National Trust

Managing Molinia?

Proceedings of a 3-day conference 14-16 September 2015 in Huddersfield, West Yorkshire, UK.

Edited by Roger Meade

National Trust Molinia Conference organising committee at Marsden Moor Estate office. L-R: Alan Stopher, Craig Best, Roger Meade, Nick Pollett and Andrew Underdown. With assistance from Rob Henry, Alyssa Young and Frances DeGiorgio (not in picture).

Cover image © Alan Stopher

View towards Pule Hill north-eastwards from the route of the old turnpike. Redbrook reservoir is in the middle distance. This is one of the original canal reservoirs which is maintained by Canal & River Trust with the water supplying Yorkshire Water's customers. A sailing club also uses the amenity. *Molinia* tussocks dominate the foreground.

Foreword

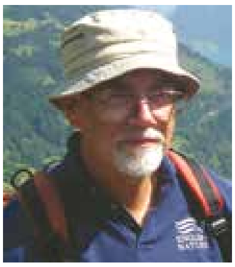
To cut, or not to cut. A very straightforward question, but so much more succinct than the answer. This is the dilemma often faced by managers of land for nature conservation where the easiest solution is to just follow what others are doing. As a former habitat specialist for a statutory nature conservation body, I am familiar with the pressures to provide clear guidance and one I remember well is the popular belief that any trees on lowland raised bogs should be cut down and prevented from regrowth. While there is a case for adopting this principle in many situations there are those in which it is not necessary, and is even undesirable from other perspectives such as the trees' contribution to the landscape. It means that the conservation land manager must not only be aware of the bare bones of the received wisdom, but also of the caveats that make it possible for him or her to arrive at a reasoned judgement for their specific situation.

So it is for *Molinia caerulea*, the Purple Moor-grass. It is a widespread species, being part of a range of wetland and damp pasture plant communities, sometimes becoming dominant, in other situations adopting a more restrained role. There are instances where its ability to dominate does, in the opinion of conservation managers, detract from what constitutes 'favourable condition', the conclusion being that it should be removed and replaced with something more 'natural'.

This conference was conceived in a culture where some conservation managers feel they should go out and cut off the *Molinia* tussocks, in the hope of replacing them with something closer to the expectations of the statutory nature conservation organisation responsible for setting conservation objectives. This is the point at which resources can be consumed in the pursuit of a sometimes uncertain goal, again, carried out on the back of the received wisdom. There was, it seemed, a need for the providers of guidance to be clearer about their objectives and for the land managers, where cutting is appropriate, to be more aware of parallel work being done on *Molinia* management elsewhere to help target their resources efficiently.

Volunteers and National Trust staff at the Marsden Moor Estate were of one mind in wanting to establish clarity in the perceptions of *Molinia*-dominated habitat in the uplands, particularly on peat. The idea was welcomed by Natural England, who, in conjunction with the International Peat Society (IPS), provided the financial backing for the event. The programme was designed to give as much theoretical background as possible within the available time and to exchange relevant land management experience. In addition to the sense of achievement arising from providing the event, the organisers feel that it would be an ample reward for their efforts if these Proceedings act as a benchmark for ongoing discussion of the subject, the development of concepts based on science, and the sharing of land management experience.

The organisers would like to thank all the contributors for the high quality of their presentations and their patience in carrying out their 'instructions'; also, all those attending, whose willingness to pitch into the discussions made the event, we believe, a great success. We are particularly grateful to Natural England and the IPS, without whose support the event would not have taken place. For further information, please contact marsdenmoor@nationaltrust.org.uk



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Chair
Molinia Conference Organising Committee (Craig Best, Rob Henry, Roger Meade, Nick Pollett, Alan Stopher, Andrew Underdown, Alyssa Young, Frances DeGiorgio)

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Figs 1 and 2: Close-up and distant views of Molinia caerulea on the Marsden Moor Estate.

Introduction

Purple Moor-grass can be a real asset to the landscape, particularly in the autumn when it changes colour from green to yellow, to orange-red and finally to bleached white (Figures 1 & 2). Reason enough to love it, but talk to representatives of nature conservation bodies and a rather different perception quickly emerges. This noble and majestic grass stands accused of crimes against ecology; the charge is that it occupies space to the exclusion of other more valued species.

Although the charge is now levelled at *Molinia* in the uplands, the motivation behind it is not new. Its invasion and dominance on abandoned cutover lowland peat bogs was noted back in the 1970s as an impediment to their restoration as peat-forming ecosystems in the state of Lower Saxony's Moorschutzprogramm (e.g. Eigner & Schmatzler, 1980). Over the years robust conceptual models have been developed for the restoration of lowland bogs and peat formation has been re-established on many after relatively simple hydrological manipulation. In these lowland habitats the area of peatland affected is less and the gradients are gentler, thus requiring less resources to tackle the retention of water and repair the consequences of its erosive power.

The field excursion on the third day of the conference pointed out large areas of the local moorland around Marsden where *Molinia* tussocks have been cut off in the expectation of it being replaced by plants of greater conservation interest. Such actions and use of the necessary resources demands a high degree of confidence in a positive outcome. The conference was conceived with the aim of testing the underlying concepts, not to undermine them, but to make sure they are expressed unequivocally and underpinned with sound science.

The aim of this paper as an introduction to the conference is to provide a picture of *Molinia caerulea* in its various ecological niches, particularly through its presence in many National Vegetation Classification (NVC) plant communities. Then, to touch on how we come to decide whether it is a *bona fide* component of our upland habitats, particularly in blanket mire, or an ecological 'weed'. It draws heavily on the many different NVC communities with *Molinia* found in the New Forest because the author has recent experience of them there. On these heaths and mires in Hampshire, Dorset and Wiltshire, *Molinia* is found in all plant communities except the dry heaths and some of the woodlands. It is acknowledged without reservation that the New Forest does not match the altitude of the uplands forming the focus of the conference but it has a very fine array of different habitats in which *Molinia caerulea* plays an important part.

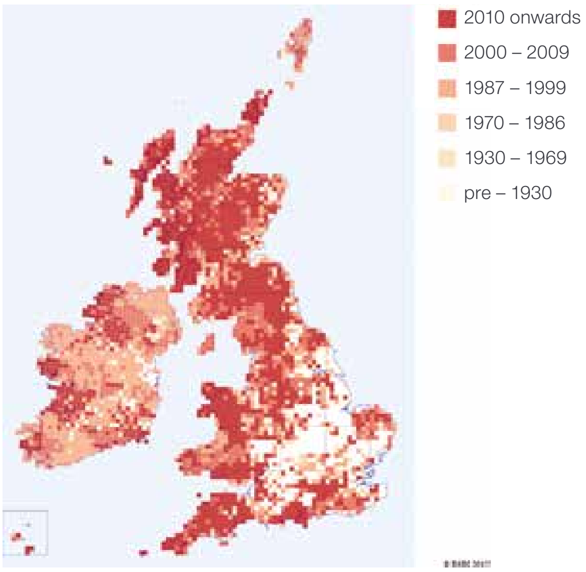

Figure 3: Distribution of Molinia caerulea in the British Isles.

From: BSBI website.

The distribution of *Molinia caerulea* in the British Isles

The presence of plant species in 10km squares has been mapped at intervals over decades by the Botanical Society of the British Isles (BSBI). Maps available on the internet (Figure 3) show it has been extremely widespread but that there may have been a reduction since 1970-1986, particularly in Ireland. It has a north-westerly distribution but is also found, for example, on fens in Norfolk (East Anglia) and on cutover lowland bogs in South Yorkshire, The East Riding of Yorkshire and North Lincolnshire.

The BSBI also describes sub-species and varieties within the *Molinia caerulea* taxon (Table 1). The sub-species *arundinacea* and *caerulea* var. *viridiflora* are associated with fens, sandy heaths and rivers, such as those found in parts of the New Forest, whereas sub-species *caerulea* var. *caerulea* is described as widespread and is likely to be that found on Marsden Moor. In essence, sub-species *arundinacea* is bigger than sub-species *caerulea* var. *caerulea*.

Table 1: Characteristics of the Molinia caerulea subspecies and varieties

Name:	arundinacea	caerulea var. caerulea	caerulea var. viridiflora
Height cm	70-150	8-65	40-85(-100)
Tussock cm	20	No info	30
Leaf length cm	28-70	5-50	12-48
Leaf width mm	4-8.5	1-6(-8)	3.3-5.5(-6)
Panicle length cm	25-65	1-30	8-35
Spikelet length mm	(3-)4-7.5	3-5.5	3.3-5.5(-6)
Lemma mm	3.5-6	3-4	2-6.5(-8)
Habitat	Dense tussocks in fens, fen scrub and by rivers	Widespread	Open woodland, valley fens, spring areas and on sand heath

Molinia caerulea in plant communities

The concept of plant communities is based on the observation that individual plant species occur together with certain others more frequently than would be expected by chance; the groupings of these species are known as plant communities.

These groupings have been described in different ways. The lack of detail for the UK types in the 'continental' phytosociology (Braun-Blanquet, 1928) (*inter alia*) led to the development of a bespoke scheme in the United Kingdom (UK), the National Vegetation Classification (NVC) in the early 1990s. It is widely used in describing, evaluating and selecting sites for designation as e.g. Sites of Special Scientific Interest (SSSI). *Molinia caerulea* occurs in many NVC communities.

The NVC (Rodwell (Ed), *et al.* 1991-2000) has become 'industry standard' in the UK, becoming written into formal documents such as Conservation Objectives for SSSI. It is worth noting that while the NVC has become a useful aid in all sorts of ecological endeavours, it was preceded by other descriptions of vegetation types, some of which were very helpful in individual site studies and communities in which *Molinia caerulea* is dominant (e.g. Wheeler, 1980). Amongst other things, the NVC provides a contemporary platform for describing the ecological niches in which this grass is found.

Molinia occurs in all the NVC communities listed in Table 2 and more besides. The table concentrates on the mires, heaths, grasslands and woodlands of which *Molinia* is a significant component as this is judged sufficient to demonstrate the ecological range over which the species is found.

Table 2: A selection of NVC communities in which Molinia caerulea is an important component.

NVC community		Molinia constancy (Domin cover) in sub-communities	Place in blanket mire
M1	*Sphagnum auriculatum* bog pool community.	I (1-7)	**Bog pools**
M2	*Sphagnum cuspidatum/recurvum* bog pool community.	I (3-5)	**Bog pools**
M3	*Eriophorum angustifolium* bog pool community.	I (4)	**Bog pools**
M4	*Carex rostrata – Sphagnum recurvum mire.*	II (3-5)	Sumps
M5	*Carex rostrata – Sphagnum squarrosum mire.*	II (1-4)	Sumps
M6	*Carex echinata – Sphagnum recurvum mire*	V (2-9); II (2-5); 2 (2-7); IV (1-8)	Water tracks, sumps
M9	*Carex rostrata – Calliergon cuspidatum / C. giganteum mire*	III (1-5); II (1-4); III (1-5)	Flushes
M10	*Carex dioica – Pinguicula vulgaris mire*	III (1-7); IV (1-6)	Flushes
M13	*Schoenus nigricans – Juncus subnodulosus mire.*	IV (1-4); V (1-7); V (1-7)	
M14	*Schoenus nigricans – Narthecium ossifragum mire*	V (6-8)	
M15	*Scirpus cespitosus – Erica tetralix wet heath*	V (4-8); V (1-9); V (4-7); V (1-9)	
M16	*Erica tetralix – Sphagnum compactum wet heath*	V (3-9); V (2-8); V (4-6); III (2-8)	
M17	*Scirpus cespitosus – Eriophorum vaginatum* blanket mire	V (1-8); IV (1-7); II (1-6)	**Major component**
M18	*Erica tetralix – Sphagnum papillosum* raised & blanket mire.	II (1-4); II (1-4)	**Major component**
M19	*Calluna vulgaris – Eriophorum vaginatum* blanket mire	II (1-7); I (1-4)	**Major component**
M20	*Eriophorum vaginatum* raised and blanket mire		**Major component**
M21	*Narthecium ossifragum – Sphagnum papillosum* valley mire.	V (2-9); V (2-7)	Within macrotope
M22	*Juncus subnodulosus – Cirsium palustre* fen meadow	II (1-7); III (1-4); II (1-3); I (1)	
M23	*Juncus effusus/acutiflorus – Galium palustre* rush pasture.	III (1-7); II (1-5)	Within macrotope
M24	*Molinia caerulea – Cirsium dissectum* fen meadow	V (3-6); V (1-8); V (4-8)	
M25	*Molinia caerulea – Potentilla erecta* mire	V (4-10); V (2-9); V (6-10)	Degraded areas
M26	*Molinia caerulea – Crepis paludosa* mire	V (4-8); V (1-8)	Within macrotope
M27	*Filipendula ulmaria – Angelica sylvestris* mire	II (3-4)	
M29	*Hypericum elodes – Potamogeton polygonifolius* soakway	III (1-5)	Soakways
W4	*Betula pubescens – Molinia caerulea* woodland	IV (1-10); IV (3-8); IV (1-9)	

The constancy of a species in a community is the percentage of the contributory lists in which it occurs, and is usually expressed in five percentage classes using Roman numerals; they are in steps of 20% so that class I means it is occurring in 1-20% of quadrats, if V it is 81-100%. The Domin scale is used to express the mean species' cover, and this is based on percentage of the sample area (e.g. 4m^2) it covers, and ranges from 1 (lowest) to 10 (highest). Some of the communities listed in Table 2 have more than one set of constancy and cover range values and this is because each pair of figures refers to a different sub-community.

Those communities with a maximum *Molinia* cover greater than Domin 8 (51-75%) are highlighted in red to distinguish between those in which *Molinia caerulea* can be a major component, and the remainder in which it has a much smaller representation in the vegetation stand. Each is listed separately in *Figures 4* and *5*.

Figure 4. Main NVC groupings in which Molinia can become dominant

Water tracks with rushes and *Sphagnum* spp (M6).
Wet heath (M14,M15, M16). Lowland and also upland in the west, can become dominant and merge into e.g. M25; also in other NVC heaths of lesser geographical extent.
Blanket mire (M17). In the north and west.
Valley mire (M21). Lowland and upland, can merge into e.g. M25a sub-community.
Molinia 'grassland' (M24, M25, M26).
Betula pubescens-Molinia caerulea woodland (W4).

Figure 5. Some NVC groupings in which Molinia is present but does not become dominant

Bog pools (M1, M2, M3). Around rather than in the pools, though can stand proud as tussocks.
Sedge-dominated wetlands (M4, M5)
Groundwater seepage wetlands (M9, M10, M13)
Soakways in wet heath (M29)
Blanket mire M18, M19, M20. But beware circularity of argument if 'blanket mire' becomes defined by the NVC community rather than by structure and hydrology. The use of the term blanket mire still holds good for M17 even when it has a high cover of *Molinia*.
Rush pastures (M22, M23)
Mesotrophic fen (M27)

Communities in which *Molinia* is cited as achieving more than 50% cover *(Figure 4)* include water tracks, wet heaths, blanket mires, valley mires, certain types of grassland and even woodland. In blanket mire it can become dominant in very wet peaty but not anaerobic soils, and is described by Rodwell (Ed) *et al.* (1991-2000) as a component of M17 blanket mire. It forms its own suite of grasslands: M24, M25, and M26, some of which are included in the EU Habitat and Species Directive's Annex 1 Habitat, Natura 2000 code 6410 '*Molinia* meadows on chalk and clay' (European Commission, 1996).

The grass also occurs in a suite of communities at much lower cover, and it is not confined to acidic habitats *(Figure 5)*. They include blanket mire communities such as M18, but in which they are in balance with many other species, including *Sphagnum* mosses. The *Molinia* may be held in check by waterlogging within these communities, where it is inclined to form tussocks above the peat water level.

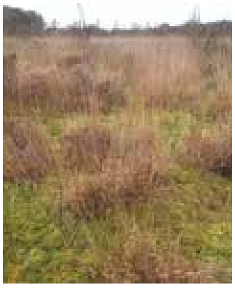

Figure 6: Tussocks of Molinia caerulea within a Sphagnum moss carpet at Danes Moss, Cheshire.

Tussock-formation is important from many perspectives, not least, that of survival for *Molinia caerulea*, where the water table may be high or fluctuating, creating temporarily hostile hydrological conditions for the grass. It provides a niche for species, both plant and animal, that would not be able to prosper in the surrounding waterlogged mire, such as the ericaceous plants and a number of invertebrates. It develops tussocks in a number of its communities, including the bog pools with communities M1 *(Sphagnum auriculatum)* and M2 *(Sphagnum cuspidatum/recurvum)*. It has survived as tussocks in the M2 community developed on the re-wetted surface of lowland bogs such as Danes Moss, Cheshire. (*Figure 6*; Meade, 2014). The M2 *Sphagnum cuspidatum/recurvum* bog pool community is also found on blanket peat in the UK.

The term blanket bog has been deemed misleading by Tallis (1997) in that the wetland macrotope includes types other than bog in the strict ecological meaning of the word (Wheeler & Proctor, 2000). For example, it encompasses valley mires in which the wetland is sustained by groundwater seeping through peat and other strata, as well as directly from atmospheric precipitation. The term blanket mire follows Tallis and is used here to encompass both bog and fen being hydrologically linked and lying within the same wetland complex.

Figure 7. Gradation of wet heath and mire communities in a New Forest wetland.

It is arguable whether the New Forest mire illustrated in Figure 7 includes any true bog rather than mineralogically different types of fen and wet heath, but it does illustrate a linked series of wetland plant communities, all inclusive of *Molinia caerulea*. It is a valley mire within a heathland, the most adjacent non-mire community being the M16 *Erica tetralix-Sphagnum compactum* wet heath, in which *Molinia* can be a major low tussock-forming component. There is a central water-track within the mire in which *Molinia* tussocks are conspicuous, and that is the M25a *Molinia caerulea-Potentilla erecta* mire, *Erica tetralix* sub-community. The same sub-community is found along the 'landward' edge of the mire, merging with the M16 wet heath. The most *Sphagnum*-rich community, occupying the remainder of the mire surface is the M21a *Narthecium ossifragum-Sphagnum papillosum* valley mire, *Rhynchospora alba-Sphagnum auriculatum* sub-community, also containing *Molinia* (Meade, in prep). Valley mires occur within the upland topography and are often included as part of the blanket mire, not least, because they can accumulate a considerable depth of peat matching or exceeding the depth of peat deposit in the entirely rain-fed parts of the mire.

Table 3. Some important plant species associated with the M25a NVC sub-community also found in blanket mire.

Species	Constancy	Cover range
Molinia caerulea	V	4-10
Potentilla erecta	IV	1-4
Erica tetralix	IV	1-7
Calluna vulgaris	II	1-7
Eriophorum angustifolium	III	1-5
Myrica gale	II	2-9
Sphagnum fallax	II	1-9
Sphagnum auriculatum	II	1-6
Sphagnum papillosum	II	2-6
Sphagnum palustre	I	1-6
Sphagnum capillifolium	I	1-6
Narthecium ossifragum	II	1-7
Polytrichum commune	II	1-7
Vaccinium oxycoccos	I	1-4

The representation and physiognomy of *Molinia caerulea* is very variable in the M25a community but it includes a number of species associated with blanket mire in favourable condition (Table 3), including *Sphagnum papillosum, S. capillifolium* and Cranberry *Vaccinium oxycoccos; Sphagnum papillosum* achieves 26-33% cover. *Molinia* cover ranges from Domin 4 (4-11%) to 100%. The cover of *Erica tetralix* can be high (Domin 7, 34-50%); *Calluna vulgaris* may also achieve the same cover.

