace (1991 and subsequent editions). Nomenclature in the present article follows WCSP (2023).

For lower plants the position is even more complex. Until publication of *The Student’s Handbook of British Mosses* (Dixon & Jameson 1904) there was little in the way of a standard work for mosses. The 3rd Edition of that work appeared in 1924, but as Smith (1978) notes, “*...Dixon had an extraordinarily broad concept of the genus* [compared to today]*...*”. Watson (1955) subsequently provided a widely-used guide to the mosses and liverworts of Britain, then some 20 years later Smith (1978) produced a radical re-working of British and Irish moss taxonomy based on *Index Muscorum* (Wijk, Margadant & Florschütz 1959–1969), increasing the 115 genera of Dixon to 175 genera and his 625 species to 692 species. As Smith observes, “*Since [Dixon’s] time the very considerable taxonomic and nomenclatural changes have been such that it is often difficult for the non-expert to equate the 1924 taxa with those of today.”* Smith, albeit the 2004 2nd Edition, remains the accepted authority for British and Irish mosses. It is the authority used in the present article, except for the geneus *Sphagnum* which has undergone substantial re-working in recent years, the currently definitive authority being Michaelis (2019) albeit with a few alternates offered in Laine *et al*. (2018).

The accepted authority for liverworts was Macvicar (1912) until Watson (1955) provided an updated though not comprehensive guide. Today the accepted authority, used in the research for the present article, is Paton (1999). The taxonomic authority used for lichens was Dobson (1992).

TRAJECTORIES OF VEGETATION CHANGE IN SOUTH PENNINES PEATLANDS

The earliest descriptions of the vegetation of the South Pennines describe the peat as being formed by grey bog moss (*Sphagnum palustre*), cottongrass (*Eriophorum* spp.), heathers (*Calluna vulgaris* and *Erica* spp.), marsh horsetail (*Equisetum palustre*) and rushes (*Juncus* spp.) (Farey 1811). This is interesting because *Sphagnum palustre* in contemporary times is more associated with the fen conditions found at the margins of individual bog units while *S. papillosum* is the main *Sphagnum* species associated with peat bog conditions. It is impossible to know whether this is simply a case of mis-identification (the two species can only be definitively separated microscopically) or whether this indicates a former degree of enrichment across the main bog areas. Mis-identification is, however, the most likely explanation. The marsh horsetail (*Equisetum palustre*) and rushes (*Juncus* spp.), meanwhile, are generally restricted to fen flushes and pool margins.

Farey also describes attempts to 'improve' the peatland areas by drainage, liming and burning on areas that had been recently enclosed, though these appear to have experienced mixed success, the difficulty in adequately draining the peat and incidences of fires burning uncontrolled leading to large unvegetated patches within the landscape. By the time of Farey's survey, collection of peat for fuel was decreasing, though in some areas coal pits were excavated through the peat, indicating early pressures on the landscape as industrialisation was beginning.

Farey describes both *Sphagnum*-dominated areas containing "*Mosses… thinly sprinkled with heaths [heather], aquatic grasses, &c*" as well as areas where he describes the "*herbage of these disgusting Moor Lands*" as containing: heaths (*Calluna* and presumably *Erica* spp.), grasses, bilberry (*Vaccinium myrtillus*), cloudberry (*Rubus chamaemorus*), clusterberry (probably an alternative local name for *Vaccinium vitis-idaea*), cowberry (*Vaccinium vitis-idaea*), *Erica tetralix* and *Erica cinerea*, with cranberry (*Vaccinium oxycoccos*) in wetter areas. This is similar to the description given by Atkinson (1824) of common vegetation being heathers, *Empetrum nigrum*, *Vaccinium oxycoccos* and *V. vitis-idaea*, with *Rubus chamaemorus*, *Galium saxatile*, *Lycopodium clavatum*, *L. selago*, *L. alpinum* and *Arctostaphylos uva ursi* at higher elevations. All of these species are generally associated with the bog habitat or also, in the case of *Erica cinerea*, *Galium saxatile*, *Lycopodium alpinum* and *Arctostaphylos uva-ursi*, with thinner peats on steep slopes or around rocky outcrops as well as with dry upland heath.

Later in the 19th Century, Taylor (1879) begins to discuss processes of change on the moors, noting the disappearance of *Eriophorum alpinum* (*Trichophorum alpinum*) where drainage had occurred and the beginning of erosion of peat via gullying at Rossendale. Drainage was also suggested to be the cause of the disappearance of *Scheuchzeria palustris* and *Viola lactea* from west Yorkshire by Lees (1888), the former species being typical of bog pools but also occurring in some fen flushes, the latter entirely restricted to fen systems, grass heath or (rarely) vegetated rock ledges.

Despite the loss of some species, Taylor still paints a picture of much greater biodiversity than is currently present in the South Pennines. Instead of the 'monotonous' areas of either cottongrass or heather described by Smith (1903), Pearsall (1950) or Rodwell (1991) and a landscape familiar to visitors to the area today, Taylor suggests "*these moors are a floral glory - a mass of diversified colour*". As well as flowering plants, Taylor states the peaks of Derbyshire are noted for their alpine mosses, with Stag's horn clubmoss (*Lycopodium clavatum*) common at higher elevations and alpine clubmoss (*Lycopodium alpinum*) at lower elevations. The extent of these clubmosses was such that there are: "*rope like stems trailing on the ground for a great distance, and actually setting a trap for the feet of the incautious sportsman or rambler*" (Taylor 1879).

For the late 19th century, the floristic diversity described generally by Taylor is confirmed by the more rigorous survey of Lees (1888). Table 1 shows the occurrence of moorland species across west Yorkshire given by Lees, suggesting that many species considered rare on moorlands today, such as orchids and clubmosses, were still common, though drainage and agricultural improvement were beginning to change this.

By the 20th century, however, clubmosses are described as very rare by Smith (1903) and *Sphagnum* as not occurring on the *Eriophorum* dominated moors at all. Just 15 years after the account provided by Lees, Smith (1903) discusses the vegetation of the same moorlands in Yorkshire as containing much less diversity, though his account is perhaps more generalising than that of Lees. In this work Smith divides the local vegetation into distinct habitats, characterised as *Eriophorum* moor, bilberry (*Vaccinium myrtillus*) edges, heather (*Calluna vulgaris*) moor, wet heather moor, wet grass heath and dry grass heath. Smith suggests the *Eriophorum* moor occurs at high altitude and in wetter regions, whilst bilberry edges can be found at the highest

Table 1. Occurrence of moorland species in west Yorkshire, collated from Lees (1888) with habitat distinctions added. Modern taxonomy is used where possible.

Occurrence	Habitats and species
Common or very common	**Bog** *Drosera rotundifolia* (common in West but rare in East Riding), *Erica tetralix*, *Vaccinium oxycoccos*, *Empetrum nigrum*, *Eriophorum vaginatum*, *E. angustifolium*, *Sphagnum* spp., *Potentilla erecta*, *Vaccinium myrtillus*, *Lycopodium clavatum* (rare and decreasing at low elevation), *Aneura pinguis* (found with *Sphagnum*) **Fen** *Viola palustris*, *Galium palustre* (becoming rare due to drainage), *Pedicularis palustris*, *Pinguicula vulgaris* (becoming rare in cultivated areas), *Potamogeton polygonifolius*, *Dactylorhiza incarnata* (in higher areas), *D. maculata*, *Juncus effusus*, *J. inflexus*, *J. articulatus*, *J. acutiflorus*, *J. squarrosus* (becoming rare at low elevation), *Carex pulicaris*, *Molinia caerulea*, *Equisetum palustre*, *Polytrichum commune*, *Bryum pseudotriquetrum* **Grass heath** *Climacium dendroides* **Dry/*Calluna* heath** *E. cinerea*, *Calluna vulgaris*, *Hypnum* spp.
Infrequent	**Dry heath** *Ulex gallii* (locally abundant) **Fen** *Parnassia palustris* (locally abundant), *Carex dioica*, *C. curta*, *Selaginella* sp.
Rare	**Bog** *Drosera anglica*, *Drosera intermedia*, *Utricularia minor*, *Neottia cordata*, *Andromeda polifolia* **Fen** *Juncus obtusifolius(?)*, *Carex stricta* (locally abundant) **Grass heath** *Helleborus* spp., *Poa alpina* **Dry heath** *Lycopodium alpinum* (locally plentiful)

elevations where it surrounds rocky outcrops and steep slopes. Heather moors are found at lower altitudes and are generally drier, with grass heaths being drier still. Typical vegetation composition of Smith's *Eriophorum* moor is given in Table 2 with species lists for all habitats available in the Appendix; these lists broadly concur with the description of vegetation on the south-west Yorkshire moors given by Moss (1902), who suggests that heather moor is quite rare, but increasing with encroaching agriculture - suggesting that wetter peatland areas are being converted to drier *Calluna*-dominated upland heath.

It should be noted, however, that by the time Smith surveyed the vegetation of moorlands in Yorkshire, many species, such as the already-noted clubmosses, may already have decreased in abundance due to drainage, burning and acidic deposition. Woodhead (1929) includes in their history of the vegetation of the Southern Pennines a list of common species including those species that had recently become extinct in the area. This includes *Potentilla erecta*, *Galium saxatile*, *Vaccinium oxycoccos*, *Arctostaphylos uva-ursi*, *Ardromeda polifolia*, *Hammarbya paludosa*, *Neottia cordata*, *Helleborine latifolia [Helleborus foetidus?]*, *Gymnadenia conopsea*, *Pseudorchis albida*, *Dactylorhiza viridis*, *Paris quadrifolia*, *Narthecium ossifragum*, *Trichophorum cespitosum*, *Lycopodium clavatum, Lycopodium alpinum*, *Cryptogamma crispa* and *Botrychium lunaria*. All but the orchids and *Paris quadrifolia* are associated to a greater or

Table 2. Occurrence of moorland species in typical *Eriophorum* moor (Smith 1903).