It raises the question as to whether the list of communities cited by the Joint Nature Conservation Committee (JNCC, 2006) as able to contribute to blanket mire in favourable condition in England, such as M18 and M19 is really sufficient to describe the range that the SSSI series in England is designed to represent. This theme is developed further by Jepson *(vide infra)* for blanket mires in Lancashire that appear to be dominated by *Molinia caerulea*.

The distinction between the communities in the New Forest and elsewhere in which *Molinia* can be dominant is not always clear-cut. For example, Marsh Plume Thistle *Cirsium dissectum* is distributed throughout a number of communities alongside *Molinia* but becomes conspicuous in the M24c *Molinia caerulea-Cirsium dissectum* fen-meadow, *Juncus acutiflorus-Erica tetralix* sub-community (Figure 8). Its distinction from M25 and M16 is dependent on the overall difference in species complement but when grazed heavily (Figure 9), the structural distinctions are lost. It demonstrates the impact of management on *Molinia*-dominated vegetation and in the case of the New Forest the grazing is provided by ponies and cattle.

The tussocks of *Molinia caerulea* are augmented by those of Common Sedge *Carex nigra* and Fibrous Tussock-sedge *Carex appropinquata* in the M26 *Molinia caerulea-Crepis paludosa* community (Figure 10; Meade, 2011). It contains a wide array of associates, including lime-loving species such as Great Burnet *Sanguisorba officinalis*.

Figures 8 and 9. Molinia caerulea forming the NVC M24c sub-community in a New Forest mire, a) ungrazed and b) grazed.

Figure 10. Molinia caerulea in NVC M26 community at North Fen, Malham.

The status of *Molinia*-dominated blanket mire

In all these examples the presence and physical structure of *Molinia* is acceptable and indeed defines them. The NVC records and describes vegetation as it is, without judgements about whether it is natural, semi-natural or unnatural. The defining of favourable condition for indigenous habitat, part of the process of choosing, designating and managing SSSIs, differs in that it does involve judgements. Future progress is dependent on developing a shared view of what is to be represented and what is an unnatural trend unworthy of representation.

Few would disagree that our natural heritage needs to be protected and that the attributes of the habitats and the numbers of the species they host may shift as a result of environmental changes. Distinctions may be drawn between factors that are natural and others that arise as a consequence of human activity, though it could be argued that what we do is as natural as what any other species does. We need fixed points in the argument to which all can subscribe and then plan the wise use of our resources.

The 'Moore Criteria' for choosing SSSI have been used since early 1980s. It involves concepts such as typicalness, naturalness, size, rarity, and fragility and is published as the guidelines for SSSI selection (JNCC, 2013). Applying these involves many judgements dependent on the breadth of experience held by the practitioner. For naturalness, the Guidelines say that specific guidance is extremely difficult, since so much depends on particular circumstances, but the guiding principle is: the presumption against the site meeting the qualifying standard for naturalness increases as signs of artificiality increase. Judgement on naturalness may also be influenced by the prospects for reversing the damage or loss of quality. Adaptation to climate change means that a flexible approach is needed more than ever before, accepting that some change will be irreversible.

In the New Forest example, the SSSI citation recognises the ecological basis for variation – enrichment (mineral ions and nutrients) decreasing with distance from source and within flow lines. *Molinia* exploits the cumulative enrichment believed to be associated with distance from seepage source and with water-flow dynamics. Rightly or wrongly, the perceived diversity is underpinned by an ecological rationale and dominant *Molinia* is acceptable within its niches. Such a rationale is not yet developed, or at least expressed in the public domain, for *Molinia*-dominated blanket mire.

How does our approach to blanket mire conservation incorporate succession and changes in climate and/or air quality? How do we know blanket mire should have M17, M18, M19 or M20 NVC communities? Does *Molinia*-dominated bog have any of the desired botanical diversity? Have these changes happened before? Is it a 'still-stand' or just a phase in succession; do we really have to intervene?

If *Molinia*-dominated blanket mire is to be deemed unnatural and not worthy of representation in the SSSI series it is incumbent on the statutory nature conservation bodies to answer these questions and demonstrate that this condition is both artificial and reversible. It may, for example, on the one hand be the consequence of a changing climate; on the other, it may have arisen from a mix of grazing practices, air quality and (anti-)social behaviour such as torching the moors, all arguably unnatural. The jury may still be out on whether it is reversible in the longer term, and if the alternative vegetation bears any relation to the presumptions of what blanket mire should be like.

The dilemma facing many at the conference will be to decide how typical is your example? It relies on preconceptions about what blanket mire quality means in all parts of the UK, and these, in the author's opinion, need to be re-evaluated. In reaching this conclusion the author has taken account of the seriousness of changing written official guidance and the repercussions it can have on the conservation 'process'. However, the familiar old mantra 'this is not the time' cannot hold good for ever, and the current revision of the SSSI selection guidelines for bogs provides a rare opportunity. For the future, guidance for blanket mire should:

- Define and include the full range of ecological variation and geographical variants;
- Ensure structural, vegetational and animal assemblages are well-represented;
- Review the current presumption in favour of *Sphagnum*-based attributes to include types with less *Sphagnum*;
- Critically review the primacy of peat formation capability and its predication on the presence of *Sphagnum*.

Only then can the management of tussocky *Molinia* in blanket mire be justified on places such as the Marsden Moor Estate, West Yorkshire. Meanwhile, we can just continue to appreciate its beauty in the landscape while we are able.

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Palaeoenvironmental evidence for the recent rise of *Molinia caerulea*: vital information for conservation managers

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Introduction

Concern over the abundance of ***Molinia caerulea*** in bog and moorland habitats, and particularly its alleged recent rise to dominance in some upland areas (see Figure 1), has given rise to conservation-management attempts to reduce that supposed unprecedented dominance and to 'restore' former peat-forming communities. This short review highlights the value of palaeoecological studies to ascertain (a) whether the *Molinia* dominance is as short-lived as believed; (b), if so, when the alleged rise to dominance took place; (c) what were the causes; (d) what plant communities were dominant previously; and (e) what recommendations might be made as to a viable path to restoration.

Figure 1. Landscape dominated by Molinia caerulea in upland mid-Wales.

The review is informed by examples of collaborative research conducted between palaeoecologists based at the Centre for Environmental Change and Quaternary Research, University of Gloucestershire, and these conservation agencies:

- The Heather Trust: recent rise to dominance of *Molinia* in Environmentally Sensitive Areas, Exmoor;
- (former) Countryside Council for Wales (CCW): recent human impact on blanket bog/moorland in Mid and South Wales;
- (former) English Nature (EN): preliminary investigation of recent vegetation changes on moorland in Northern England;
- Yorkshire Peat Partnership: palaeoenvironmental evidence from moorland in Yorkshire to provide data to support conservation management.

Here, we provide the rationale for each; list some of the palaeoecological techniques available, their utility and application; and we provide some conclusions from the collaborative studies and reference the published work.

Rationale for collaborative studies

(a) Collaborative research with The Heather Trust, on Exmoor (Chambers et al., 1999)

- Concern over alleged replacement of heather by *Molinia*, Exmoor;
- The Heather Trust was conducting experiments to control *Molinia*;
- Palaeoecological data might add to anecdotal evidence for recent rise to dominance by *Molinia*;
- Palaeoecological techniques to be applied and tested for efficacy;
- Long-term palaeoecological data might provide greater legitimacy for control of *Molinia* than merely anecdotal evidence.

(b) Studies commissioned by CCW into recent human impact on blanket bog/moorland in upland South and mid-Wales (Chambers et al., 2007a, 2007b, 2013)

- Much of blanket bog in South Wales seems degraded, and depauperate;
- Concern over loss of Sphagna, and at some sites, overwhelming dominance of *Molinia*;
- Believed to result from one or more of burning, overgrazing, erosion, atmospheric pollution;
- Thought that palaeoecological data could provide evidence as to timing and causes of assumed 'recent' human impact;
- This greater understanding would help inform future conservation management and the viability of imposed 'targets'.

(c) Study commissioned by EN (Project VT0419): palaeoenvironmental examination of moorland in Northern England (Chambers & Daniell, 2011)

- 95% by area of SSSIs to be in 'favourable condition' by 2010 (a GPSA[1] target);
- Many moorland sites would fail to meet this criterion;
- Concern over the effects on moorland of land-use intensification in the English uplands;
- Understanding of site vegetation history would help determine the relevance and viability of these targets;
- This understanding would also be vital for the development of any restoration programmes.

[1]Government Public Service Agreement.

(d) Palaeoecological research sponsored by Yorkshire Peat Partnership (McCarroll et al., 2015, in press, submitted).

- Mossdale Moor (MDM), Oxenhope Moor (OXM) and West Arkengarthdale (ARK) were selected for palaeoecological analysis by YPP;
- OXM is the most 'degraded' and ARK the least;
- Areas of bare peat, extensive areas of *Eriophorum vaginatum* and a lack of Sphagna at Mossdale and Oxenhope Moors;
- Palaeoecology can help determine causes of recent changes and which factor(s) led to recent degradation;
- Data could aid understanding of the previous habitat, whether and how it can be restored.

These studies exemplify calls for more dialogue between ecologists and palaeoecologists to realise the benefits of informing conservation and management by genuinely long-term (centennial to millennial-scale) datasets (Davies & Bunting, 2010; Gillson, 2015).

Techniques

Many of the palaeoecological techniques that can be applied to inform conservation management are those that have been developed for reconstructing vegetation history and for investigating climate change from peats (De Vleeschower *et al.,* 2010a; Chambers *et al.,* 2012).

They include methods of field sampling (De Vleeschower *et al.,* 2010b) and laboratory analysis (see Table 1). *Molinia* epidermis is distinctive (Figure 2) and can be distinguished from other graminaceous material; it is more likely to be found abundantly when relatively fresh, although its recognition in older samples provides at least some reassurance that any recent rise recorded by palaeoecological data is real.

Table 1. Examples of palaeo-ecological techniques used to inform conservation management.

Field sampling
monolith sampling (see Figure 3)
Investigating vegetation changes
Quadrat Leaf-Count Macrofossil Analysis (QLCMA) (Mauquoy ***et al.***, 2010)
pollen and non-pollen microfossil analysis (Chambers ***et al.***, 2011a)
charcoal analysis (Mooney & Tinner, 2011)
peat humification (Chambers ***et al.***, 2011b)
Dating the profiles
Conventional radiocarbon dating (Piotrowska ***et al.***, 2011)
AMS ^{14}C dating (Piotrowska ***et al.***, 2011)
SCP analysis (Swindles, 2010)
pollen analysis
mineral magnetic susceptibility
^{210}Pb dating; ^{137}Cs record
Other techniques can be found in the review volume by De Vleeschower ***et al.*** (2010a) and in the review by Chambers ***et al.*** (2012).

Figure 2. Epidermal cells of Molinia caerulea under the microscope: note the characteristic 'crinkle-cut' appearance (photo courtesy of Dr Dmitri Mauquoy). Scale bar is 25µm.

Figure 3. A one-metre long, stainless steel peat cutter for field sampling, adapted from one found at Lindow Moss that was used by hand peat-cutters (Lageard et al., 1994).

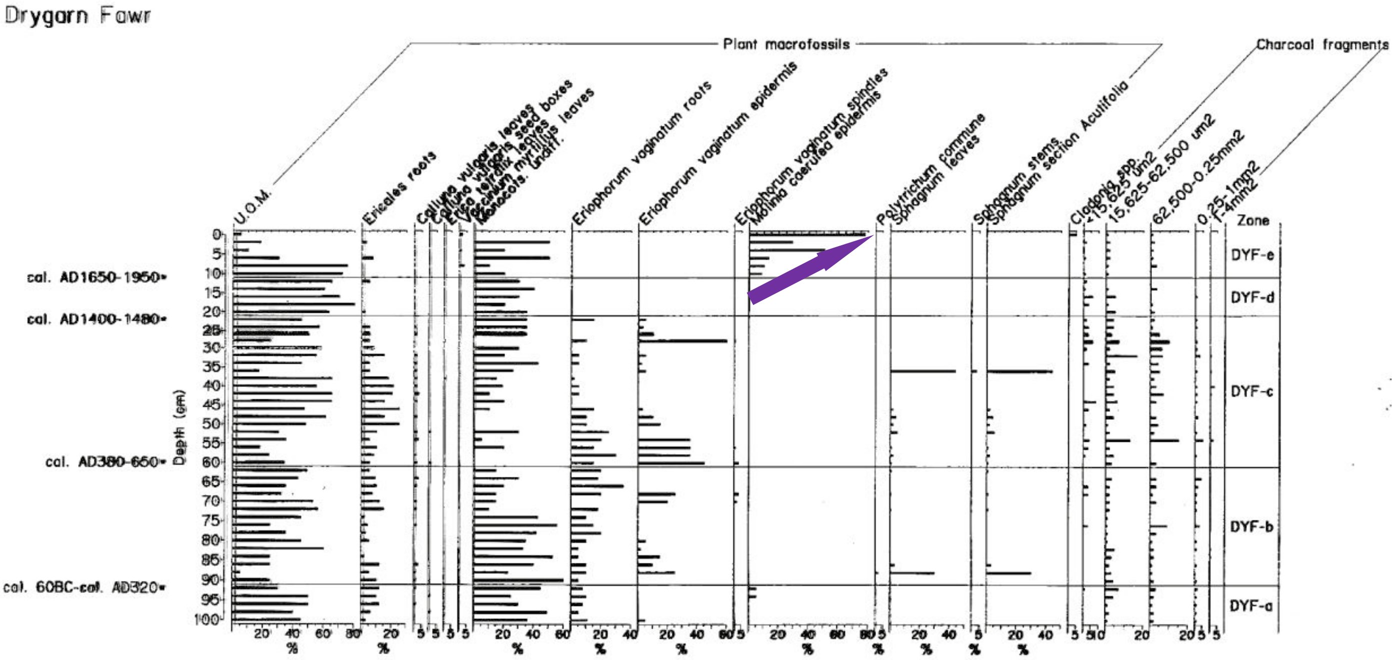

Figure 4. A profile from Drygarn Fawr (Elenydd) in mid-Wales, for which macrofossil records of Molinia show a recent and unprecedented rise to dominance, shown by purple arrow (after Chambers et al., 2007a). Note: UOM = unidentified organic matter

Example of some results

As an example of some of the results that might be obtained, Figure 4 shows the plant macrofossil data from one of the sites investigated on Drygarn Fawr, Elenydd, mid-Wales. The data show clearly a recent rise to dominance of *Molinia caerulea* epidermis in Zone DYF-e, with only sporadic appearance of *Molinia* subfossil material earlier, in Zone DYF-a.

Overall Results

Data suggest that at most sites investigated in the four studies mentioned above, a major vegetation change post-dated the start of the Industrial Revolution. There is some evidence for increased burning activity, but this was not present in all profiles; so it is unlikely that fire was the sole or principal agent in vegetation change. Rather, at several sites, increased atmospheric input, plus a change in grazing pressure, may have been responsible.

The implications for conservation management are far-reaching. The main vegetation change at several sites is to single-taxon dominance (esp. *Molinia*) within the 20th Century. The present overwhelming dominance of *Molinia* at Drygarn Fawr (mid-Wales) is unprecedented (Chambers *et al.,* 2007a); the same is true at the Brecon Beacons site (Chambers *et al.,* 2013); similarly on Exmoor (Chambers *et al.,* 1999). So, conservation management to reduce the current pre-eminence of *Molinia* would not run counter to long-established dominance.

Evidence suggests a change in the nature and intensity of grazing may help: from sheep back to cattle (or ponies) at lower stocking densities. Palaeoecological data show that some taxa have become locally and regionally extinct; innovative conservation management to translocate extinct species to assist in peat-forming vegetation at specific sites has been suggested by McCarroll *et al.,* (in press) following suggestions that inter-regional translocation can be justified by palaeoecological data (Chambers & Daniell, 2011).

Methods used in this study have wide applicability in mire and moorland conservation, as a prelude to mire and moorland restoration to ascertain the vegetation history, previous vegetation type(s), to chronicle supposed reduction in biodiversity, to identify the causes of degradation, and to suggest potential targets for restoration and to indicate the species locally that might be encouraged and which missing species might be translocated.

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The importance of atmospheric quality in determining upland vegetation

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Introduction

Evidence from observations and experiments suggests that air pollution has had an important influence on ecology and landscape in many parts of Britain (Caporn and Emmett, 2009). Despite air quality improvements in recent decades, the stored legacy of past acidic and metal pollution is still evident and nitrogen deposition and ozone pollution seem likely to affect vegetation and ecosystems into the future. This section outlines these issues and the consequences for the expansion of *Molinia caerulea* (Purple Moor-grass) and other more desirable elements of blanket bog and moorland vegetation, with a particular reference to the southern Pennines.

Air-borne pollution from past to present

Air pollution since the Industrial Revolution is frequently blamed for the poor condition of habitats in the southern Pennines. While in the towns, artists like Valette and Lowry captured lasting images of air pollution in their paintings, natural historians noted the poor variety of vegetation in rural regions such as the Peak District. For example, in 1859, Grindon attributed the decline of lichen species around Manchester to coal smoke pollution (Grindon, 1859).

In the mid-19th century the air pollution inspector Angus Smith working in Manchester concluded that *'when the air has so much acid that a grain can be found in a gallon of rainwater then there is no hope for vegetation in a climate such as we have in the northern parts of the country'* (Smith, 1872). More than a century after Smith, in his Presidential address to the British Ecological Society, Professor John Lee noted: *'the virtual absence of Sphagnum species from southern Pennine blanket peats and the loss of angiosperm species characteristic of Sphagnum carpets (eg Andromeda polifolia and Drosera spp) remains a remarkable feature of British vegetation'* (Lee, 1998). The wide-scale demise of *Sphagnum* and other bog species was almost certainly the result of the closeness of these peatlands to major centres of the Industrial Revolution and their emissions of atmospheric pollutants, notably sulphur dioxide (SO_2) and its secondary products. The decline and almost disappearance of *Sphagnum* from the hills of the southern Pennines is attributed specifically to exposure to SO_2 and solution product bisulphite in precipitation, which could cause immediate injury to moss photosynthesis and growth (Ferguson *et al.*, 1978). Classic experiments involving treatment of *Sphagnum* in 'cleaner' sites in North Wales with concentration of pollutants that were recorded in the air around the industrial centres clearly indicated a role for sulphur in the demise of these plants (Ferguson and Lee, 1980).

In recent decades there have been major improvements in air quality, notably in sulphur-derived pollutants, but air quality is still a major issue for vegetation and ecosystems (RoTAP, 2012). The average annual concentrations of sulphur dioxide in the UK are now a small fraction of the levels 30 years ago and a tiny proportion of levels a century earlier (Ferguson and Lee 1983a; RoTAP, 2012). Related improvements can be detected at the ECN (Environmental Change Network) Moor House-Upper Teesdale site in the north Pennines between 1992 and 2013 where rain and soil pH has steadily increased (Environmental Change Network, 2015; Monteith *et al.*, in press). Gaseous concentrations of oxides of nitrogen in air have declined much less than sulphur, and ammonia levels have changed even less (RoTAP, 2012). The total nitrogen deposition over most of the UK is above recommended levels (see Critical Loads below) and is spatially very variable with the southern Pennines receiving some of the highest inputs because of its considerable rainfall and proximity to a high density of power generation, traffic and intensive farming.