Habitat	Species	Occurrence
Eriophorum moor (peat bog)	*Eriophorum vaginatum*	usually dominant
	Eriophorum angustifolium	sometimes dominant
	Empetrum nigrum	occasionally dominant
	Rubus chamaemorus	sometimes abundant
	Vaccinium myrtillus	sometimes abundant
	Calluna vulgaris	not abundant
	Erica tetralix	not abundant
	Carex curta	infrequent
	Drosera rotundifolia	rare
	Narthecium ossifragum	rare
	Lycopdium spp.	very rare
	Selaginella selaginoides	very rare

lesser extent with the peat bog habitat. Although *Arctostaphylos uva-ursi* is commonly associated with dry heath, its extent includes peat bog habitats, particularly in Scotland (Stroh *et al*. 2023).

The lack of *Sphagnum* noted by Smith (1903) is at odds with both earlier accounts of its dominance in forming peat in the area (Farey 1811), being cited as common by Lees (1888) and within peat cores containing both *Sphagnum* remnants and spores present across many peat depths (Tallis 1964, Blundell & Holden 2015). The earlier accounts of *Sphagnum* occurrence suggest a landscape which had already become floristically degraded by the time Smith completed their survey of moorland vegetation, leading to a baseline cited in later studies (e.g. Anderson *et al.* 1996) that already included a great deal of human influence. The timeline established by these historical sources also agrees with palaeoecological evidence of the disappearance of *Sphagnum* from the South Pennines during the mid-19th century (Yeloff *et al.* 2006).

Ten years after Smith (1903), the aptly named Moss conducted a similar survey of the moorlands of the Peak District (Moss 1913) and again classified the moorland areas into similar habitat types dominated by either *Eriophorum* or heather. These are defined in Tables 3 and 4, though with much more diversity noted for heather moors than by Smith. This may be due to differences in methodology as much as to differences between Yorkshire and the Peak District, because in his earlier work Moss highlighted the plant diversity of the heather moors of south-west Yorkshire (Moss 1902).

These lists suggest a high degree of habitat diversity as well as greater biodiversity on what is broadly termed 'heather moor', particularly considering that elsewhere Moss notes there are 18 different species of *Sphagnum* occurring in the South Pennines, with only two of these (*S. molle* and *S. teres*) described as being rare. The former is a species associated with wet heath, the latter with moderately base-rich fen conditions - while many of the remaining 16 species of *Sphagnum* noted are also likely to be associated with fen systems.

Moss also includes a new category of moor not included by Smith, namely the 'retrogressive moor', which is characterised by bilberry (*Vaccinium myrtillus*), crowberry (*Empetrum nigrum*), cloudberry (*Rubus chamaemorus*) as well as bare peat, appearing as the highest moors were becoming denuded of vegetation.

In the 1950s, Elliott (1953) conducted extensive surveys of the South Pennines to ascertain the effect of burning on vegetation biodiversity. He compared the results of these surveys to the Jonathan Salt herbarium, a naturalist's collection of local flora which was collected from the moors above Sheffield between 1775 and 1800, to ascertain changes in species abundance during the intervening period. He lists the following species as being either absent from the moors or at least no longer common in the early 1950s: *Arctostaphylos uva-ursi, Neottia cordata, Lycopodium alpinum, L. clavatum, L. selago, Vaccinium oxycoccos, Pedicularis palustris, P. sylvatica, Pinguicula vulgaris, Potentilla erecta, Erica cinerea* and *E. tetralix*. This largely confirms the evidence collated from other sources, in that Elliott's work suggests there has been a decrease in vegetation biodiversity since the beginning of the Industrial Revolution, with species of both bog and fen habitats being lost, whereas dry *Calluna* heath has been less affected.

Table 3. Occurrence of species on *Eripohorum* dominated moors in the Peak District (Moss 1913) with habitat distinctions added.

Occurrence	Habitats and species
Dominant	**Bog** *Eriophorum vaginatum*
Locally sub-dominant	**Bog** *E. angustifolium* **Fen** *Molinia caerulea*
Locally abundant	**Bog** *Empetrum nigrum*, *Erica tetralix*, *Calluna vulgaris*, *Vaccinum myrtillus*, *Trichophorum cespitosum* **Fen** *Carex curta*
Local or rare	**Bog** *Andromeda polifolia*, *Vaccinium oxycoccos*, *Narthecium ossifragum* **Fen** *Pinguicula vulgaris* **Grass heath** *Agrostis canina*

VEGETATION DIE-OFF AND BARE PEAT EROSION

Discussion of the formation of gullies begins with Taylor in 1879 at Rossendale with further discussion of bare peat found on Kinder Scout by Fry in 1892 and Holme Moss by Smith (1903), leading to the need for a new local habitat category, named as ‘eroding, retrogressive moors’ by Moss in 1913. The process of denudation seemingly accelerates in the 20th century. Writing of the Pennine moorlands, Trueman (1949) describes a landscape affected by the ‘smoke’ of nearby industrial areas of Lancashire which has killed off much of the vegetation, leading to an encroachment of heather. In some areas, this has gone further, as: “*Even the heather is dying out in the smokiest regions, leaving the more vigorous crowberry to expand into irregular masses which form islands in the dreary stretches of dark-brown peat*” (Trueman 1949). Such an account suggests a step-change in the transition from *Eriophorum* - and heather-dominated moors in which crowberry flourished, before the next stage eventually resulted in a landscape largely characterised by bare peat. This corresponds well with Moss’s classification of retrogressive moor. This step-change is confirmed by Woodhead (1929) who discusses an expansion of bilberry, crowberry and cloudberry where cottongrass has died back. These species are described as forming a temporary carpet over the bare peat before themselves being undermined by erosion and cracking of the peat surface. Both Woodhead in 1929 and Trueman in 1949 agree that most of the South Pennines are degenerating rapidly due to erosion of bare peat and that very little peat formation is still occurring.

Pearsall (1950) comments at some length on the widespread occurrence of ‘cotton-sedge moor’ (landscapes dominated by *Eriophorum vaginatum*) on deep peat in the South Pennines. He highlights the relative species poverty of this type compared with areas of deep peat in other parts of Britain and Ireland, but also notes the evidence that such areas had a very different character in earlier times. He observes, for example, that *Andromeda polifolia* was described as abundant in 1835 but by 1942 there were only two known locations for this plant in the region. Most particularly, Pearsall notes the complete absence of *Sphagnum* in the living vegetation yet reports that, in contrast, extensive observations reveal the almost continuous evidence of *Sphagnum* remains within the peat. The conclusion drawn by Pearsall from the collective evidence of change is that such *Eriophorum*-dominated peatlands have, in the preceding 150 years, suffered “*potent and widespread*” anthropogenic degradation as a result of

Table 4. Occurrence of species on heather dominated moors in the Peak District (Moss 1913) with habitat distinctions added. Modern taxonomy is used where possible.

Occurrence	Habitats and species
Dominant	**Dry/*Calluna* heath** *Calluna vulgaris*
Locally sub-dominant	**Dry/*Calluna* heath** *Erica cinerea, Vaccinium myrtillus*
Locally abundant	**Dry/*Calluna* heath** *Polytrichum* spp., *Pteridium aquilinum, Ulex gallii, Empetrum nigrum, Vaccinium vitis-idaea, Galium saxatile, Deschampia fluxuosa, Juncus squarrosus*
Occasional	**Dry/*Calluna* heath** *Cladonia* spp., *Lecanora* spp., *Dicranum scoparium, Campylopus paradoxus, Pohlia nutans, Plagiothecium undulatum, Blechnum spicant, Potentilla erecta, Pyrola media* **Grass heath** *Festuca ovina, Nardus stricta* **Fen** *Molinia caerulea* **Bog** *Trichophorum cespitosum*
Local, rare or very rare	**Dry/*Calluna* heath** *Lycopodium clavatum, Dryopteris dilatata, Salix repens, Betula pubescens, Quercus petraea, Rumex acetosella, Calluna vulgaris, Genista anglica* **Fen** *Carex dioica* **Wet heath/Bog** *Polygala serpyllifolia* **Grass heath** *Agrostis capillaris, Aira praecox, Carex nigra* subsp. *nigra, C. flacca, C. pilulifera, C. binervis, Luzula multiflora, Trientalis europaea, Melampyrum pratense, Lathyrus montanus* **Clough woodland** *Crataegus monogyna, Ilex aquifolium, Alnus incana, Sorbus aucuparia*
Only in wetter areas	**Fen** *Sphagnum* spp., *Polytrichum commune, Lycopodium* spp., *Ranunculus flammula, Potentilla palustris, Viola palustris, Hydrocotyle vulgaris, Pedicularis palustris, Pinguicula vulgaris, Cirsium palustre, Agrostis canina, Eleocharis quinqueflora, Carex echinata, C. nigra* var. *juncea, C. flacca, C. panicea, C. flava, Juncus acutiflorus, Dactylorchis maculata* subsp. *maculata* **Wet heath/Bog** *Drosera anglica, D. rotundifolia, Andromeda polifolia, Erica tetralix, Vaccinium oxycoccos, Eriphorum vaginatum, E. angustifolium, Narthecium ossifragum, Pedicularis sylvatica, Hypnum* spp.

burning, drainage and grazing and that this has led to the loss of species typical of the bog environment while encouraging the establishment of species associated with degraded peat. It is interesting that Pearsall appears not to recognise or acknowledge the role of atmospheric pollution in giving rise to such change.

CAUSES OF VEGETATION CHANGE IN THE SOUTH PENNINES

From the historical accounts consulted, two major drivers are proposed for the particularly marked vegetation change in the South Pennines, and this is likely to be true for much of the UK's upland area.

Firstly, and as a regionally potent driver of change in the South Pennines, fossil fuel usage from the later 18th century onwards was noted at the time to be killing off vegetation due to the 'smoke' emitted by the combination of industrial activity and the use of coal for domestic heating and cooking (Trueman 1949). More modern studies have confirmed that this was caused largely by a rapid increase in acid deposition (Ferguson *et al*. 1978), resulting in a fall in soil pH and increased sulphate and heavy metal concentrations. Lee (1998) attributes *Sphagnum* die-off in all but the minerotrophic flushes of the South Pennines to this deposition. Furthermore, the soot deposited on the vegetation, reducing photosynthetic capacity and water-exchange ability, was sufficiently thick and widespread that those walking on the hills at the time reported clothing completely blackened by soot (Chris Dean, Moors for the Future, personal communication). See Figure 1 for an approximate timeline of this effect. Here, we use the consumption of coal in the UK as a general proxy for industrial development and likely acid deposition to indicate the expected change in species distribution and development of bare peat over time. Whilst this gives an understanding of the increasing rate of atmospheric pollution in the Pennines, it should be noted that recovery of soils is often slow (Akselsson *et al*. 2013) and, therefore, a decrease in coal usage would not necessarily indicate or initiate an immediate change in soil chemistry; although declining use of this fuel and the introduction of flue gas desulfurisation in power plants has led to dramatic reductions of acid deposition (RoTAP 2012).