Recovery of *Sphagnum* and other bryophytes

Encouraging recovery and actively restoring blanket bog vegetation with a particular focus on *Sphagnum* are now major goals of conservation managers who recognise the significant wider benefits for ecosystem services of actively growing *Sphagnum* peatlands (Evans *et al.* 2014). It is therefore encouraging that field observations indicate that the improvements in air quality and fall in soil acidity have been accompanied by some degree of natural recovery in *Sphagnum* mosses in parts of the country and in particular in the southern Pennines, one of the worst affected areas in the UK. Caporn *et al* (2006) revisited sites in the southern Pennines that were part of research by Lee and colleagues several decades earlier. In the 1980s, researcher Colin Studholme searched the Dark Peak ombrotrophic bog surfaces for *Sphagnum* to use in population studies but very little was found. In 2005-6, he and others revisited two of these sites near Holme Moss and Alport Moor with good bryophyte records and recorded in detail the changes in species composition (Caporn *et al.*, 2006). In just over 20 years, a marked increase in bryophytes was observed at both sites; at Holme Moss, the *Sphagnum* species increased from 2 to 6, while at Alport Moor they went from 1 to 5 species between 1983-5 and 2005-6. Other mosses and liverworts had also increased. The marked changes in *Sphagnum* in the southern Pennines mirror the increase in abundance of bryophytes recorded across the UK in the recent Bryological Atlas as discussed by Pescott *et al* (2015).

Caporn *et al* (2006) also recorded the changes in a specific trial area near Holme Moss where Lee and colleagues, in around 1980, introduced 30 cm blocks of six *Sphagnum* species and peat moved from north Cumbria into Cotton-grass dominated bog surface where the water table was usually high. Initially there was very poor establishment (Ferguson *et al.*, 1983b) but after 25 years, in 2005, the recovery was impressive for two of the most valuable hummock species *S. papillosum* and *S. capillifolium* and by 2010 all but *S. austinii* were recorded. A subsequent wider survey in the Peak District moorlands reported by Carroll *et al* (2009) found a good variety of *Sphagnum* species present, although mainly in isolated patches, in the blanket bogs in the region. However, *Sphagnum* abundance in most areas of the Peak District moorlands is still very low and this is probably true of the larger southern Pennines region.

Factors limiting recovery of bog vegetation

Despite improvement in SO_2 and acid rain, there are other constraints limiting recovery, and understanding the factors that influence natural re-emergence of *Sphagnum* and the competing flora will help decide strategies for restoration and *Sphagnum* introduction.

In recent transect studies on the heavily degraded Bleaklow area of the Peak District, Rogers (2014) provided detailed knowledge of the precise favoured locations of naturally recovering *Sphagnum*. In the eroded area known as Joseph Patch near Bleaklow summit, *Sphagnum* occurred only in the margins and bottoms of gullies close to flushes and streams while there was a complete absence of *Sphagnum* on the normal bog surface despite the high rainfall and cloud cover (Rogers, 2014). In a contrasting area near to the Snake Pass summit with relatively intact blanket bog condition there was much greater abundance of *Sphagnum* on the hydrated bog surface.

The studies outlined above and other surveys by Moors for the Future Partnership show that *Sphagnum* is returning in the Dark Peak part of the southern Pennines where its presence appears to be intimately linked to water. Although air pollution is now much improved it remains unclear if the legacy of air pollution in the soils – acidity and metals - along with the continuing high levels of nitrogen deposition are affecting the recovery of *Sphagnum* in general and true ombrotrophic species in particular (Rosenburgh, 2015). In comparison with further north and west in the UK, the blanket bogs of the southern Pennines have a greater abundance of *S. fimbriatum and S. subnitens*, species typically associated with more minerotrophic conditions while *S.capillifolium*, an indicator of good ombrotrophic conditions is rare (Carroll *et al.*, 2009; Rogers, 2014; Rosenburgh, 2015).

Impacts of nitrogen deposition on plant communities

Nitrogen (N_2) is the largest gaseous component of the atmosphere and, in the form of reactive compounds nitrate and ammonium, plays a major role in ecological processes in soils, plants and through trophic levels.

However, human actions now dominate the global nitrogen cycle because emissions from human activities now exceed those from natural processes (Sutton *et al.*, 2011). Increased anthropogenic emissions of reactive nitrogen compounds ammonia and nitrogen oxides and the subsequent generation of secondary compounds nitrate and ammonium is emerging as a key challenge facing an increasingly large proportion of global regions where a wide range of impacts occur including eutrophication, acidification, ozone pollution, climate change and damage to the ozone layer. Deposition of nitrogen pollution to soils can contribute to acidification since acidity is generated in normal nitrifying (i.e. nitrate generating) soils in which ammonium is converted by soil microbes to nitrate with the release of hydrogen ions (H+). Roots and soil microbes also release protons into the soil in exchange for uptake of ammonium ions. In addition to soil acidification, the most obvious potential influence of pollutant nitrogen is as a fertiliser causing eutrophication (excess nutrient supply), threatening the species balance within those ecological communities that are well adapted to and dominate on poor nutrient soils (Bobbink and Hettelingh, 2010).

In Europe and America, there is evidence that nitrogen deposition is a key factor in the deterioration of several of these types of plant communities (Dise *et al.*, 2011). At a landscape scale, the observed changes in vegetation are often spatially correlated with increased nitrogen deposition and with the levels of nitrogen in the soils and/or plant tissues. However, alternative factors such as the presence of other pollutants or changes in soils, climate and land management can also be involved. Several mechanisms appear to explain the impact of nitrogen pollution on vegetation including direct toxicity, growth stimulation (of some plants more than others), acidification and interactions with climatic and biotic stresses.

Many of these responses have been demonstrated in nitrogen manipulation experiments (e.g. Edmondson *et al.*, 2010; Phoenix *et al.*, 2012) and through these varied mechanisms, nitrogen inputs may favour certain plant species over others causing a shift in the botanical composition of the community. The outcome, observed in a number of recent studies along pollution gradients in Europe, appears to be a significant fall in plant species richness in various habitats (Maskell *et al.*, 2010; Payne *et al.*, 2013; Stevens *et al.*, 2006). In a similar investigation by Field *et al.*, a co-ordinated approach was taken to determine the species richness and plant community composition of five widespread, semi-natural habitats (bogs, lowland heath, upland heath, acid grassland, sand dunes) across Britain in sites stratified along gradients of climate and pollution (Field *et al.*, 2014). In every habitat, there was reduced species richness and changed species composition associated with higher nitrogen deposition, with remarkable consistency in relative species loss across ecosystem types. While the diversity of mosses, lichens, forbs, and graminoids fell with nitrogen deposition in different habitats, the cover of grasses and sedges generally increased.

Exceedance of the nitrogen critical load

Over the UK, the rate of atmospheric nitrogen deposition ranges from around 5 to over 30 kg N ha^{-1} y^{-1} between the remotest north-west to the most polluted regions, but can be much more close to point sources such as intensive farming units (RoTAP, 2012). In the southern Pennines, nitrogen deposition is around 25-35 kg N ha^{-1} y^{-1} (Air Pollution Information System, 2015) which is well above the critical load for blanket bog and related communities (Table 1).

Table 1. Summary of empirical critical loads of nitrogen deposition for selected natural and semi-natural ecosystems classified by the European nature information system (EUNIS) as revised in 2010.The reliability is qualitatively indicated by ## reliable; # quite reliable and (#) expert judgement. The last column gives an indication of the effects that can occur when critical loads are exceeded. (Adapted from Bobbink and Hettelingh, 2010, Review and revision of empirical critical loads and dose-response relationships Proceedings of an expert workshop, Noordwijkerhout, 23-25 June 2010)

Ecosystem	Eunis code	Critical Load kg N ha-1y-1	Indication of exceedance
Raised and blanket bogs	D1	5-10 ##	Increase in vascular plants, altered growth and species composition of bryophytes, increased N in peat and peat water
Valley mires, poor fens and transition mires	D2	10-15 #	Increase in sedges and vascular plants, negative effects on bryophytes
Northern wet heath Calluna-dominated (heather moorland)	F4.11	10-20 #	Decreased heather dominance, decline in lichens and mosses, increased N leaching
Northern wet heath Erica tetralix-dominated (lowland)	F4.11	10-20 (#)	Transition from heather to grass dominance
Dry heaths	F4.2	10-20 ##	Transition from heather to grass dominance, decline in lichens, changes in plant biochemistry, increased sensitivity to abiotic stress

Nitrogen critical loads are based on experimental evidence and have been revised regularly since their inception in the early 1990s. In a range of related plant communities of bogs, wet and dry heaths, the indication of exceedance of the critical load are stated to be an increase in vascular plants and alterations in growth and species compositions of bryophyte communities (Bobbink and Hettelingh, 2010). In the southern Pennines such community changes are evident where bogs have become dominated by vascular graminoid plants like *Molinia* and *Eriophorum* and by *Deschampsia* flexuosa in drier areas.

The mechanism behind such changes in bogs can be appreciated by considering a simple model of atmospheric nitrogen deposition and movement into the surface bog layer and then into the rooting zone of competing vascular plants. The *Sphagnum*-dominated surface layer provides a natural nitrogen filter up to around 10 kg N ha^{-1} y^{-1} and the absorbed nutrient stimulates *Sphagnum* growth. Above this threshold the *Sphagnum* sink is gradually saturated and increasing nitrogen inputs move through the moss layer and promotes higher plants growth. Furthermore, nitrogen may accelerate mineralisation releasing further nutrient and also promoting growth of higher plants and causing shading of the bryophytes (Lamers *et al.*, 2000).

Evidence for the role of nitrogen deposition in *Molinia* expansion

In the UK, Purple Moor-grass and rush pasture are valued communities of the National Vegetation Classification (M24, M25, M26) in moderately nutrient-enriched wet soils where *Molinia* is found in a diverse, interesting plant assemblages including species such as Devil's–bit Scabious, Meadow Thistle, Tormentil and Self-heal. However, in the normally nutrient-poor habitats of blanket and raised bog as well as heathlands, the spread of *Molinia* is undesirable in terms of its effect on plant biodiversity even though its influence on ecosystem services including long term peat formation is uncertain (Shepherd *et al.*, 2013).

Hughes *et al* (2007) examined historical vegetation change in Welsh bogs using paleoecological methods and suggested that *Molinia* dominance of Welsh bogs was a relatively recent event, consistent with other experimental evidence showing that increasing atmospheric nitrogen deposition has been a significant cause of *Molinia* expansion. In the review of European critical loads for nitrogen deposition, Bobbink and Hettelingh (2010) discuss several lines of evidence from western Europe using observation from low and high deposition areas (eg. Aaby, 1994) and fertiliser experiments indicating that *Molinia* occurrence in varied habitats including bogs and wet heaths has been increased by atmospheric nitrogen deposition. In the Netherlands the potential problem was recognised in the late 1970s and 1980s where very high levels of nitrogen deposition arising from intensive agricultural units was linked to the increasing cover of the competitive grasses *Molinia* and *Deschampsia* at the expense of *Calluna vulgaris* in heaths and *Sphagnum* and related species in bogs. Dutch experiments using turfs in the glasshouse and field plots showed that nitrogen addition increased *Molinia* growth much more than the dwarf-shrub *Erica tetralix* and other bog species (Aerts and Berendse 1988, Berendse and Aerts 1984, Tomassen *et al.*, 2003). In bogs, Limpens *et al* (2003) studied the effects of nitrogen deposition on the competition between plants on an intact bog and found that the *Molinia* biomass was positively related to the inorganic nitrogen concentration in the soil pore water, an observation consistent with the model of Lamers *et al.*, (2000).

Water-table level and availability of phosphorus were also important in explaining species-specific responses to nitrogen deposition (Limpens *et al.*, 2003). Tomassen *et al.* (2004) studied the effects of nitrogen on *Molinia caerulea* and *Betula* pubescens in a 3-year nitrogen addition experiment in an Irish raised bog. Although the water table on the experiment had been reduced by past peat cutting, it was concluded that the invasion of *Molinia* and *Betula* in bogs was likely to be less affected by desiccation than by increased availability of nitrogen (Tomassen *et al.* 2004). Research in the heathlands of northern Germany by Falk *et al* (2010) showed similar effects of additional nitrogen in stimulating *Molinia* growth and also found that nitrogen increased allocation to flowers and seed thereby raising the potential for rapid invasive spread by sexual reproduction.

If nitrogen deposition has been a major factor in the spread of *Molinia*, this will be difficult to reverse since much of the deposited nitrogen accumulates in the soil–plant system. For example, Pilkington *et al* (2005) added nitrogen to a heather moorland (*Calluna-Vaccinium* upland heath) and found that after 11 years the majority of the nitrogen added was still present in the soil and plants. The long term accumulation of nitrogen means that current and past nitrogen deposition will exert an influence on plants and soil organisms even if nitrogen deposition is lowered (Duprè *et al* 2010, Phoenix *et al*., 2012). Evidence from the Rothamsted Park Grass long term experiments show that recovery of grassland species composition may occur where declining atmospheric deposition is accompanied by regular mowing – which removes plant nitrogen from the system (Storkey *et al*., 2015). The feasibility of mowing and other nitrogen removal techniques in a range of UK habitats were examined by Stevens *et al* (2013) and the possible options for removal of nitrogen stored in *Molinia* (eg. burning, mowing, turf removal) on bogs are likely to be damaging and may be undesirable.

Uncertain threats to upland vegetation – Ozone and Carbon dioxide

While evidence discussed above supports the view that the recent period of increased dominance of *Molinia* on bogs is related to rising atmospheric nitrogen deposition, there has been a substantial rise in carbon dioxide (CO_2) concentration over the same time. Atmospheric CO_2 concentration was around 320 ppm in 1960 rising to just over 400 ppm by late 2015 (Carbon dioxide Information Analysis Centre, 2015) and shows no sign of slowing down. The history of research on photosynthesis and CO_2 suggests that such change in CO_2 would typically cause an immediate and significant stimulation of photosynthesis. However, several studies of plant response to CO_2 in nutrient poor native ecosystems have also found that low soil nitrogen supply may limit the photosynthesis and growth response to CO_2 (Reich *et al*., 2006). There is very little knowledge of how *Molinia* responds to CO_2 but it is reasonable to speculate that the long term growth response will be increased when nitrogen availability is enhanced (Franzaring *et al*., 2008). More research on the CO_2 response in *Molinia* vegetation is required to substantiate this view.

Another pollutant that could have an increasing impact on in upland vegetation is ozone, an important phyto-toxic gaseous pollutant which, unlike CO_2 and oxides of nitrogen, is an increasing threat (Ashmore, 2005) with global concentrations in the lower atmosphere rising at approximately 0.1 ppb per year. As a secondary pollutant, ozone concentrations are normally higher in rural than in nearby urban areas, and in spring and summer the night-time concentrations in the uplands can remain elevated, in contrast to the stronger cyclical pattern seen in the lowlands. This phenomenon, observed widely across upland areas of the world may result in continuous exposure to elevated concentrations for several days (RoTAP, 2012). Experimental exposure of *Molinia* to ozone has shown mixed results; in a glasshouse experiment in north Wales, *Molinia* and other species from bog and fen were exposed to controlled levels of ozone and this increased leaf senescence in all species, but only in *Molinia* was there a significant reduction in biomass (Williamson *et al*., 2010). However, in earlier work ozone exposure increased biomass in *Molinia* but not in other species (Franzaring *et al.*, 2000). A recent novel experiment using field ozone exposure on Keenley Fell in the north Pennines uplands clearly showed the effect of ozone under natural conditions in UK uplands. Wedlich *et al.*, (2012) used a field release method to expose mesotrophic grassland – hay meadow – to modest increases in ozone and found that grasses were not affected but there were strong, significant reductions in forbs, notably *Rhinanthus* and *Ranunculus* species, valuable components of this conservation habitat. Although *Molinia* was not a part of this community, the experimental results point to the potential for effects of ozone on the balance of functional groups, in this case favouring grasses.

Summary

This paper has reviewed air pollutants that have had serious impacts on upland habitats in the past and others that may continue to influence them in to the future, with a focus on the southern Pennines.

There is strong evidence from experiments and field observations that past air pollution, notably sulphur dioxide and its by-products had a strong influence on vegetation and soils and was at least partly responsible for the wide-scale decline in cover and diversity of characteristic species of ombrotrophic upland blanket bogs. In the past 3-4 decades, the major decline in emissions of sulphur dioxide and accompanying increase in rainfall and soil pH may be key factors contributing to the observed return of *Sphagnum* moss.

While some degree of recovery is visible, the longer prognosis is uncertain since nitrogen deposition remains high and may limit the types of species that return. Furthermore, many areas of blanket bogs have degraded to the point where the water table is probably not consistently high enough to support *Sphagnum* and other desirable ombrotrophic species. In other parts of the uplands, favourable species of blanket bogs appear to have been swept aside by the aggressive competitor *Molinia caerulea* which may have expanded into blanket bog because of the high levels of nitrogen deposition over several decades.

Research into *Molinia* expansion on bogs and heaths in Netherlands and Germany provides further evidence that nitrogen deposition has played a significant role in the invasion of this species into a number of nutrient-poor habitats. Deposited nitrogen does not easily leave these systems and will remain a source of eutrophication even if nitrogen pollution is halted tomorrow. Methods of removal of nitrogen from enriched habitats without causing further damage will require investigation. While acidification and eutrophication pose known threats, the pollutants ozone and carbon dioxide are both increasing in atmospheric concentrations (the latter rapidly) but their direct impact on the composition of upland vegetation is not well understood especially when we consider the delicate balance between recovering bog species and aggressive competitors such as *Molinia*.

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Molinia – the importance of controlling water and other management techniques

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Introduction

Rather than producing an account of personal experience or first-hand research, this paper synthesises the available literature on the water relations of *Molinia caerulea* with the aim of using this knowledge to help advance *Molinia* management and control. The objective is to investigate how far *Molinia* can be manipulated based on its ecological preferences to move the community towards what is desirable on any site.

The key features that have been researched here are soil preferences and the relationship of *Molinia* with water tables and water flows, but in addition, it is necessary to consider nutrient relationships to some extent since these interact with the soils and eco-hydrology.

The paper then considers how water tables have changed in blanket bog and wet heath in particular, over possibly many decades, to illustrate some of the mechanisms by which the *Molinia* expansion that has been witnessed by various observers has occurred and where control or reduction may be possible or advantageous.

Soils

Taylor *et al.* (2001) lists the wide range of soil types on which *Molinia* is found (Table 1) which demonstrates the common theme of *Molinia* being found on soils with some kind of moisture present. Gleys are characteristically poorly drained, saturated by groundwater for periods that result in lack of oxygen in the subsoil horizon. In anaerobic conditions the insoluble iron oxides change to ferrous iron giving the characteristic blue/grey streaks in the subsoil. Stagnosoils are also periodically wet and mottled in the upper and subsoil horizons and develop on a variety of unconsolidated materials like glacial till.

Molinia has a bi-modal pH distribution, with abundance peaking on highly acidic soils (pH <4) as well as calcareous soils with a pH >7.0, thus it can occur in acidic upland or lowland peat environments and more base-rich fens. James (1962), however, showed that *Molinia* is not limited by high calcium concentrations in either well drained or waterlogged soils, but that it becomes phosphate-limited at high pHs in well drained soils at least. The best growth of *Molinia* occurs on soils where there is ground-water movement, good soil aeration and an enriched nutrient supply (Taylor *et al.* 2001) as evidenced by research largely carried out some 50 or more years ago.