Recently, in long-term studies of vegetation change between 1954 and 2016, recovery from SO_x and NO_x pollution has been suggested to still be the dominant driver compared to local management (Alday *et al.* 2022). Although the increase in coal usage had mainly negative effects on the moorlands, one positive effect was that the availability of coal

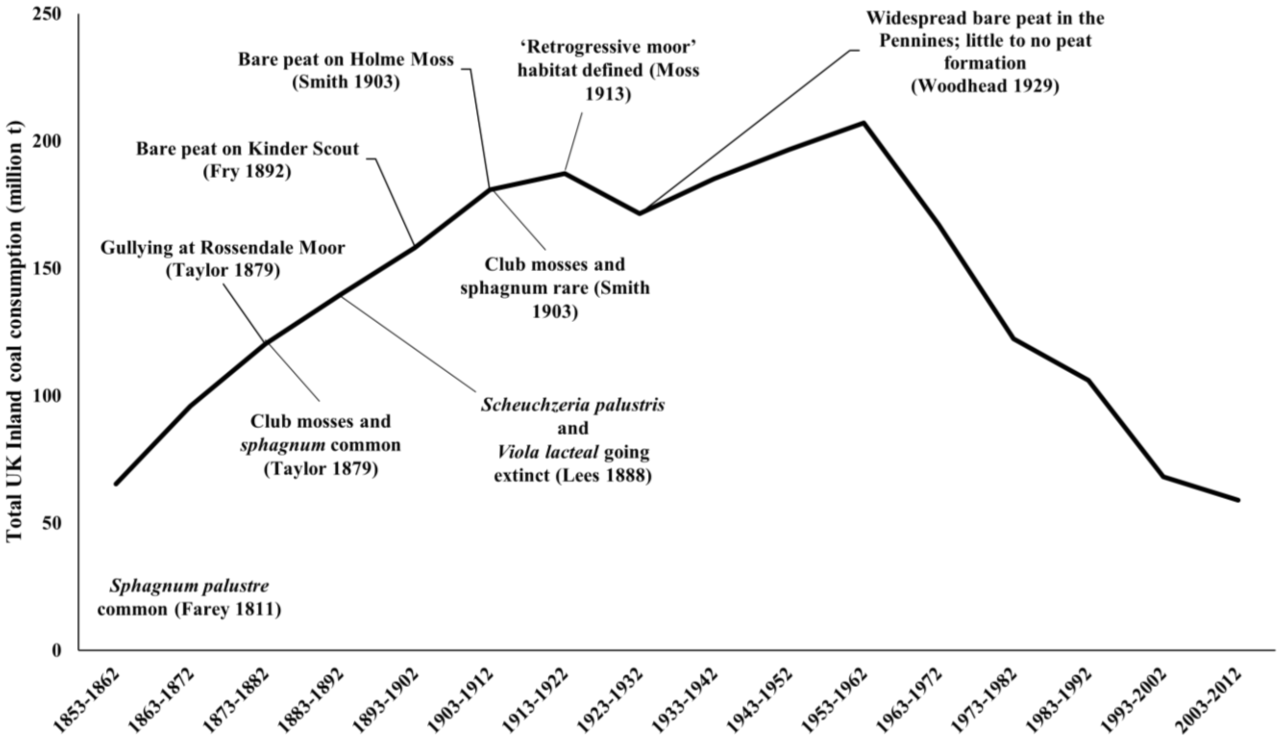

Figure 1: Moorland species abundance and bare peat occurrence in the South Pennines compared to UK coal use as a proxy for industrialisation and acid deposition. Coal data from GOV.UK (2022).

meant peat cutting (i.e. manual extraction of peat) for fuel, which had been locally important in some areas such as the town of Hope, died out (Farey 1811).

The second driver of change, which began affecting the moorlands around the same time with potentially interacting effects, was the socio-economic process of enclosure, a legislative mechanism by which formerly common land was brought under private ownership. Because acts of enclosure were passed through Parliament typically to benefit local aristocracy, this meant that the individuals now in control of land management decisions had access to capital large enough for landscape-scale interventions. The effect of this process on the moors is, therefore, an early example of public policy being used to leverage private investment for land management.

Enclosure led directly to a large increase in the area of moors which were limed, drained, and came under burning management (Farey 1811). Young (1771) confirms this, describing the attempts at agriculture on an area of 900 acres of 'black peat moor'. Once this area had been enclosed by a dry-stone wall it was drained, limed, paired (raked and burned) and then ploughed to crop turnips. Rennie *et al.* (1794) suggest that replacement of the former system of commoning, where each commoner was restricted in the number of sheep they could graze, was leading to an increase in liming, draining and burning as well as grazing intensity. As more land area came under agricultural production, Moss (1904) suggests a decrease in the area of *Eriophorum* and bilberry moor and an increase in the area of heather and rough grasses.