Table 1. Range of soils on which Molinia is mostly found (after Taylor et al. 2001)

Soil type	Examples
Calcareous surface water gleys	Over Carboniferous limestone, eg Upper Teesdale
Calcareous strongly irrigated mud of silt, sand, gravel or humus	Over Dalradian limestone in Scottish Highlands
Ground-water gleys	Over alluvium, Norfolk Broads
Basin peats	Norfolk Broads ,
Blanket peat	Various locations
Basin and flushed peat low base status	S W Galloway
Non-calcareous gley, low base status	Aberdeenshire
Stagno-podzol over lithoskeletal siltstone and sandstone	Ashdown Forest, East Sussex
Humus-ironpan stagnopodzol on loamy drift	Bloxworth, Dorset
Orthic gley soils over loamy drift	Llangadog, Dyfed, Epping Forest
Brown podzolic soils of Manod series over base-poor Lower Palaeozoic shales & mudstones	Near Llyn Brianne reservoir, mid-Wales

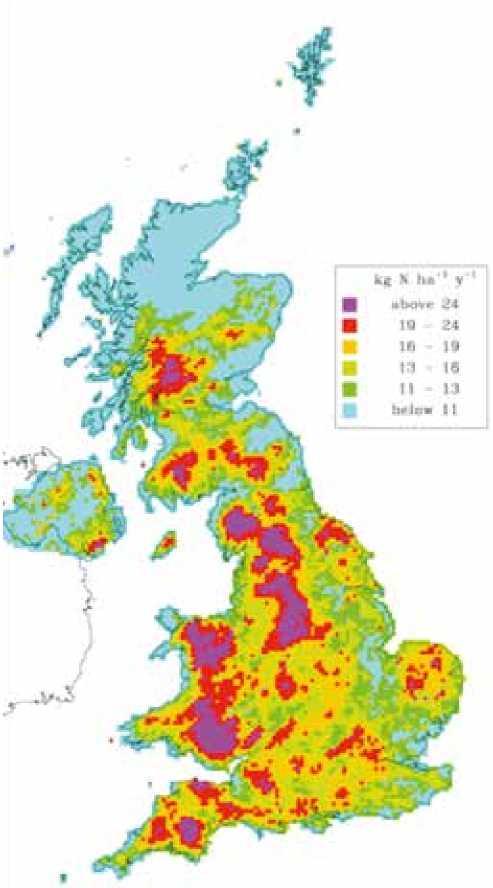
Vegetation communities

As might be expected from the wide range of soils it can occupy, *Molinia* occurs in an equally diverse range of vegetation communities (see Meade, 2016, in these Proceedings). The main ones are listed in Table 2 but there are more heath and mire communities in which the grass is found. Again, there is a clear relationship with vegetation growing on damp or wet conditions.

Table 2. Main range of vegetation communities in which Molinia grows (after Taylor et al. 2001)

Plant community	Key species used in NVC community names	Comments
M19/M20	*Eriophorum vaginatum-Calluna* and *Eriophorum vaginatum mires;* can grade into *Molinia-Myrica mire*	Marginal areas of blanket bogs in Great Britain, can be big tussocks where soligenous
M25	*Molinia-Potentilla erecta* mire	
M24	Molinia-Cirsium dissectum fen-meadow	Moist to fairly dry peats and peaty mineral soils
M15/16	*Erica tetralix-Sphagnum compactum; Scirpus cespitosus* wet heath	Seasonally waterlogged
M17	*Scirpus cespitosus-Eriophorum vaginatum* blanket bog	Blanket mire, waterlogging and ombrogenous peat, especially W Britain, + other wet mire communities such as W4
M21	*Narthecium-Sphagnum* valley mire	Valley mire on waterlogged acidic peats
M26	*Molinia-Crepis paludosa* mire	Moist moderately base-rich calcareous peat in the Pennines
M6	*Carex echinata -Sphagnum fallax/ auriculatum* mire	Peaty gleys

Figure 1. Total Nitrogen dry deposition levels across the UK (DEFRA 2005)



Nutrient and eco-hydrological relationships

Since there are interactions between nutrient relations and hydrology, it is important to consider these together rather than eco-hydrology alone since the level of total nitrogen deposition across the uplands of the country is still high (Figure 1). *Molinia* is well known to respond positively to nitrogen deposition (Marrs 1993, Bobbink *et al*. 1998) and this is particularly strong in the Netherlands and Germany, where *Molinia* has been found to encroach into lowland heath, replacing dwarf-shrubs. Aerts and Berendse (1988) for example applied nitrogen or phosphorus experimentally to wet heath and found that with increasing phosphorus (especially) or nitrogen availability, the *Molinia* increased its biomass significantly and outcompeted the *Erica tetralix*. It was found that *Molinia* invests 48% of its above ground biomass into its leaves, compared with only 12% for *E. tetralix*, with a corresponding higher rate of photosynthesis per unit of leaf weight. *Molinia* has an efficient photosynthetic apparatus to enable it to respond more rapidly to increased nutrient availability. However, in earlier experiments, Berendse and Aerts (1984) found that when phosphorus was added with a low water table depth, the *Erica* was more negatively affected by *Molinia* than when nitrogen was added, whereas when an intermediate water table depth was applied, the effect of nitrogen and phosphorus additions were similar.

Invasion in dry heath situations, this time found in Germany, can be similarly enhanced through fertilisation (Falk *et al*. 2010). The researchers in their experiments found that growth of *Molinia* is primarily nitrogen limited, but in dry heaths the kind of nutrient limitation may be mediated by other factors such as water availability (drought or wet conditions for example). Invasion into dry heaths was shown to be related to increased leaf biomass (as in wet heath above) and higher investment in reproductive tissue (30-45% increase in flowering tillers) with concomitantly increased seed production which accelerated encroachment.

Several different studies have explored the relationship between *Molinia* and water levels, sometimes in association with enhanced nutrients. Sheikh was particularly interested in the competitive relationships between *Erica tetralix* and *Molinia* on a valley bog (high water table), drier wet heath, and an intermediate *Molinia* dominated community in Hampshire. He examined the effect of growing the plants in culture in different levels of oxygen (O), carbon dioxide (CO_2) and hydrogen sulphide (H_2S) as might be found in soils with different levels of waterlogging (Sheikh 1969a). The picture that emerged was of *Erica tetralix* being tolerant of the valley bog conditions, using it as a refuge site as it could tolerate the low nutrient availability which reduced the growth and hence competition from *Molinia*. This was despite the *Erica* being more sensitive than *Molinia* to high levels of CO_2 and H_2S such as those found in the valley bog. Rather it evades these constraining levels through having a very shallow root system.

Molinia was found to be very sensitive to high concentrations of CO_2 and H_2S such as would be found in the valley bog. In the Molinietum, the absence of *Erica tetralix* was considered to be due to strong competition from the grass. *Molinia* tussocks were higher and larger compared with those in the valley bog. It was concluded that the *Molinia* grows best where soils are poorly aerated but richer in nutrients. However, Sheikh (1969b) found significant differences in growth of *Molinia* in the different conditions which is very relevant to management solutions, with 453mg dry wgt/plant in the valley bog and 768mg dry wgt/plant on wet heath with no added nutrients.

Loach (1968), using the same Hampshire site, explored the effects of adding nutrients to the valley bog and wet heath soils under different hydrological regimes – either well drained or water logged. He found that drainage without added nutrients did not improve growth of *Molinia* in valley bog soils (in the greenhouse) but that growth with added phosphorus was five-fold more and equivalent to that on wet heath. On valley bog soils, there was no improvement in growth when freely draining compared with waterlogged owing to the naturally low nutrient levels.

Gore and Urquhart (1966) explored the relations between *Molinia* and Cotton-grasses, mostly *Eriophorum vaginatum*, in a series of experiments using peats from Deer Dike Moss and Moor House under waterlogged or free draining conditions with or without additional nutrients. Their results mirrored in general those found in the research described above. *Molinia* in Moor House surface peat yielded a low dry weight in waterlogged conditions with short shoots that were much branched. On other peat soils used in the experiment, the *Molinia* roots reached the bottom of the 12.5cm deep pots whether they were waterlogged or not. In contrast *Eriophorum vaginatum* grew well, with its roots reaching the bottom of all pots where the water table was successfully maintained at a high level. Compared with the experiments on *Erica tetralix* with *Molinia*, Gore and Urquhart (1966) found that the Cotton-grass responded very little to an increase in nutrients in the waterlogged situation whilst there was a significant increase in *Molinia*, especially of phosphorus, and in the roots.

Taylor *et al.* (2001) notes that *Molinia* has the ability to divert a high biomass allocation to its roots. It can develop an extensive root system, exploiting a large volume of the soil and exhibits a high level of plasticity in the spatial arrangement of leaf layers within its tall canopy. For example, Salim *et al.* (1995) compared the morphology and growth of *Molinia* growing on shallow high pH soils on a Leblanc waste tip near the Rivers Croal/Irwell (Greater Manchester region) with a population in Lyme Park (Peak District National Park in Cheshire) but concluded, despite significant differences in appearance, that they were of one species exhibiting considerable plasticity in morphology and chemistry. This is important since soil and hydrological conditions can affect the growth form and any advantage that *Molinia* might have over other competitors.

The rooting system is fundamental to understanding how *Molinia* could respond to different management. Taylor *et al.* (2001) describes the enormous root system that forms a tangle near the soil's surface and which can extend down to more than 80cm. There are strongly twisted cord roots, 15-45cm long and narrower fibrous roots that branch freely up to 5-13cms (Jefferies 1915, 1916). Profitt (1985) provides further descriptions showing that the system remains active for three seasons, with most lateral growth in the second and third seasons. Of greatest significance for this paper is the fact that it is the root system that responds to water logging. In anaerobic soils, with a high water table, the adventitious roots become orientated along the zone between the anaerobic and aerobic layers so that they avoid the reducing environment below. Where such root systems are exposed to a fluctuating water table, the result is a 'shaving brush' effect caused by roots growing well while the water level is lower, but the apices are killed as the water table rises, although the root bases remain healthy. Repeated fluctuations results in the 'shaving brush' effect.

The mechanism for survival in low oxygen and high CO_2/H_2S conditions is exudation of oxygen from the roots. However, this mechanism is far lower for *Molinia* than, for example, *Eriophorum angustifolium*, which is thus better adapted to more waterlogged conditions. Webster (1962) shows that air cells – aerenchyma – contain between 15 and 20% oxygen in the gaseous state in *Molinia* and Armstrong (1967) demonstrated that the rate of oxygen loss from the roots is 14ng cm^{-2} min^{-1} in the apex of the root compared with 128ng cm^{-2} min^{-1} in Common Cotton-grass.

Further relevant investigations focus on growth of *Molinia* in differing water table conditions and soils. Webster (1962b) found the mean number of tillers/cm^2 with the water table 15cm below the surface with moving ground water was 54.5, but a significantly lower 25.6 with stagnant ground water. Dry shoots were 40 and 23.7gm respectively. With ground water at the surface but flowing, productivity is higher than with stagnant water at the surface. Thus it is clearly shown that with waterlogged conditions and no water movement, *Molinia* grows less and would be less competitive. This fits the earlier observations of Jefferies (1916) who described *Molinia* as being most abundant on sites where there is water movement, good soil aeration and an enriched nutrient supply.

Other possible factors

Other factors found in the literature that might be relevant in the control of *Molinia* are limited. Jefferies (1915) suggests that the thin flat leaves can suffer from exposure to cold spring weather; the leaves turning an orange/yellow colouration with die back of the leaf tips. In addition, Taylor *et al.* (2001) summarises the findings of several studies on the mycorrhizal associations of *Molinia*, noting that 15-20% infection is found in different sites – mostly of vesicular-arbuscular endophytes. What is not clear, however, is any effect of waterlogging, where *Molinia* does not grow so well, on the mycorrhiza, which could be an important source of nutrients in low fertility situations.

Conclusion

The research shows that *Molinia* growth is much poorer on waterlogged soils provided the water table is close to the surface (10cm maximum in depth) and the water is stagnant. The plant cannot oxygenate its root environment sufficiently in such conditions to grow vigorously. The plant in these conditions tends to have a thin canopy, poor growth and be less tussocky. However, if there is added nitrogen and or phosphorus, the *Molinia* can respond positively and be more vigorous, even if waterlogged. However, this effect is much greater if the water is flowing and the soils aerated, or if the water table is lower.

Why soils have dried out

The implications for management/ control

The rest of this paper focuses now on the uplands, particularly peatlands, to examine why the soils may have dried out and how re-wetting is a management option. It can be surmised that various single or combinations of mechanisms have resulted in a reduction of the water table and hence enhanced growth conditions for *Molinia*. The importance of these factors needs to be balanced by the effects of grazing regimes and stock types over the decades and or burning (managed or wildfires) to be able to determine the main drivers for each site. Added to this is the more recent effect of nitrogen deposition (See Figure 1) which gives cause for concern in the uplands in particular.

Sulphur dioxide pollution

Although levels of sulphur dioxide are probably not now at levels that would affect upland peatland vegetation (Carroll 2009), it has in the past had a major, long-lasting effect on upland communities by removing most Sphagnum from large areas as well as other bryophytes. This is particularly significant in the Peak District (Moss 1913), South Pennines and South Wales where SO_2 levels were highest resulting in acidity of the peat below pH 3.3 and in some cases lower than pH 3.0 (Matt Buckler pers. com. Moors for the Future). Carroll (2009) states that Sphagnum cannot grow in soils this acid. The loss of Sphagnum over some 200 years is considered to have affected the hydrology of the peatlands since without its water absorbing capacity, the bogs are drier (Lindsay 2010). Figures 2 and 3 illustrate the differences between Sphagnum-rich and monotonous Cotton-grass blanket peats. Lindsay (2010) presents evidence that dried peat shrinks and is convinced that large areas of blanket peat, for example, has shrunk to a lower surface as a result of loss of Sphagnum and other factors (see below).

Figure 2. Sphagnum-rich peatland in Scotland (Photo: Penny Anderson)

Figure 3. Eriophorum-dominated blanket bog in South Pennines with no Sphagnum that resulted from sulphur dioxide pollution over 200 years resulting in reduced pH and toxicity to most Sphagnum species (Photo: Penny Anderson)

Wildfire

Shrinkage and drying of peat make it much more vulnerable to the damaging effects of wildfire and managed fire. All over the blanket peats of this country, but more particularly in areas where SO_2 pollution was most severe and where urban or visitor populations are closest, the evidence of the damage from wildfires is widespread. A damaging wildfire is where root stocks are destroyed and bare peat exposed. The fire can create gaps in the vegetation, without Sphagnum and other bryophytes to provide the Elastoplast to cover the surface, subsequent rain can wash out the peat and start rill formation. In 1976, the author witnessed 1m of peat being lost from a moorland in the Peak District in the wettest September then on record after being droughted for two years and many moorland wildfires. The remaining peat is heavily gullied and eroding still, nearly 40 years later. Figures 4 to 9 show a range of situations that can occur leading to multiple gullies, often close together, eventually with no peat at all as on the top of parts of Kinder Scout, Holme Moss and Bleaklow in the Peak District.

Figure 4. Wildfire on blanket bog vegetation – a light burn, Sphagnum tussocks damaged, Calluna destroyed (Photo: Penny Anderson; Northern Ireland)

Figure 5. Wildfire on Cotton-grass dominated blanket bog, leaving 'peat pans' of bare peat that can persist, wet after rain, but dry and brittle in summer. These are not peat pools. Southern Pennines (Photo: Penny Anderson)

Figure 6. Peat pans beginning to form rills and link together. South Pennines (Photo: Penny Anderson)

Figure 7. Extent of peat pans after multiple wildfires in South Pennines (all dark patches are bare peat, the straight line is the boundary of the most recent fire)

Figure 8. Deep gullies develop with erosion continuing (Photo: Penny Anderson; Peak District)

Figure 9. Peat pipes form from underground drainage, collapsing to form more gullies and 'swallow holes' (Photo: Penny Anderson; Peak District)

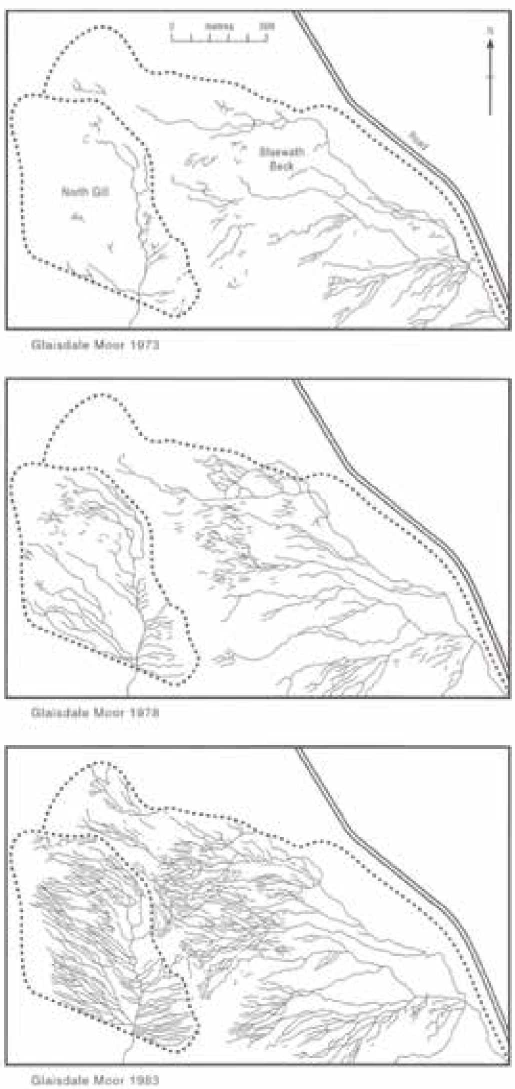


Figure 10. Gullying before and after the Glaisdale Fire, North York Moors (from Alam and Harris 1987)

The sketches show a dendritic pattern of gullies that becomes more intense with time after a severe fire in 1976

Allott *et al.* (2009) has shown that the water table is much reduced in areas with multiple gullies, particularly where close together. Average levels varied from 26 to 451mm depth below the surface (Allott *et al.* 2009), but multiple gullies resulted in a drawdown zone of up to 300mm lower than gullies on intact sites. A lowered water table results in aeration of the peat, which in turn would provide ideal conditions compared with the original wet blanket bog surface for *Molinia* spread in the right circumstances.

Most revealing is the evidence from Alam and Harris reported in Simmons (2003) for the Glaisdale fire (1976 in the North York Moors) where repeat mapping of the extent of gullies in 1973, 1978 and 1983 shows a very significant increase in the density, overall lengths and extent into the peat of gullies (reproduced as Figure 10). The same pattern has been detected by Tallis for Holme Moss in the Peak District between the 18th century and 1995 (Anderson *et al.* 1997). This indicates that wildfires (and possibly managed fires in particular situations) have the potential to drive the formation of gullies and their erosion into wider and deeper channels, which will reduce the water table and dry out peat.

Managed burning

Controlled burning was carried out regularly from about 1800 onwards, but the peatlands were burnt previously to that, there being regular layers of charcoal dateable to the 14th century and burning apparent in the Mesolithic Age as well (Tallis and Switsur 1990). This burning could also result in bare peat and gully formation as evidenced by Farey (1815) who describes how shepherds would go out on horseback in the Peak District with their tinder box for the day, setting fires until dark and returning leaving them to burn. Burning was done every four years in places.

Firing of the heath in dry weather has set fire to the peat, into which it continued to penetrate and make large and irregular holes. This source of unevenness and of the groughs and gullies, and of local dead black places on the surface of these mosses is perhaps more common than has been supposed.

Managed burns can be too hot and escape control (Anderson 1986) and, although there is a move to use cooler burns on many places now (G Eyre, pers. com.), there is evidence of damaged peatland thought to be derived from managed burns that have been too hot. It is not known when these took place (Figure 11). In addition, more burning has been conducted on blanket bogs over the last 40 years (Penny Anderson Associates, unpublished work for NT, Yallop *et al.* 2006), possibly in some areas as a requirement for part of the Environmentally Sensitive Area prescriptions (that no longer apply).

Figure 11. Small gutter sized holes and rills forming after too hot managed burns in the Peak District – eastern side where climate is drier. These will dry out the peat and are exposed to future erosion in heavy rainfall (Photo: Penny Anderson)

Figure 12. Clay pipe drainage in blanket bog on Oswaldtwistle moor (Photo: Penny Anderson)

Drainage

In addition to burning, drainage has contributed significantly in some areas to drying of peats. This is more prevalent in wetter climates, with very little such drainage in the Peak District for example. Grips were MAFF grant-aided in the 1960s-80s, although some are older. They can be very densely packed across sites in characteristic herringbone or other configurations, but differ from gullies in that they tend to cut across slopes and do not form part of the dendritic drainage system until they empty out into streams or gullies. However, trapping surface flows dries out land below the drain as well as land on either side of it. Holden *et al.* (2008) estimates that this can extend 400m or more downslope in some situations depending on the local topography.

As well as grips, there are many other types of drains in place – clay pipes, ridge and furrow and other drains, mostly around blanket bog margins (often just where *Molinia* is invading). Figure 12 shows one such area in the Western Pennines, and some of the ridge and furrow effects witnessed nearby may be old 'lazy beds' where attempts were made to grow crops during the last World War. All such activity would have contributed to the drying of peat.

Overgrazing

Overgrazing can also result in drying of the peat surface owing to the reduction in biomass, development of bare ground mostly in small patches and trampling damage to the Sphagnum and many other bryophytes which are much reduced as a result. There is little in the literature on the scale or magnitude of these effects. Light grazing to control *Molinia* using animals like cattle or ponies that will forage on *Molinia* would be unlikely to make the soils drier.

Peat extraction

Finally, peat extraction has the potential to alter the drainage significantly. First, drains are excavated in order to extract the peat. Where peat is fully extracted, such drainage can become flowing instead of stagnant and the vegetation changes from a peatland one to rushy grassland or a mixture of Sphagna, but in flushed conditions. This changes the peat drainage radically. However, at a half way stage, the drainage and extraction in cells at a hand/small machine scale, can result in drying of the marooned former bog surface at the higher level, but wetter conditions for new blanket bog to develop on the lowered extracted surfaces, provided these are still holding stagnant water. This does not mean to say that such extraction is good for the mire, but more that the damage may not be so extensive in this situation.

Controlling *Molinia* through re-wetting

The research set out above has shown that *Molinia* grows best in flowing water rather than stagnant conditions, and where the water table is not close to the surface. It has been described how peats have dried out through a variety of mechanisms. The logical next step therefore is to identify where re-wetting might be feasible and contribute to a reduction of *Molinia* where it is too abundant now. Where *Molinia* has invaded blanket bog or wet heath at the expense of more characteristic species and where drying can be seen to have occurred, there are opportunities to re-wet the peat and control the *Molinia*. Such action may not eliminate *Molinia*, and indeed, the grass is a typical component of many vegetation types, but control of its dominance may be the key. Even poorly growing *Molinia*, less competitive and more able to mix with other species, could be a better option than its dominion in some places.

Where *Molinia* is growing strongly in just the conditions it favours, other management options such as cattle grazing may be more useful in increasing diversity.

Figure 13. Peat dams in grips within Molinia-dominated vegetation on blanket peat on fairly steep slope. Water table not really high enough for Molinia control. Peak District (Photo: Penny Anderson)

Figure 14. Plastic piling in gully on blanket bog, good water table elevation. Peak District. Water flows from top centre down the photograph to bottom left in a small gully on fairly flat ground. Note the overflow lip in the centre of the dam (Photo: Penny Anderson)

Options for re-wetting might include drain, gully or ditch blocking and increasing Sphagnum cover. Dams can be constructed using wood, plastic, peat, stone, heather bales or coir barriers, each type being suited to different situations depending on water flow, drain size and slope. Thus, heather bales are best where there is little and slow flows, where rills are beginning to develop or at the upper reaches of shallow gullies or grips. Wood, plastic or peat are more suited to slightly deeper gullies or grips, with peat dams being the simplest and cheapest method adopted for most grip blocking. Large gullies would take too much peat out of the surrounding land and could wash out if flows are significant, but could be doubled up with stone or other materials. Stone or wood are more appropriate in deeper gullies, with stone more suitable where the gully has eroded into the mineral soils beneath the peat. Wood and plastic piling need enough peat at the bottom of the drain/gully to be embedded successfully, unless the mineral layer beneath is soft. In very deep gullies, dams generally only reach part way up the space and will not re-wet the surface peat. There could be opportunities to add to the dam heights over time as peat accumulates and so raise the water table possibly over several decades, but this may not be sufficient to reduce *Molinia* effectively. Figures 13-16 show some re-wetting examples.

Figure 15. Wooden dams installed by NT volunteers in gully on blanket bog. South Pennines. Some were lost subsequently in moorland fires, others began to erode underneath and round the sides, whilst the best still hold water. It is not always easy to install effective dams. (Photo: Penny Anderson)

Figure 16. Stone dams in deep gully, raising water table in a number of stages. Peak District. It will take many years before the water table is close to the surface in such situations. (Photo: Penny Anderson)

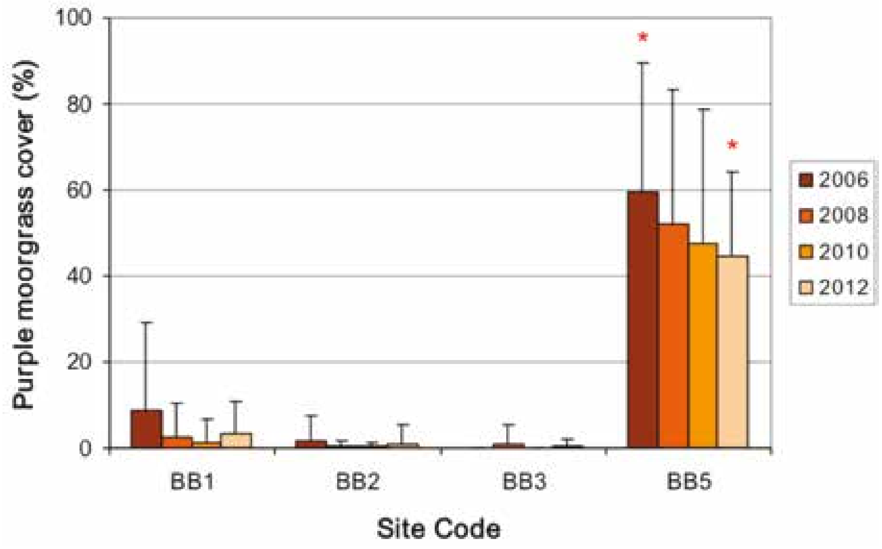


Figure 17. The Abundance of Molinia in Goyt plots, SCaMP (Penny Anderson Associates 2011)

BB1 and BB2 – peat-blocked grips 2006

BB3 Peat blocked grips from 2010 (reference site until 2010)

BB5 plastic and peat blocked grips 2005, started with more Sphagnum and Molinia than other patches

** = significant differences at P=0.5*

It is important to plan dams comprehensively rather than on an ad hoc basis, even if this takes several years as resources become available. First a strategy should be developed that identifies where all the drains and gullies are, their slopes and sizes, their catchment in terms of the amount of water likely to be running down each, the peat depth or lack of it in the bottom of the drains and how they all link with each other in the sub-catchment. These factors all determine the best dam type and sequence to select. Dam installation should then start at the top of the catchment, be close enough together to ensure widespread water table elevation and avoid erosion below each dam, and be comprehensive to have the optimum effect.

There is little scientific research available to demonstrate that re-wetting can reduce *Molinia* in the uplands possibly owing to the lack of adequate monitoring or the dearth of re-wetting projects that affect *Molinia* in particular. One example is the SCaMP project in the Peak District (Penny Anderson Associates 2011) where regular monitoring on one of the restored sites in the Goyt has shown a significant reduction of *Molinia* (Figure 17) and increase of Sphagnum cover after grip blocking in blanket bog over six years. The Exmoor Mires Restoration Project found similar results, with reduced dominance of *Molinia* and a shift towards a more diverse, and usually wetter community on five out of seven restoration sites (Smith *et al.* 2014). Bearing in mind that water tables may not always respond immediately and may take a number of years to reach their optimum levels after drain/gully blocking (Penny Anderson Associates 2011), these are very promising results.

Conclusions

Re-wetting shallow and deep peats, where possible, to reduce *Molinia* dominance would appear to be one option in the suite of management alternatives for management of the grass when it becomes dominant. However, during the search for evidence for this paper, Moss (1913) was consulted to understand better what the *Molinia* vegetation may have been like 100 years ago in the Peak District. The drier ground species included familiar names like *Empetrum nigrum, Erica tetralix, Calluna* and *Deschampsia flexuosa* that were described as locally abundant growing with *Molinia*. This suggests derivation from mixed dry or wet heath vegetation where the change to dominance by *Molinia* has occurred where overgrazing or too frequent managed burns may have been the main drivers. Indeed, G Eyre (pers. com.) remembers his father-in-law burning *Molinia* nearly annually to give the extensive dominance that he has recently spent some years diversifying on Howden Moors.

Moss' wet ground species list of abundant species associated with *Molinia* was longer and contained *Sphagnum* at the top of the list, followed by *Ranunculus flammula, Hydrocotyle vulgaris, Eriophorum angustifolium, Vaccinium oxycoccus,* and a number of sedges like *Carex echinata, C. panicea* and *C. demissa*. The commoner rushes *Juncus effusus* and *J. acutiflorus* were equally abundant in places, and *Narthecium* locally abundant. Less frequently encountered species produced a long list that included orchids, other sedges, other wetland plants including Deer Sedge, other grasses and species that are very rare in the region now such as *Pinguicula vulgaris, Drosera spp* (only *D. rotundifolia* is present now) and *Andromeda*.

This list suggests two things – one is that *Molinia* was abundant in a wide variety of community types and secondly that many of these along with some of the species are now rare. Browsing the adjacent pages revealed some interesting ideas on why this might be. The list of plants that were associated with acid grasslands included a number described as abundant or locally so like *Lotus corniculatus, Centaurea nigra, Linum catharticum, Gentiana amarella* and *Rhinanthus minor,* which today are either absent or very rare in the Dark Peak and much more likely to be found on the limestones or shales outside the Dark Peak. The question to ask is whether it was 200 years of sulphur dioxide pollution that has acidified the mineral soils as well as the peats and resulted in the loss or significant reduction of a wide range of species that were once associated with *Molinia*. This may not be an issue outside the regions that have been particularly affected by sulphur dioxide pollution in the past, but it gives another perspective to the issue of dominant *Molinia* and how to diversify it. Re-wetting is not the only answer and there may be more factors to consider than those discussed so far to date.

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The place of *Molinia* in blanket mire and other upland peat habitats: defining what is ‘good’

Molinia caerulea in upland habitats: a Natural England perspective on the perceived issue of 'over-dominance'

David J Glaves[1]

Introduction

Purple Moor-grass[2] *Molinia caerulea* (hereafter referred to as *Molinia*) is a widespread, perennial, deciduous grass that is frequent in a range of generally wet or moist vegetation types in the UK where it may attain dominance in response to a range of environmental and management factors (Anderson this volume; Grime *et al.,* 1988). Its dominance can be overwhelming to the extent that few other species accompany it and there is evidence that it is increasing (Anderson *et al.,* 2006; Averis *et al.,* 2004, JNCC 2011; Marrs *et al.,* 2004). Such 'over-dominance' is widely perceived to be detrimental to vegetation diversity and structure, and hence to habitat condition (e.g. Anderson, 2002; Anderson *et al.,* 2006; Yeo 1997), and potentially to ecosystem function and associated services, although there appears to be limited evidence on this (Shepherd *et al.,* 2013; Walker this volume).

This paper presents a review and summary from a Natural England (NE) perspective on the perceived issue of *Molinia* 'over-dominance' in the English uplands, particularly on moorland, with a focus on habitat condition. In doing this, it draws on Natural England's recent monitoring, research and evidence reviews to consider: *Molinia* as a component of upland habitats; data on *Molinia* frequency, cover, distribution and extent; the implications for habitat condition and hence targets for management and reporting; findings of the Uplands Evidence Review and other key evidence; and, briefly, management options to address 'over-dominance'. Stone (this volume) provides further detail on Natural England's approach to setting site conservation objectives and the importance of *Molinia* cover in this for upland designated site habitat features.

Molinia as a component of upland habitats

Molinia is widely distributed across the UK, especially in the north and west, where it occurs in a range of generally wet or moist grassland, bog, fen and heath vegetation types in both the uplands and lowlands (Grime *et al.,* 1988; Meade this volume; Preston *et al.,* 2002). It tends to be associated with acidic peat, and peaty and gleyed mineral soils with a well-oxygenated soil profile normally associated with flowing water, though it also occurs locally in calcareous mires and grasslands (Armstrong & Boatman 1967; Averis *et al.,* 2004; Grime *et al.,* 1988). High cover is particularly associated with repeated late-winter burning which favours this deciduous plant that is further fire-adapted through protection of its buds by its sheathing leaves and often tussocky growth form (Grant *et al.,* 1963, JNCC 2011).

Table 1. Main upland habitats and vegetation communities in which Molinia occurs at high frequency in England by UK BAP priority habitat, CSM habitat feature and European Annex 1 habitat.

UK BAP priority habitat (and main [and other] associated NVC community types)	Upland CSM habitat feature	European Annex 1 habitat (code and differences in NVC community types from BAP PH or specific types for habitat)
Blanket bog (M1-3, M17-20, [M15, M21], [more modified forms on deep peat can also include M16, M25, H9, H12, U6])	Blanket [and valley] bog (upland)	Blanket bogs (7130); (depressions on peat substrates of the Rhynchosporion (7150))
Upland heathland (wet heath part) (M15/16, [M25, U6])	Wet heath (upland)	North Atlantic wet heaths with Erica tetralix (4010)
Upland flushes, fens and swamps (M4-6, M21, M23a, M29 [M9a, M10-11, M13, M23c, M24, M25c, M26])	Alkaline fen (upland); Alpine flush; [blanket and] valley bog (upland); mire grasslands and rush pastures (upland) [follows lowland grassland CSM guidance]; short-sedge acidic fen (upland); soakway and sump (upland); spring-head, rill and flush (upland); transition mire, ladder fen and quaking bog (upland)	Alkaline fens (7230); (Alpine pioneer formations of the Caricion bicoloris-atrofuscae (7240)); Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae) (M24, M26); (petryifying springs with tufa formation (Cratoneurion) (7220) (M37-38)); transition mires and quaking bogs (7140).
		Some types included in the BAP PH do not relate directly to Annex 1 habitats, notably acidic fens, and neutral and acid springs, although the springs may have affinities to other wetland Annex 1 types not recognised in the UK.

Its dominance can be particularly marked and extensive on moorland and the moorland fringe (Averis *et al.,* 2004; Yeo 1997). In the English uplands *Molinia* is a frequent component in three UK BAP priority habitats: blanket bog; upland heathland (mainly the wet heath part); and upland flushes, fens and swamps (Maddock, 2011). At high cover it represents a modification of the habitat that is likely to impact on its condition.

These three habitats are covered by upland Common Standards Monitoring (CSM) habitat features used in assessing habitat condition in designated sites (JNCC 2009) and, at least in part, are 'Annex 1' habitats of European importance under the EC Habitats Directive (JNCC 2010). The relationship between these habitats and associated National Vegetation Classification (NVC) communities (Rodwell, 1991) is shown in Table 1 and is reviewed in more detail by Meade (this volume). *Molinia* can also be frequent, sometimes at high cover, in other apparently drier vegetation types and transition zones to them, especially in the oceanic, wetter west, such as some 'humid'/dry heath types (particularly H4 *Ulex gallii-Agrostis curtisii* ['western'] heath).

Blanket bog is the most extensive of the three priority habitats in England, although there are a number of differing estimates of its extent reflecting the use of different datasets at different scales ranging from vegetation community and habitat maps derived from ground survey and/or remote sensing usually with 'ground truthing', to peat soils maps (usually 'deep peat', 40 cm in England, JNCC 2011), or combinations of these. The range varies from c.255,000 (NE 2008) to c.355,000 ha (NE 2010) representing 32-44% of the area of moorland in the Severely Disadvantaged Area (SDA) in England (c.790,300 ha) as mapped by the Defra Moorland Line (ADAS 1993).

Wet heath and upland flushes, fens and swamps are less well mapped although they cover much smaller areas than blanket bog. JNCC (2013) estimated the area of wet heath in England as 25,000 ha of which the majority is in the uplands; applying the same percentage figure of upland (wet and dry) heathland to all English heathland (77% as in given by Natural England 2008) to this wet heath area gives c.19,300 ha of wet heath in the English uplands, though this may be an underestimate. A new, unpublished Natural England priority habitat inventory maps 14,350 ha of upland flushes and swamps, though this is known to exclude some important areas so may also be an underestimate.

Molinia frequency, cover, distribution and extent

Previously unpublished information on *Molinia* frequency, cover and distribution was extracted from data collected as part of a national sample survey of the condition of English blanket bog carried out in 2008-09 (Critchley 2011). This comprised a representative, stratified random sample of 97 habitat polygons (hereafter referred to as sites) drawn from Natural England's then Blanket Bog Priority Habitat Inventory. Each site was sampled using 37 random points with the aim of achieving at least 28 samples within the target habitat (though the actual number varied between sites) based on Scottish Natural Heritage's sampling method for the condition assessment of upland features (MacDonald 2004).

All blanket bog CSM attribute targets were recorded at each point (generally in a 2 m × 2 m quadrat although some were also recorded at a larger scale) together with a number of additional variables including frequency and percentage cover of other key moorland species, fortunately including *Molinia*, and peat depth. Although a similar sample survey of upland wet and dry heath was carried out concurrently, data were unfortunately not collected on *Molinia* frequency/cover. Critchley (2011) presented the results for CSM attributes for all vegetated samples (i.e. excluding bare rock and other unvegetated ground) and a sub-sample which more closely reflected the target blanket bog habitat based on peat depth of ≥40cm (hereafter referred to as 'deep peat') which is followed here for the new data on *Molinia*. The survey provides a snapshot of the recent condition of English blanket bog although it is hoped that future resurveys will supply additional information on trends over time.