The new management regime was established primarily to improve the income from grazing sheep on the moors (Farey 1811), though priorities would change throughout the 19th century as grouse shooting became the dominant economic driver (Moss 1904). Farey (1811) suggests bilberry and heather moors support grazing of 0.5 sheep per acre, corresponding to 0.19 livestock units (LSU) ha^{-1} in modern units (using a conversion factor of 0.15 LSU per sheep). This is an order of magnitude greater than the sustainable grazing density of 0.05 LSU ha^{-1} for heather moorland and 0.06 LSU ha^{-1} for blanket bog suggested by Chapman (2007) and 'restoration' levels of grazing at $<$ 0.05 LSU ha^{-1} suggested by Natural England (Glaves 2008). Although many estimates exist of what level of grazing is truly 'sustainable' in these landscapes, the magnitude of the difference suggests that the moorlands of the South Pennines have been overgrazed for at least the 200 years since Farey's survey of Derbyshire in 1807, particularly as local records suggest large increases in grazing density throughout the 20th century (Yeloff *et al.* 2006).

As noted by Pearsall (1950), as well as in an extensive body of published literature, burning and grazing have played a major part in shaping the character of South Pennines blanket mire landscapes. Rodwell (1991) describes the prevalence of *Eriophorum* mire as having resulted from the over-riding influence of land-management practices, particularly grazing and burning (which often go hand-in-hand) while also noting the influence of drainage and aerial pollution. Bragg & Tallis (2001) observe that peat bog habitats are sensitive to various management activities and that both heavy grazing and frequent burning will tend to give rise to *Eriophorum*-dominated vegetation while low-intensity grazing and/or infrequent burning encourages the development of a more dwarf-shrub-dominated community. They also note, however, that such practices are widespread across the upland peatlands of Britain and so the particularly depauperate nature of blanket mire throughout the South Pennines requires additional explanation.

Other drivers of change are likely to have been much more localised. Farey notes that peat extraction for fuel had become uncommon by the time of his survey despite whole towns previously being heated by peat; a century later, Moss (1904) suggests the practice has virtually died out. Similarly, digging through layers of peat to access coal seams occurred in at least two places in Derbyshire, and at least one moor was worked for bog iron (Pilkington 1789), but this seems unlikely to have the same landscape-scale impact as industrialisation and enclosure. Finally, resident population and visitor numbers have both increased significantly over the period in question. Farey suggests the population of the High Peak region (more or less coincident with the modern Peak District National Park) to be approximately 37,000 in 1810, whereas it was around 91,000 in the 2021 census with nearly three million living nearby in Greater Manchester (ONS 2021), which led to localised trampling and erosion near pathways (Anderson *et al.* 1996).

FUTURE TRAJECTORIES

Whilst moorland denudation began in the later 19th century (Fry 1892, Smith 1903) and accelerated in the 20th century (Woodhead 1929), serious attempts at reversing this process were not made until the 1980s (Tallis & Yalden 1983). Stabilising the rapidly eroding, artificially acidified peat proved difficult, leading to development of a method of liming, fertilising, mulching and seeding a nurse grass crop to establish some vegetation cover to halt the erosion while native vegetation could establish (Anderson *et al.* 2009). This method has been broadly successful in re-establishing vegetation cover (Alderson *et al.* 2019), creating a new habitat type we term recovering moor (Figure 2), where introduced grass and native moorland species develop post-restoration.

With a viable method of restabilising bare peat in many instances, attention has focused on methods of reintroducing more moorland species. *Sphagnum* has received much attention due to benefits for carbon sequestration based on its recalcitrance to decomposition, as well as its natural flood management role by introducing increased surface roughness (Roberts *et al.* 2022). Other species, such as cloudberry (*Rubus chamaemorus*), *Eriophorum* spp., bilberry (*Vaccinium myrtillus*), crowberry (*Empetrum nigrum*) and cross leaved heath (*Erica tetralix*) have also been reintroduced (Moors for the Future 2022).

The re-introduction of *Sphagnum* is an important step in the establishment of peat forming conditions and the wet environment favoured by bog plants, but when assessing the desirable end-point for peatland restoration, consideration should also be given to the level of diversity observed in the pre-industrial era, rather than just to a small number of species (for example 13 indicator species in Alderson *et al.* 2019). From the Tables above we can see that many species which were once common on *Eriophorum* and heather moors are now absent. Whilst it may not be possible to bring back all of the species described, these lists serve as a useful resource for understanding lost biodiversity because current standard methods of assessing upland vegetation communities and restoration success do not include many of these species as indicators (JNCC 2009).

We therefore suggest the expanded list of positive indicator species for healthy *Eriophorum* and heather dominated moors in the Pennines shown in Table 5. We have combined the species listed as common or locally abundant by Farey (1811), Atkinson (1824), Lees (1888), Smith (1903) and Moss (1913) as well as the Jonathan Salt herbarium (1775–1800), but removed *Molinia caerulea* based on the suggestion that this has encroached onto moorlands as a result of nutrient enrichment (Pilkington *et al.* 2021), which certainly could have occurred by the time of the early 20th century surveys. While many more species could be added to this list (see Tables 1 and 4), Table 5 gives an indication of which ones were once common on these moors. It should also be noted that much diversity has been lost in the broad categories used by the UK Joint Nature Conservation Committee (JNCC), e.g. 'pleurocarpous mosses' and '*Sphagnum* spp.'. Reference should be made to Table 6, taken from Moss (1913), to understand the great diversity in bryophytes once found in the South Pennines, all of which have greater or lesser potential to be adopted as positive indicators.