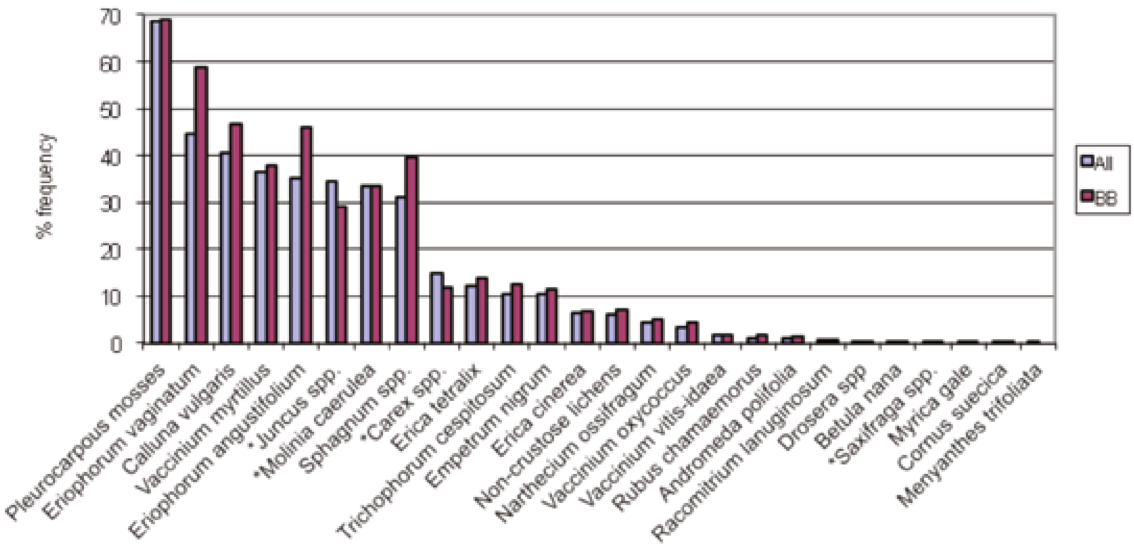
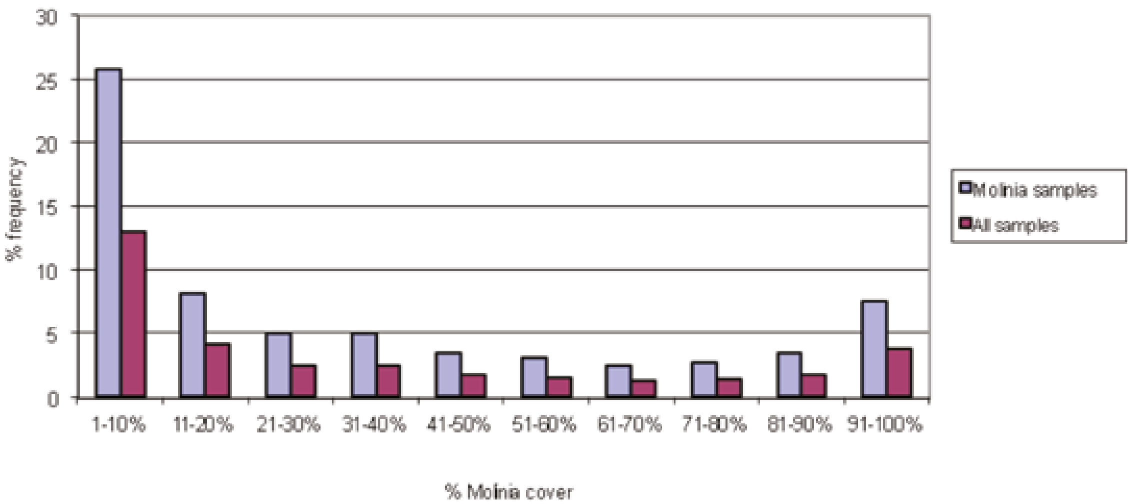


Figure 1. Percentage frequency of Molinia and other species/ groups in 4 m2 samples from a sample survey of English blanket bog (n = 3,393 for all samples (All) and 2,196 for a subset of samples on peat >30 cm deep (BB)). (indicates additional species recorded which are not CSM indicators.)*

Figure 2. Frequency of samples by percentage Molinia cover classes from a sample survey of English blanket bog (n = 3,393 for all samples and 1,138 for samples with Molinia present).

Molinia occurred in a mean of 33% of 4 m^2 samples per site (all samples). Across the whole sample, it occurred in 34% of both all and deep peat samples (Figure 1) suggesting that it occurs at a similar frequency on deep and shallower peat/peaty/mineral soils at least in areas included in the Blanket Bog Priority Habitat Inventory (where 91% of samples were on peat soils). This made it the seventh most frequent species/group (of those recorded, which were mostly CSM positive or negative indicators) in all samples, and sixth in blanket bog samples, after pleurocarpous mosses (69% in both all and deep peat samples), Hare's-tail Cotton-grass *Eriophorum vaginatum* (45%, 59%), Heather *Calluna vulgaris* (41%, 47%), Bilberry *Vaccinium myrtillus* (37%, 38%), Common Cotton-grass *Eriophorum angustifolium* (35%, 46%) and rushes *Juncus* species (35%, 46%). Thus, it was the fifth most frequent individual species recorded overall. Interestingly, the key peat-forming *Sphagnum* bog-mosses as a group were only slightly less frequent than *Molinia* in all samples (31%) and were more frequent in deep peat samples (40%).



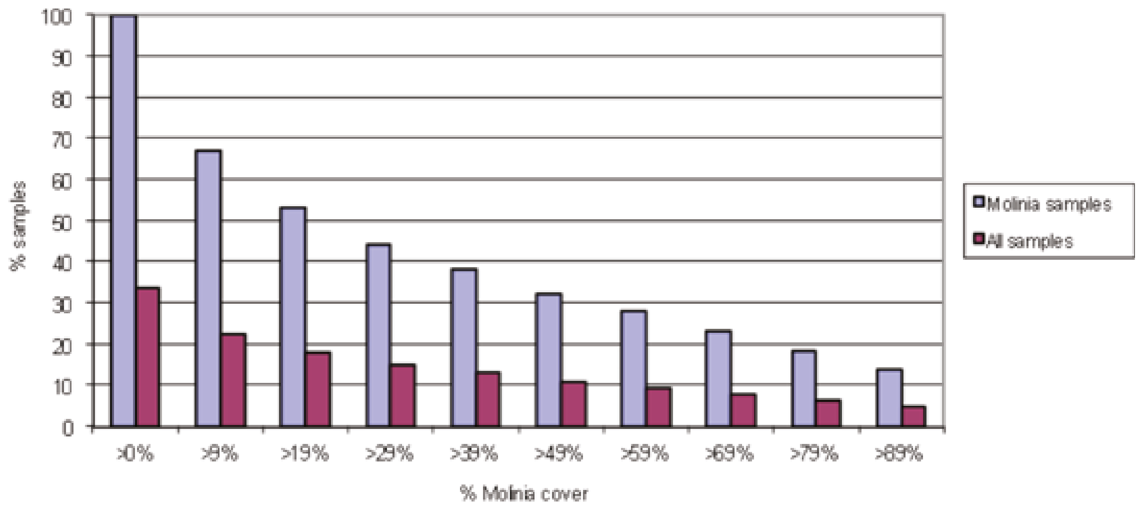


Figure 3. Cumulative frequency of samples exceeding arbitrary percentage Molinia cover thresholds from a sample survey of English blanket bog (n = 3,393 for all samples and 1,138 for samples with Molinia present).

The mean site cover of *Molinia* was 12% (all samples). Over all samples, the mean cover was also 12% and, as with frequency, it was the same in both all and deep peat samples. It had the second highest mean cover of all species in all samples and third highest in deep peat samples after *Calluna vulgaris* (17% in all samples and 18% in deep peat samples) and *Eriophorum vaginatum* (11%, 15%). The range of cover of *Molinia* is presented by the frequency of samples in cover bands in Figure 2 and by the cumulative proportion exceeding arbitrary percentage cover thresholds in Figure 3, for all samples and those containing *Molinia*. Overall, there was a reasonably even spread of all samples across the cover bands with 2-4% of all samples in all bands apart from the 1-10% band which had 13%. There was a similar pattern for samples with *Molinia* present with 26% of samples in the 1-10% cover band, 8% in the 11-20% and 91-100% cover bands, and 5% or less in all others.

Overall, as would be expected, the cumulative proportion of samples exceeding percentage cover thresholds decreased with increasing *Molinia* cover, with 22% of all samples with 10% or greater cover (67% of samples with *Molinia* present) and only 5% with 90% or greater cover of *Molinia* (14% of samples with *Molinia* present) (Figure 3). Only 11% of all samples (32% of samples with *Molinia* present) had ≥50% cover and 7% (20% of samples with *Molinia* present) had ≥75%.

Using these figures on the frequency of samples with high cover from this representative sample survey of English blanket bog and the mapped extent of the habitat, it is possible to estimate the area affected by *Molinia* dominance. This suggests that the area with ≥50% cover of *Molinia* on blanket bog in England may be c.28,000 ha (based on the area of blanket bog given by NE (2008) see earlier). This increases to c.39,000 ha if the greater area of deep peat on moorland given by NE (2010) is used, suggesting a range of around 30-40,000 ha (which declines to c.17,000-24,300 ha with ≥75% cover of *Molinia*). This represents 4-6% of the total area of moorland (in the SDA above the Moorland Line) though it excludes the area dominated by *Molinia* on other upland habitats, particularly flushes, fens and swamps, and wet heath, though they cover a much smaller area.

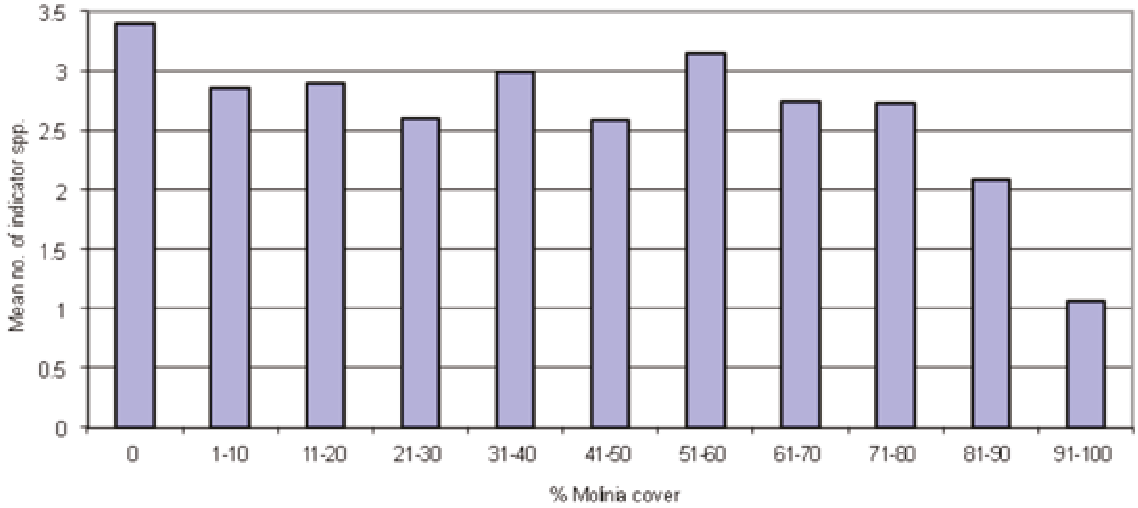


Figure 4. Number of CSM positive indicator species per 4 m2 sample by Molinia cover bands from a sample survey of English blanket bog (n = 3,393).

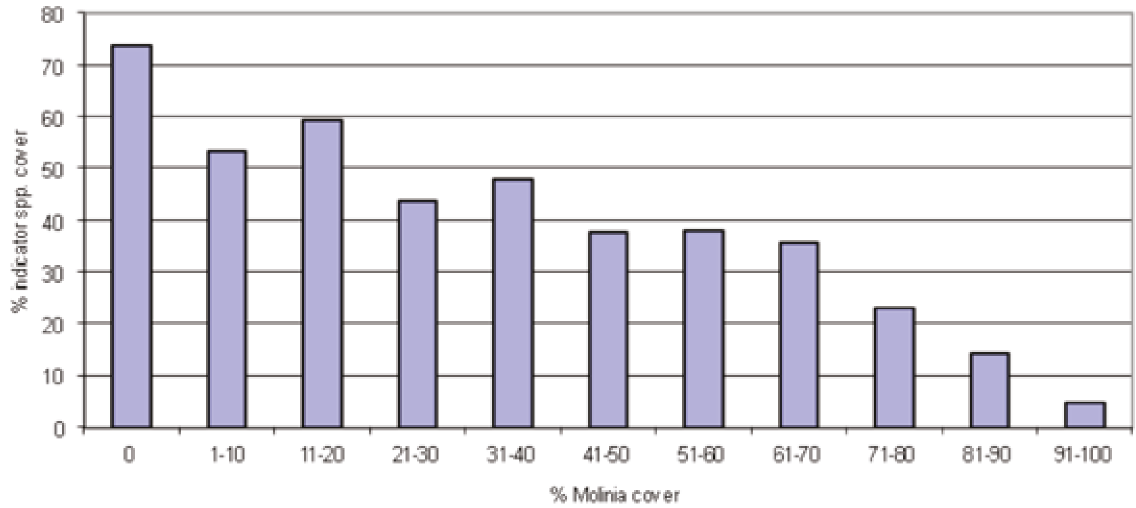


Figure 5. Mean cover of positive indicator species by Molinia cover bands from a sample survey of English blanket bog (n = 3,393).

Assuming that their combined area is c.35,000 ha (see earlier) and applying the same frequency of *Molinia* cover of 50% or more as for blanket bog (11%) gives a rough estimate of a further 3,850 ha, contributing to a total of up to c.44,000 ha with ≥50% cover of *Molinia* (and c.27,000 ha with ≥75% cover).

The relationship between *Molinia* cover and number and cover of CSM blanket bog positive indicators is shown in Figures 4 and 5. The mean number of indicator species per 4 m^2 sample was highest when *Molinia* was absent (3.4) and in the range 2.6 to 3.1 up to 80% *Molinia* cover, but declined thereafter to only 1.1 at 91-100% cover (Figure 4). Mean indicator species cover was highest when *Molinia* was absent (74%) or at low cover (53% and 59% at 1-10% and 11-20% *Molinia* cover, respectively) (Figure 5). At moderate *Molinia* cover (21-70%), mean indicator species cover was lower (in the range 36-48%) and declined further at higher *Molinia* cover (to only 5% at 91-100% *Molinia* cover).

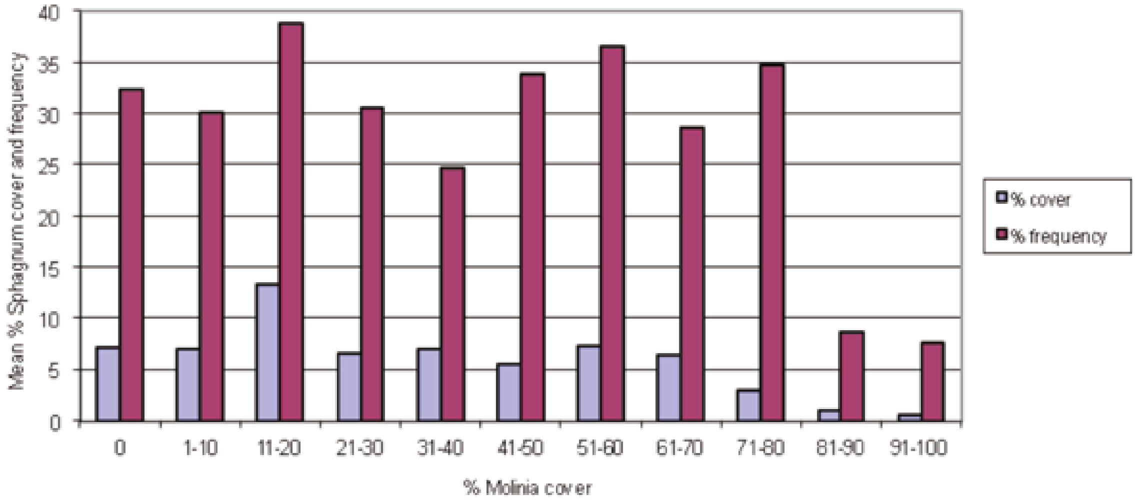


Figure 6. Mean cover and frequency of Sphagnum species in 4 m2 samples by Molinia cover bands from a sample survey of English blanket bog (n = 3,393).

A similar relationship was shown with frequency and especially cover of the key blanket bog species group, *Sphagnum* (Figure 6). Mean indicator species frequency at 4 m^2 scale was in the range 25% to 39% at up 80% *Molinia* cover, but declined to 8-9% at higher cover. Mean *Sphagnum* cover was in the range 7-13% up to 70% *Molinia* cover, but thereafter gradually declined to only 0.5% at 91-100% *Molinia* cover.

The distribution of samples with high *Molinia* frequency and cover is shown by National Character Areas (NCA) in Table 2. Whilst care is needed in interpreting these data, especially for the NCAs with few sites and/or samples, some observations can be made.

NCA	n sites	n sites Molinia present	Mean % frequency /site	Mean % cover /site	n samples	% freq.	% freq >=50% cover	% freq >=75% cover
Exmoor	2	2	94.5	77.3	73	94.5	84.9	71.2
Dartmoor	4	4	75.0	47.7	148	75.0	53.4	37.8
Southern Pennines	18	18	65.0	23.3	620	64.4	21.0	15.0
North York Moors	1	1	94.6	24.1	37	94.6	21.6	5.4
Border Mires & Forests	8	8	28.0	7.1	288	29.2	5.9	2.8
Dark Peak	5	4	33.0	8.9	184	33.2	6.0	1.6
Bowland Fells	2	1	8.3	2.5	72	8.3	2.8	1.4
Yorkshire Dales	39	27	21.3	4.8	1367	21.9	3.7	1.2
South West Peak	3	3	26.8	6.0	101	27.7	4.0	0
Cumbria High Fells	5	3	15.4	3.6	174	15.5	1.7	0
Black Mountains & Golden Valley	1	1	25.0	0.6	36	25.0	0.0	0
North Pennines	8	4	3.9	0.1	272	3.7	0.0	0
South Cumbria Low Fells	1	0	0.0	0.0	21	0.0	0.0	0

Table 2. Molinia frequency and cover per site and across all samples by National Character Areas from a sample survey of English blanket bog (n = 97 sites and 3,393 samples).

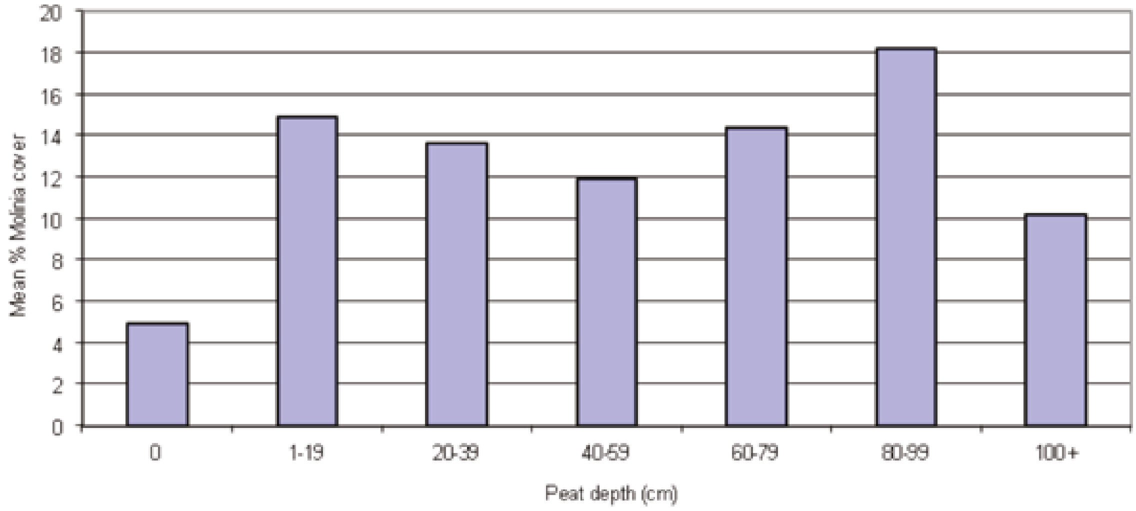


Figure 7. Mean percentage Molinia cover in relation to peat depth from a sample survey of English blanket bog (n = 3,393).