While it may not be possible for all of the species to recolonise the Pennines once bare peat has been stabilised and water tables restored, these highlighted species nevertheless represent a more accurate picture of the extent of plant biodiversity from pre-industrial - or at least early industrial - times. It also serves to highlight the fact that fen components of the peatland environment have suffered as much as bog elements, and attention should be devoted to ensuring that these areas of water movement benefit from the same level of attention and restoration action as the more evident bog components. This expanded list of less common species is also relevant because long-

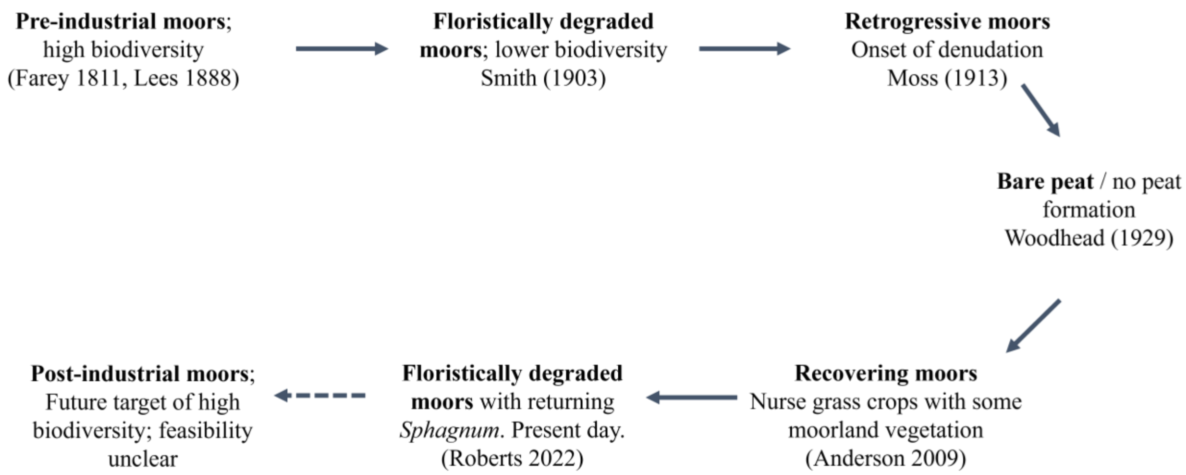

Figure 2. Schematic showing progression between different moorland states from the early 19th century to present-day restoration.

term studies on similar moorlands in the UK suggest measures aimed at increasing floristic diversity such as the cessation of sheep grazing do not alter the dominant vegetation but may alter sub-dominant communities (Alday *et al.* 2021, Marrs *et al.* 2020).

Some of the species mentioned as rare in earlier accounts, for example *Scheuchzeria palustris*, have suffered habitat destruction such that they are now confined to only very small areas within the UK (Tallis & Birks 1965) and are unlikely to reappear without intervention. More broadly, local seedbanks are likely to be deficient in rarer species (Marrs & McAllister 2020). Furthermore, the alpine species may no longer find their previous ranges suitable, given current and expected climate change. However, many of the suggested indicator species listed still occur in the Pennines (Stroh *et al.* 2023) and may spread as conditions become more favourable through restoration programmes. Monitoring of these expanded species lists could therefore be used to assess broader biodiversity gains from peatland restoration than those which are included in current monitoring practice, as well as ascertaining the extent to which the current floristically degraded moors move into a 'post-industrial' recovered state.

ACKNOWLEDGEMENTS

The authors thank Mike Brook of the Halifax Scientific Society for providing access to their archive, and the Special Collections team at the University of Manchester for providing access to their own collections along with that of the Manchester Geographical Society. Both authors were funded by the UKRI Greenhouse Gas Removals Demonstrator - Peat project (Grant Number BB/V011561/1).

Table 5. Comparison of current indicator species with suggested expanded species list from historical accounts. Modern taxonomy is used where possible.

Current indicator species for blanket bog (JNCC 2009)	Suggested additional indicator species
Andromeda polifolia, *Arctostaphylos uva-ursi*, *Betula nana*, *Carex bigelowii*, *Calluna vulgaris*, *Cornus suecica*, *Drosera* spp., *Erica tetralix*, *Empetrum nigrum*, *Eriphorum angustifolium*, *E. vaginatum*, *Menyanthes trifoliata*, *Narthecium ossifragum*, non-crustose lichens, Pleurocarpous mosses, *Racomitrium lanuginosum*, *Rubus chamaemorus*, *Rhynchospora alba*, *Sphagnum* spp., *Trichophorum cespitosum*, *Vaccinium* spp.	**Bog** *Neottia cordata*, *Lycopodium* spp., *Selaginella selaginoides*, *Aneura pinguis* **Fen** *Carex curta*, *Viola* spp., *Dactylorchis* spp., *Potentilla* spp., *Galium palustre*, *Pedicularis palustris*, *Pinguicula vulgaris*, *Potamogeton polygonifolius*, *Juncus* spp., *Equisetum palustre*, *Parnassia palustris* **Wet heath** *Galium saxatile*, *Ulex gallii*

Table 6. Mosses and liverworts noted as occurring on the south Pennine moors by Moss (1913). Modern taxonomy is used where possible.