The two south west NCAs, Exmoor and Dartmoor, had much higher *Molinia* frequency (95% and 75%, respectively) and cover (85% and 53% of samples with ≥50% cover). The Southern Pennines also had a high frequency of *Molinia* (64%) in samples but lower frequency of samples with ≥50% cover (21%) and ≥75% cover (15%). The single North York Moors site had high frequency of *Molinia* in samples (95%) and similar frequency of samples with ≥50% cover (22%) to the Southern Pennines but lower frequency of samples with ≥75% cover (5%). Of the rest, only the Dark Peak, Border Mires and Black Mountains had ≥25% frequency of *Molinia*. None had more than 6% of samples with ≥50% *Molinia* cover. Thus, high *Molinia* frequency and especially high cover is unevenly distributed with the concentrations on the SW moors and Southern Pennines.

The relationship between *Molinia* cover and peat depth in all samples is shown in Figure 7. Mean cover was lower on mineral soils (5%, though only 9% of all samples) than on peat (14%), with relatively little difference between peat depth bands other than slight peaks on shallow peat (15% at 1-19 cm) and especially deeper peat (18% at 80-99 cm).

Effects on habitat condition

High, and especially very high, cover of *Molinia* may have an impact on habitat condition when there is an objective to maintain or restore a priority habitat. *Molinia* does not itself appear in a CSM attribute for blanket and valley bog. However, there is a target not to exceed a maximum cover (>75%) of two other potentially dominant graminoids, *Eriophorum vaginatum* and Deergrass *Trichophorum cespitosum*, (and Ericoids). Given its tendency to local dominance, it has been suggested that this target ought also to apply to *Molinia* (e.g. Glaves *et al*. 2005) or possibly to graminoids as a group (as for wet heath). Nevertheless, very high cover of *Molinia* is likely to result in other species composition attribute targets being failed (see earlier), in particular indicator species diversity (≥6 spp./sample) and indicator species cover (≥50% cover comprising at least 3 indicator spp.), although there may occasionally be instances where this is not necessarily the case and indicator species diversity remains relatively high. Natural England condition assessment data suggest that only c.10-12% of blanket bog by area is currently in favourable condition, with failure of the indicator species frequency and/or cover targets a major contribution to this (e.g. no sites passed the target for indicator species frequency and only 8% for cover in the sample survey by Critchley 2011). Nevertheless, the vast majority is classed as in unfavourable recovering condition where appropriate management is considered to be in place to deliver habitat recovery over time.

Similarly, *Molinia* is not itself a component of CSM attributes for wet (and dry) heath or upland flushes, fens and swamps features (Table 1) apart from soakway and sump which has a maximum cover threshold (<20%). In addition, the lowland grassland guidance (JNCC 2004, also used in the uplands) for lowland Purple Moor-grass and rush pastures has a maximum threshold for *Molinia* cover in some communities (≤80% cover for M24-26 in the English guidance, (Robertson & Jefferson, 2000)). However, as with blanket and valley bog, *Molinia* at very high cover is also likely to result in failure of other attributes for these habitats in particular those for positive indicator species frequency and especially cover, and, in the case of wet heath, maximum cover of graminoids (75%).

This is increasingly important as it has implications for management and reporting on the delivery of key biodiversity targets, in particular the Biodiversity 2020 targets for England (Defra 2011). These include targets to: increase the proportion of SSSIs in favourable condition to 50% by area; achieve 90% of priority habitats in favourable or recovering condition by area (95% in SSSIs); and restore at least 15% of degraded ecosystems as a contribution to climate change mitigation and adaption. Habitat condition assessments also contribute to reporting on the Favourable Conservation Status (FCS) of European (Annex 1) habitats. Improving habitat condition can also contribute to the delivery of wider ecosystem service outcomes including climate regulation, water regulation, provision and quality, land use product provision, landscape character and historic environment protection.

Evidence reviews and management guidance

There have been a number of past literature reviews and guidance on *Molinia* and its management, notably a review for the then Countryside Council for Wales (Anderson *et al.* 2006) and management guidelines which drew on MAFF/Defra-funded research (ADAS 2001, 2007, Marrs this volume, Marrs *et al.* 2004, Ross *et al.* 2003). In addition, past reviews and guidance produced for Defra/Natural England and their predecessors on the management of moorland habitats have referred to *Molinia* management issues, notably Mowforth & Sydes (1989), Coulson *et al.* (1992), Shaw *et al.* (1996), Backshall *et al.* (2001), Tucker (2003), Stewart *et al.* (2004), Glaves *et al.* (2005), O'Brien *et al.* (2007) and, more recently, Heinemeyer & Vallack (2015).

Table 3. Summary of findings from the Upland Evidence Review blanket bog restoration, peatland burning and moorland grazing topic reviews relevant to Molinia.

Evidence review topic (and reference)	Key conclusions (and strength of evidence)
Blanket bog restoration (Shepherd et al. 2013)	■ Molinia can form peat on its own. ■ Molinia dominance can be reduced by vigorous cutting, grazing and herbicide treatments. ■ Spring burning does not reduce dominance of Molinia, unless in combination with the above methods.
Peatland burning (Glaves et al. 2013)	■ Burning of blanket bog and wet heath typically leads to a period of graminoid dominance, in particular of Hare's-tail Cotton-grass, Molinia or deergrass, typically lasting 10-20 years (strong). ■ Burning on short rotations and/or heavy grazing after burning can lead to maintenance of the dense graminoid phase in wet heath (moderate). ■ Burning results in increased grazing of Molinia by sheep and deer, but this may be short-lived (moderate).
Moorland grazing (Martin et al. 2013)	■ Grazing utilisation of 33% of annual leaf growth can reduce Molinia biomass and cover and may allow increased floristic diversity (moderate), though the impact varies depending on species of grazer and site (strong). ■ Cattle graze Molinia more readily than sheep and, either alone or mixed with sheep, more effectively achieve utilisation levels that reduce biomass and cover (moderate). ■ Sheep can exert some control of Molinia in particularly in combination with cutting and burning (moderate). ■ Molinia can increase following grazing reduction or removal to the detriment of less-competitive inter-tussock species, so can be detrimental to habitat conservation (strong).

Building on these previous reviews and guidance, Natural England carried out an Upland Evidence Review (UER) in 2012/13 using a rigorous, structured approach to reviewing scientific and other literature (Stone 2013). This covered five key upland management issues, three of which are relevant to *Molinia*: blanket bog restoration (Shepherd *et al.* 2013), and the effects of burning on upland peatlands (Glaves *et al.* 2013) and moorland grazing (Martin *et al.* 2013). The key conclusions in relation to *Molinia* from these reviews are summarised in Table 3.

Management options

The findings from the evidence reviews and other evidence and experience have fed in to Natural England's ongoing uplands programme, in particular to a site-tailored outcomes approach which is being developed and implemented in partnership with stakeholders. Appropriate management will vary depending on the features and other characteristics, issues and objectives for sites following discussions with land owners and managers, and sometimes other stakeholders.

The options for managing *Molinia* over-dominance are reviewed in some detail in other papers in these proceedings including several on ongoing studies. The UER findings suggest that where management is considered necessary and the objective is to restore bog, fen or wet heath habitat, grazing and cutting/flailing are likely to be the best options where practicable. Summer grazing, particularly with cattle, can be effective in reducing *Molinia* cover especially on smaller, enclosed sites and this has been supported through agri-environment scheme options and supplements, most notably on the SW moors. However, there can be problems in getting sufficient numbers on at the right time and on the right areas particularly in large moorland grazing units, for example, on Dartmoor (A. Guy pers comm.). There is less evidence on the effects of cutting/flailing especially on moorland and it may not always be possible, for example, on stony, steep or very wet ground, although various flailing treatments accompanied with application of *Sphagnum* propagules are the subject of an ongoing study in the South Pennines (Pilkington, this volume). Grazing and/or cutting treatments may benefit from other additional interventions, including changes to hydrology, the addition of scarce or absent mire species, especially *Sphagnum*, and potentially the use of herbicides and/or burning as initial restoration (rather than routine) treatments, although consideration needs to be given to their possible effects on non-target species and wider outcomes.

However, *Molinia*-dominated moorland may have value for other outcomes including: as nesting, feeding and roosting sites for a number of bird species such as Curlew *Numenius arquata*, Short-eared Owl *Asio flammeus* and Twite *Carduelis flavirostris* (Blackshall *et al*. 2001, O'Hara, this volume); summer grazing for livestock (Job & Taylor 1978, Lance 1983); and may be considered an element of local landscape character, for example, at Exmoor Forest (ADAS 1994). There might also be other ecosystem service benefits over some alternative vegetation types and associated management practices such as rotational burning, though there is limited evidence on this. Thus, there may sometimes be a role for limited or even no intervention, especially where *Molinia*-dominated areas are considered to be delivering other benefits or are showing habitat recovery, or have the potential to, over longer timescales, especially where this is accompanied by monitoring.

Summary

Molinia is a widespread grass species that may attain dominance in generally wet or moist habitats in response to a range of environmental and management factors. Such dominance is widely perceived to be detrimental to vegetation diversity and structure, and hence to habitat condition and potentially ecosystem function. It is a frequent component in three upland UK BAP priority habitats: blanket bog; upland heathland (mainly the wet heath part); and upland flushes, fens and swamps, of which blanket bog is by far the most extensive.

Information on *Molinia* frequency, cover and distribution was extracted from data collected in a representative sample survey of the condition of English blanket bog. *Molinia* was the fifth most frequent individual species (of those, mostly indicator species, recorded) occurring at a mean site frequency of 33% and mean cover of 12%. It occurred at similar frequency and cover on deeper and shallower peat/mineral soils. Only 11% of all samples had 50% or greater cover of *Molinia* (and 7% had 75% or greater cover). The distribution of high cover was localised with concentrations on the south west moors and Southern Pennines. Based on these proportions and the extent of the habitats, it is estimated that up to c.44,000 ha may have 50% or greater *Molinia* cover representing 6% of English moorland (and c.27,000 ha with 75% or greater cover). The number of blanket bog indicator species and their combined cover declined with increasing *Molinia* cover, especially above c.80% cover.

Molinia does not itself appear in a CSM attribute target for blanket and valley bog, the other fen features and wet (and dry) heath apart from for soakway and sump which has a maximum cover target (<20%). Nevertheless, high cover of *Molinia* is likely to result in other species composition attribute targets being failed and hence result in unfavourable condition (although sites may still be recovering if appropriate management is in place). This is increasingly important as it has implications for management and reporting on the delivery of key biodiversity targets.

Building on previous reviews and guidance, Natural England recently carried out an Upland Evidence Review (UER) which included three relevant topics: blanket bog restoration, burning on upland peatlands and moorland grazing. The findings together with other evidence and experience have fed in to Natural England's ongoing uplands programme, in particular to a site-tailored outcomes approach which is being developed and implemented in partnership with stakeholders. Appropriate management will vary depending on the features and other characteristics, issues and objectives for sites. The UER findings suggest that where management is considered necessary to reduce *Molinia* cover and the objective is to restore bog, fen or wet heath habitat, grazing and cutting/flailing are likely to be the best options where practicable though there may be benefit from other additional interventions, including changes to hydrology, the addition of scarce or absent mire species and potentially the use of herbicides and/or burning as initial restoration treatments. There may sometimes be a role for limited or even no intervention, especially where *Molinia*-dominated areas are considered to be delivering other benefits or are showing habitat recovery, or have the potential to, over longer timescales, especially where this is accompanied by monitoring.

Footnotes

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[2]English names of plants are given at the first mention in the text and scientific names thereafter.

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English names of plants are given at the first mention in the text and scientific names thereafter.

Principles underpinning conservation objectives for upland Sites of Special Scientific Interest where *Molinia caerulea* is dominant

Dave A. Stone, Deputy Chief Scientist, Natural England

Introduction

The history of *Molinia caerulea* (L.) on deep upland peat; its ecology; why its dominance in these habitats might be perceived as a problem; and managing the species on peat sites. Why is there such interest in these things, particularly when it comes to sites of Special Scientific Interest (SSSI)? In part, the answer lies in the charge that *Molinia* is guilty of causing upland peat sites to be in unfavourable condition. But will waging war on *Molinia* turn things around, or is there something more that a deeper understanding of conservation objectives might shed light upon?

The purpose of this paper is to set *Molinia* dominance on upland peat habitats in a wider context by focusing on the ambitions for the vegetative components of those habitats through the medium of developing condition monitoring for designated sites.

The monitoring of the condition of SSSIs has been going for nearly 20 years. Inevitably over that period some of the basic concepts that underpin the monitoring activity and how that relates to management of a site have become shrouded in the mists of time. Going back to basics and exploring four simple questions will give some insight to principles for conservation objectives for *Molinia* on SSSIs:

- What is favourable condition?
- What are conservation objectives?
- What does 'good' look like for upland habitats underlain by peat?
- What is the contribution of *Molinia* in achieving the desired conservation outcome for a site?

What is favourable condition?

There is a plethora of terminology and jargon around the monitoring of designated sites and their 'interest features'; those being the geology, vegetation community, or notable species of plant or animal, that are found in a place and for which it was designated.

Favourable Condition is another piece of jargon that gets thrown about in conversations about designated sites. Or in this particular case, failure of a site to meet its favourable condition target due to a dominance of *Molinia* is often what's referred to. Jargon it may be, but what does it actually mean? The JNCC Common Standards for Monitoring Guidance (2004) states:

"An interest feature can be judged to be in Favourable Condition when the targets or target ranges prepared in the conservation objectives have been met."

It is important to remember that the judgement about condition of an interest feature is at the site level, and ultimately these are aggregated into a judgement for the site overall and all its interest features.

Many of our upland peat sites are also subject to international designation under the auspice of the Wild Birds and the Habitats Directives. With these designations comes another 'favourable' term, Favourable Conservation Status. The directives state that:

"The conservation status (of a qualifying feature) may be considered 'favourable' when: (a) its natural range and areas it covers within that range are stable or increasing; and (b) the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future; and (c) the conservation status of its typical species is favourable."
(Natural England, 2014a)

The assessment of Favourable Conservation Status is also underpinned by something called Conservation Objectives.

What are Conservation Objectives?

There are two things called 'conservation objectives' in our monitoring lexicon. The first identified in the Common Standards for Motoring (JNCC, 2004), the second underpinning the assessment of favourable conservation status for international sites.

Focussing on international designations, there is a statement of objectives for the qualifying features on a site. The objective statement for a site will set out, in a narrative form, the aspirations for the qualifying features of that site. The following example is typical:

"Ensure that the integrity of the site is maintained or restored as appropriate, and ensure that the site contributes to achieving the Favourable Conservation Status of its Qualifying Features, by maintaining or restoring:

- The extent and distribution of qualifying natural habitats and habitats of qualifying species;
- The structure and function (including typical species) of qualifying natural habitats;
- The structure and function of the habitats of qualifying species;
- The supporting processes on which qualifying natural habitats and the habitats of qualifying species rely;
- The populations of qualifying species, and;
- The distribution of qualifying species within the site."

(Source: Natural England, 2014b)

Objective statements for international sites can be found online. These documents also list the qualifying features of a site. Underpinning the objectives are detailed tables, called Favourable Conservation Tables, which set out parameters and or targets for the attributes of each feature. For example, attributes of blanket bog may include level of heather cover, level of *Sphagnum* cover, and area of eroded peat.

Turning our attention to domestic designated sites and Common Standards Monitoring. SSSIs will have a management statement, usually called a VAM – View about Management, which describes in a narrative the objectives for the interest feature of that site. This is also underpinned by a tabulation of attributes for interest features which sets out the targets or target ranges for the attributes of a feature. These attribute targets are the 'conservation objectives' used when assessing Favourable Condition (Natural England, 2008).

Putting all the jargon and paperwork to one side, these things are analogous to each other, and for an international site one and the same thing. What it is all about is trying to codify 'what good looks like'. It is also worth mentioning that the attribute targets can be tweaked to better reflect the individuality of a feature on a site. After all, we all know that no two patches of a vegetation community are identical.

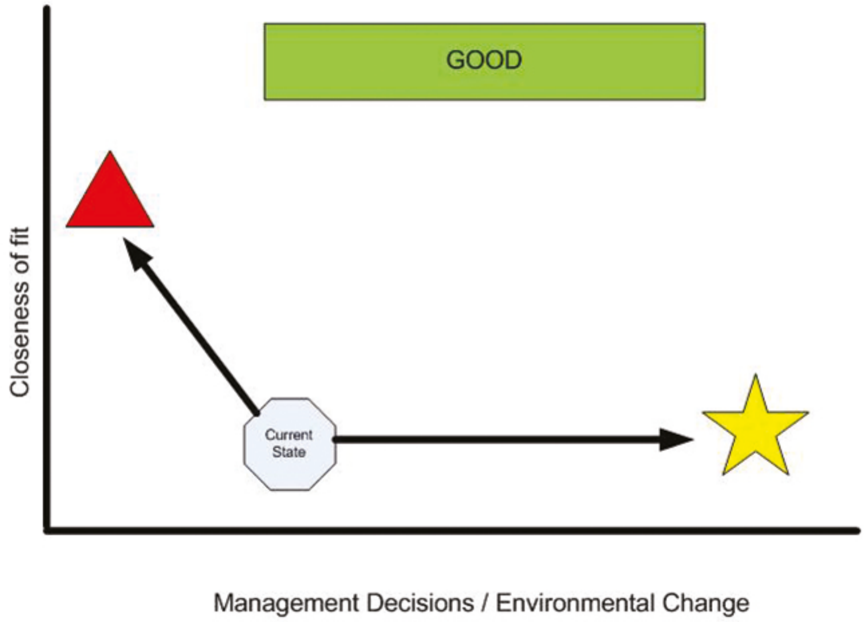
What does 'good' look like for upland habitats underlain by peat?

'Good' can be different things in different places. The narratives and tables that make up conservation objectives are simply ways of codifying what 'good' looks like. They are about expressing the desired conservation outcomes for a place. Conservation objectives express the natural variation inherent in vegetation communities that occur on functioning upland peat systems. The National Vegetation Classification is the *lingua franca* for describing these communities and the phytosociological data that underpins them describes their variability.

'Good' is a variable feast. It is dependent on physical, climatic and management factors at a site. It is dependent on scale. But describing what 'good' looks like is important for more than monitoring favourable condition or favourable conservation status. These are not arbitrary targets or goals, but codified descriptions of a desired outcome that are based on an ecological understanding of a habitat's potential. The codification of 'good' captures a description of the vegetative responses to a functional ecosystem. And we can use these descriptions to shape our decisions about the management of our upland peat habitats.