Family	Species
Liverworts (*Hepaticae*)	*Blepharozia ciliaris (Blepharostoma?)*, *Lepidozia reptans*, *L. setacea(?)*, *Kantia trichomonis*, *Cephalozia lunulifolia*, *C. bicuspidata*, *C. bicuspidata* subsp. *lammersiana*, *C. divaricata*, *Scapania irrigua*, *S. nemorea*, *Mylia anomala*, *M. taylori*, *Jungermannia inflata*, *Solenostoma sphaerocarpum*, *S. gracillimum, Lophozia ventricosa*, *L. incisa*, *Frullania? gracilis*, *Barbilophozia lycopodioides*, *Nardia scalaris*
Sphagnaceae	*Sphagnum fimbriatum*, *S. rubellum*, *S. capillifolium*, *S. subnitens*, *S. molle* (rare), *S. squarrosum*, *S. teres* (rare), *S. compactum*, *S. subsecundum*, *S. inundatum*, *S. subsecundum* var. *gravetii*, *S. rufescens (contortum?)*, *S. denticulatum*, *S. austinii/affine*, *S. cuspidatum*, *S. recurvum*, *S. palustre*, *S. papillosum*
Polytrichaceae	*Pogonatum urnigerum*, *P. nanum* (rare), *P. piliferum*, *P. juniperinum*, *Polytrichastrum formosum*, *P. commune*

AUTHOR CONTRIBUTIONS

JPR devised the study, conducted the archival work and wrote the first draft of this article. RAL expanded the study with discussion of different habitats within the broader moorland categories described in the archival sources.

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Submitted 10 Mar 2023, revision 02 Nov 2023
Editor: Olivia Bragg

Author for correspondence: Dr Jonathan P. Ritson, School of Environment, Education and Development, University of Manchester, Oxford Road, Manchester M13 9PL, UK. Email: jonny.ritson@manchester.ac.uk

Appendix: Different moorland habitats and their vegetation as defined by Smith (1903).

Habitat	Species	Occurrence
Heather Moor	*Calluna vulgaris* *Ulex gallii* *Genista anglica* *Potentilla erecta* *Vaccinium vitis-idaea* *Vaccinium myrtillus* *Erica cinerea*	dominant
	Pyrola media *Trientalis europaea* *Rumex acetosella* *Dactylorhiza incarnata* subsp. *incarnata* *Luzula pallescens* *Juncus squarrosus* *Trichophorum cespitosum* *Carex nigra* subsp. *nigra* *Carex flacca* *Carex panicea* *Agrostis capillaris* *Festuca ovina* *Nardus stricta* *Blechnum spicant* *Thelypteris limbosperma*	rare
Wet Heather Moor (as for Heather Moor with these additional species)	**Bog** *Erica tetralix* *Drosera rotundifolia* *Andromeda polifolia* *Narthecium ossifragum* *Sphagnum* spp. **Fen** *Ranunculus omiophyllus* *Juncus conglomeratus* *Potamogeton polygonifolius* *Carex echinata* *Carex flava* *Deschampia caespitosa* *Molinia caerulea* *Sphagnum* spp.	no occurrence information given
Bilberry Edge	*Vaccinium myrtillus* *Empetrum nigrum* *Rubus chamaemorus* *Calluna vulgaris* *Rumex acetosella* *Juncus squarrosus* *Eriophorum vaginatum* *Eriophorum angustifolium* *Deschampsia flexuosa* *Festuca ovina* *Nardus stricta* *Lycopdium* spp.	dominant often abundant occasionally abundant common common common common common common common common rare

Habitat	Species	Occurrence
Wet Grass Heath	*Viola palustris* *Montia fontana* *Lotus uliginosus* *Hydrocotyle vulgaris* *Galium palustre* *Vaccinium myrtillus* *Vaccinium oxycoccos* *Calluna vulgaris* *Erica tetralix* *Narthecium ossifragum* *Juncus squarrosus* *Luzula pallescens* *Carex echinata* *Carex flacca* *Carex flava* *Carex nigra* subsp. *nigra* *Carex binervis* *Deschampia flexuosa* *Nardus stricta*	no occurrence information given
Dry Grass Heath	*Festuca ovina* *Nardus stricta* *Deschampia flexuosa* *Aira praecox* *Sieglingia decumbens* *Agrostis capillaris* *Viola lutea* *Genista anglica* *Ulex gallii* *Potentilla erecta* *Galium saxatile* *Vaccinium myrtillus* *Calluna vulgaris* *Erica cinerea* *Dactylorchis maculata* *Luzula pallescens* *Carex pulicaris* *Carex binervis* *Pteridium aquilinum* *Blechnum spicant* *Thelypteris limbosperma*	no occurrence information given