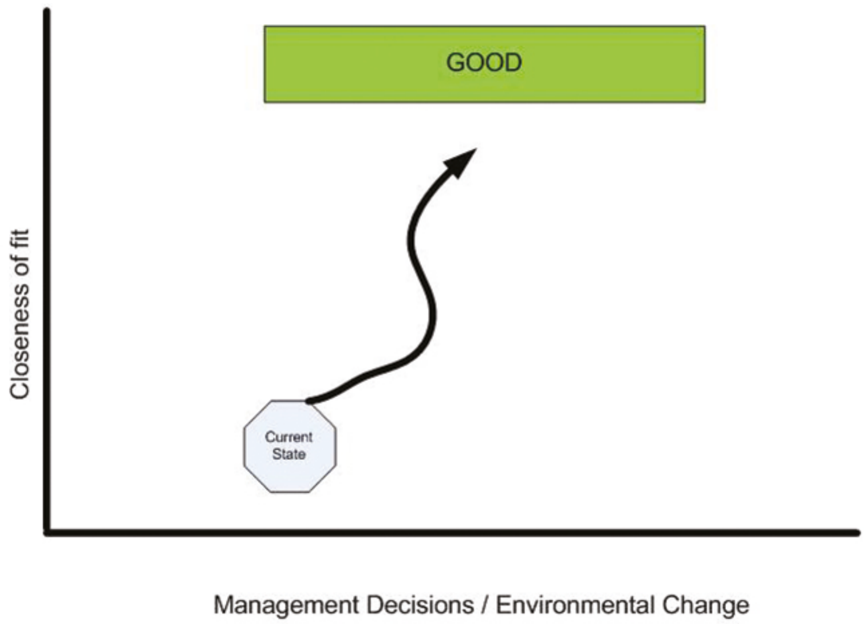
In nature conservation circles we often talk about restoration. But restoration is the act of returning something to a previous understood condition. The reality is that we rarely restore habitats. Our habitats are complex dynamic systems that evolve. To restore something means that we regard it as static, an artefact to be preserved. I would argue that environmental conservation is more about conserving the ability to evolve by ensuring functionality, and vegetative responses are one way of describing that functionality. As such, describing what 'good' looks like is a means of looking forward not backwards.

Figure 1. Difference between current state and desired outcome.



In Figure 1, the green box represents our desired conservation outcome, our 'good'. And the grey blob represents where we think things are currently. If we undertake some management without giving much thought to why we are doing it the current state will change. That change of state could take the feature in various directions which will manifest in a change of vegetative community but not move us in the direction of our desired conservation outcome. However, if we implement a science based management regime with the goal of moving our current state towards 'good' we are able to better target our resources and our efforts. Periodically we check or monitor what's happening to the vegetation community. It may be heading off in an undesirable direction so we adjust the management. So the path may not be direct but eventually it should get us close to our desired conservation outcome (see Figure 2).

Figure 2. Managing towards desired outcome.



It is the codification of what ‘good’ looks like that enables us to do that. Collectively, we can use experimental and experiential evidence about what works to help shape the conversations and decisions about management.

How does Molinia contribute to achieving the desired conservation outcome for such a site?

The focus of this conference is the dominance of *Molinia* in certain upland peat habitats. That very dominance often means that the habitat or even the site is judged to be in unfavourable condition under Common Standards Monitoring.

It is easy to point the finger and wage war on *Molinia*, but we need to ask if *Molinia* is the cause or the symptom? If ‘good’ describes the vegetative response to a functional grouping of ecosystem processes is the dominance of *Molinia* symptomatic of a break-down in those fundamental processes?

Molinia is a naturally occurring part of some upland peat vegetation communities, and we would expect to see it there in the appropriate proportion. And, in some instances, a complete absence of *Molinia* could be equally problematic in respect of condition. *Molinia*-dominated communities such as M24 and M26, are fen communities usually limited in extent to flushes in the uplands. On upland peat, *Molinia* dominance is symptomatic of a break-down in ecosystem processes. Therefore, ‘good’ in such places is determined by describing the vegetation community that should be there if processes were restored.

Conclusion

Returning to the title of this paper, “Principles underpinning conservation objectives for upland Sites of Special Scientific Interest where *Molinia caerulea* is dominant”, there aren’t any principles for conservation objectives for *Molinia per se*. However, there are principles for conservation objectives for the upland peat vegetation communities in which *Molinia* may occur as a non-dominant component. These involve defining targets or attributes for the interest features of sites based upon the vegetative response to an achievable functional ecosystem. In effect codifying the parameters of NVC communities to describe what ‘good’ looks like.

Consideration of this is important because it means that the management of upland peat bodies is not for *Molinia* but for the potential vegetation community on that upland peat body. That vegetation community may of course have a *Molinia* component. Where a peat body has been modified evidence from similar but unmodified peat bodies provides a reference for determining the potential vegetation community and functional ecosystem characteristics. This in turn should inform decisions about management interventions.

Conserving our unique upland peat habitats in the face of social, economic and environmental drivers of change is a serious challenge facing all those with an interest in these special places. Conservation objectives and associated desired conservation outcomes provide a framework that can facilitate the agreement around shared outcomes. They are a starting point for a conversation about outcomes on a site: something that gives a sense of the conservation aspiration and a sense of the trajectory we would like to achieve. They allow us to consider the art of the possible with a view to achieving multiple outcomes and multiple benefits.

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The management of deep peat moors as catchments for the public water supply and its relationship with *Molinia*

Andrew Walker, Catchment Strategy Manager, Yorkshire Water (YW)

Introduction

Locally, 45% of our raw water comes from the Pennine Uplands; nationally the figure is nearer 70% from upland catchments. Reservoirs at Scar House & Angram in Nidderdale (Figure 1) can supply 10% of our daily needs. Over the last two years YW has been working on peatland restoration in this catchment and has invested over £1m to stabilise bare peat and block grips. We have done this in partnership with the Ramsden family and their Middlesmoor Estate. They share our aspirations to protect and enhance these important habitats for mutual benefit, and build on the open and inclusive way we try to run the YWS Estate.

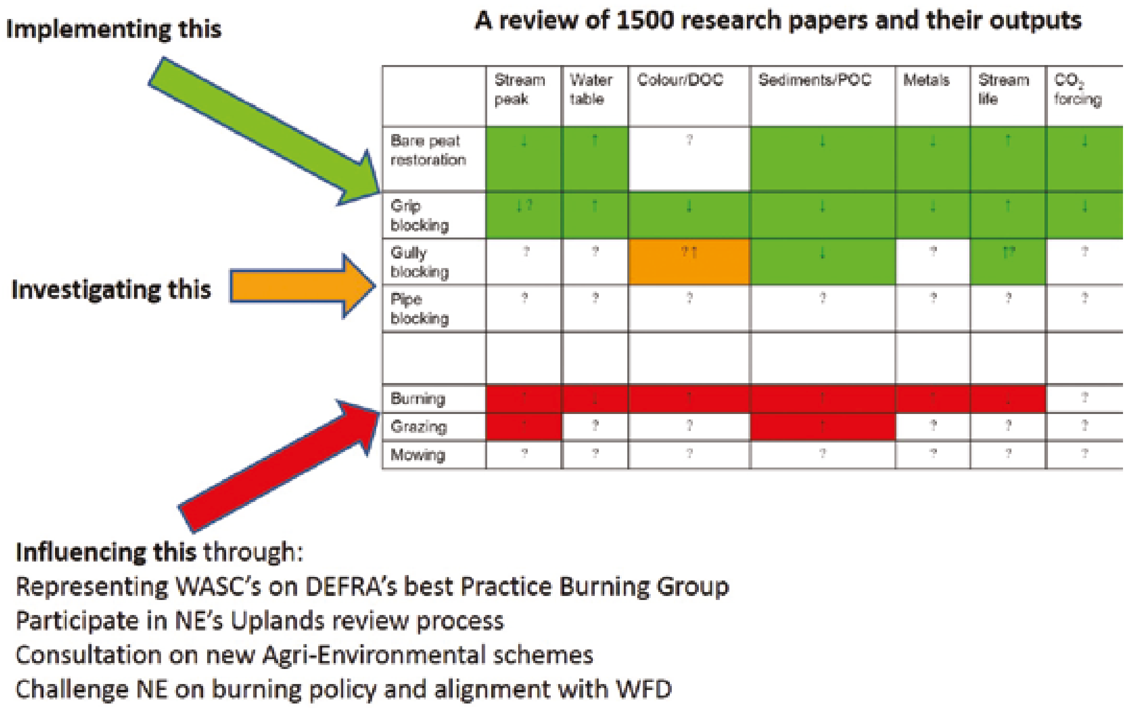
Figure 1. Reservoirs at Scar House & Angram in Nidderdale.

The main issues for maintaining water quality

The main quality issue for water from the uplands is colour contributed by DOC[1], which comes from degraded peatlands. Excess heather can dry the peat out, and the peat can be further impacted by the effects of rotational burning. It has been known for over a decade that the current management of heather moorland was not good for water quality, but a 'no burn' policy was not imposed on the Estate. Imposing such a policy may have made a positive impact on some catchments, but would also alienate the people YW most needed to work with and influence. Through the 'outcomes' approach we have reached a consensus which is good for all stakeholders. Nobody won, nobody lost, and nobody lost face. The winner is one of the most internationally important habitats, and the range of ecosystems services it provides. We can put a value on water quality, as we can with carbon storage and sequestration. We need to understand and promote the values of other services we get from the uplands, such as food, biodiversity, renewable energy and recreational opportunities for health and well-being.

Twelve years ago Yorkshire Water started to investigate why colour was increasing. There are some things that are now beyond influence, like historic atmospheric pollution, but there are others that can still be addressed. The framework within which the various factors are approached is shown in Figure 2.

Figure 2. Framework within which the various factors are approached. An investigation started twelve years ago by Yorkshire Water to find why colour due to DOCs was increasing (Source: University of Leeds).

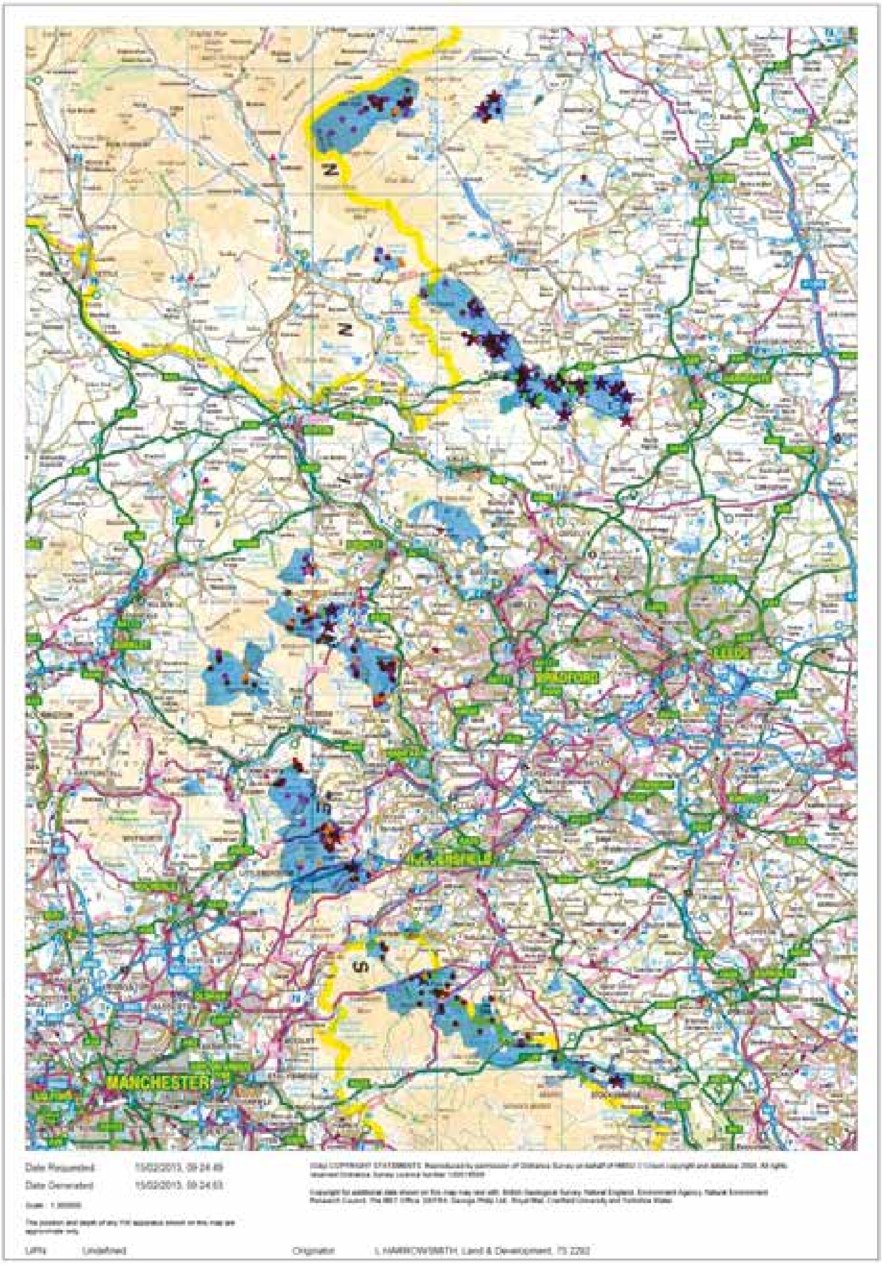


Responding to land management proposals

Much of Yorkshire Water's land ownership (Figure 3) is based around these upland reservoir catchments. On average it owns around 30% of catchment land, ranging from almost 100% in the North of the Estate to next to 0% in the South. The 30,000 Ha Estate is managed in a way that balances the needs of tenants and water quality. YW believe that is the best way to influence change on land they do not own.

The following is an example of how YW responds to land management proposals from occupiers of the land, discussions in which Natural England, as the statutory consultee on Sites of Special Scientific Interest, Special Areas of Conservation and Special Protection Areas also takes part.

Figure 3. Location of Yorkshire Water's landholdings, shown in blue.



Original proposal to diversify the sward for improved grazing:

- Spray with Round-up weedkiller;
- Burn dead vegetation;
- Scarify the soil;
- Reseed with heather.

Issues arising from the proposals:

- Pesticide risk – there is no treatment at Fixby Water Treatment Works;
- Fire risk and concomitant damage to surface and underlying peat and hydrology;
- Heather management can adversely impact peat. Heather has a higher evapotranspiration rate and draws the water table down, thereby exposing more of the peat to the aerobic conditions the bacteria need to break down the peat. Burning the heather can expose the peat surface to excess solar radiation, heating it up and further desiccating it;
- Customer perception; YW talks to their tenants and neighbours about the importance of clean water. If they are seen to be using herbicides on a large scale, or indeed setting light to vegetation when we've said it can be damaging, it gives mixed messages;
- Yorkshire Water would probably prefer grass to heather from the water quality angle; grass does not lower the water table in the same way as heather does, and is not rotationally burnt which can expose the peat to sunlight.

Through negotiation with Natural England and the tenant we were able to devise a solution which will move the land towards a more diverse structure, but also allows our tenant to expand their herd of cattle, thereby increasing profitability on the farm.

Revised proposal to diversify:

- Flail trial areas;
- Cut access tracks for cattle;
- Graze *Molinia* off;
- Natural regeneration of dormant seed stock.

Benefits:

- No Pesticide;
- No Fire;
- Increases productive land to help our tenants' business;
- Better Customer perception;
- Moves the habitat towards favourable condition whilst we discuss what we need from the uplands; current favourable condition assessments for blanket bog mean that the land must have a variety of dwarf-shrub heath. The most common is heather, but these plants are not necessarily significant in terms of forming peat. The aim is a balanced ecology which reflects the vegetation that formed the peat in the first place, that is, a lot more *Sphagnum* moss.

Dominant *Molinia* and its relationship with water quality

A literature review was carried out by Dr Ant Blundell (University of Leeds) to look at the impacts of *Molinia caerulea* on dissolved organic carbon. Its conclusions include the following:

New invading plants promote faster organic matter decomposition due to the greater degradability and the higher nutrient content of their litter.

Molinia caerulea produces a very extensive root system that can reach 80 cm in depth (Taylor *et al.,* 2001). This injection of fresh organic matter not only occurred at the surface but may also occur in deeper layers of the peat profile.

Dissolved organic carbon concentration and its mobility were higher in closed (*Molinia*- and birch-dominated) than in open *Sphagnum*-dominated vegetation. These results suggest that the vascular plant invasion of the *Sphagnum* peatland increased organic matter decomposition. Furthermore, compared to *Sphagnum* species, *Molinia caerulea* and *Betula* spp. have higher litter decomposability (Chamie and Richardson, 1978; Bartsch and Moore, 1985; Berendse, 1998).

The objective of a study by Certini *et al.* (2015) in heathland was to assess whether, in this environment, the current vegetation cover is a good proxy for SOM (Soil Organic Matter) quality and dynamics. To this end, litter decomposition was followed over a period of 1 year by placing litterbags filled with biomass from each dominant species (*Sphagnum*, *Calluna* or *Molinia*) under each type of vegetation cover (*Sphagnum*, *Calluna* or *Molinia*), so as to simulate the effects of possible climate-change-induced shift of vegetation on early stages of litter decomposition. There was a large variability in soil DOC and total dissolved nitrogen (TDN) concentrations, and vegetation types did not show any significant difference with respect to these two variables. However, the hydrophobicity index was significantly different in soils under the three types of vegetation, being highest for *Calluna* and lowest for *Molinia*. This difference indicates that a greater proportion of DOC under *Calluna* was hydrophobic and this is a treatment issue[2].

Another study with litterbags (Van Vuuren *et al.*, 1992) followed the decomposition of litter and roots from a site dominated by *Erica tetralix* and a site dominated by *Molinia caerulea*. Leaf litter and roots of each species were incubated on both sites; the experiments lasted up to 3 years. This *in situ* decomposition study showed that the litter mass remaining after 1 year of decomposition varied between 62 and 66% in the case of *Molinia* and *Calluna* and 83 and 94% for *Sphagnum*. *Molinia* litter and *Calluna* litter appear to be decaying at a similar rate no matter where the litter is placed and the decomposition is much higher than for *Sphagnum*.

The weighted decomposition constant was 0.23 per year for *Molinia* litter, and 0.10 per year for *Erica tetralix* litter; the decomposition constants for roots were 0.29 per year for *Molinia* but only 0.03 per year for the *E. tetralix*.

It was concluded that the rate of accumulation of soil organic matter per gram of plant debris is slower on the site dominated by *Molinia* than on the site dominated by *E. tetralix*. In the long term, nitrogen and phosphorus are probably released faster from *Molinia* than from *E. tetralix* plant debris. In comparison with *E. tetralix*, *Molinia* adapts to high nutrient loadings well. Unlike *Erica*, as it has a high potential growth rate but the leaves have a shorter life span and the dead material is more easily decomposed. Greater nutrient supply increases dominance of *Molinia* and this is steadily incremental because nutrients released by decomposition are recycled to assist growth in subsequent years.

Calluna dominance was associated with the highest DOC concentration, *Molinia* and *Sphagnum* dominance with lower concentrations, and sedge dominance with intermediate concentrations.

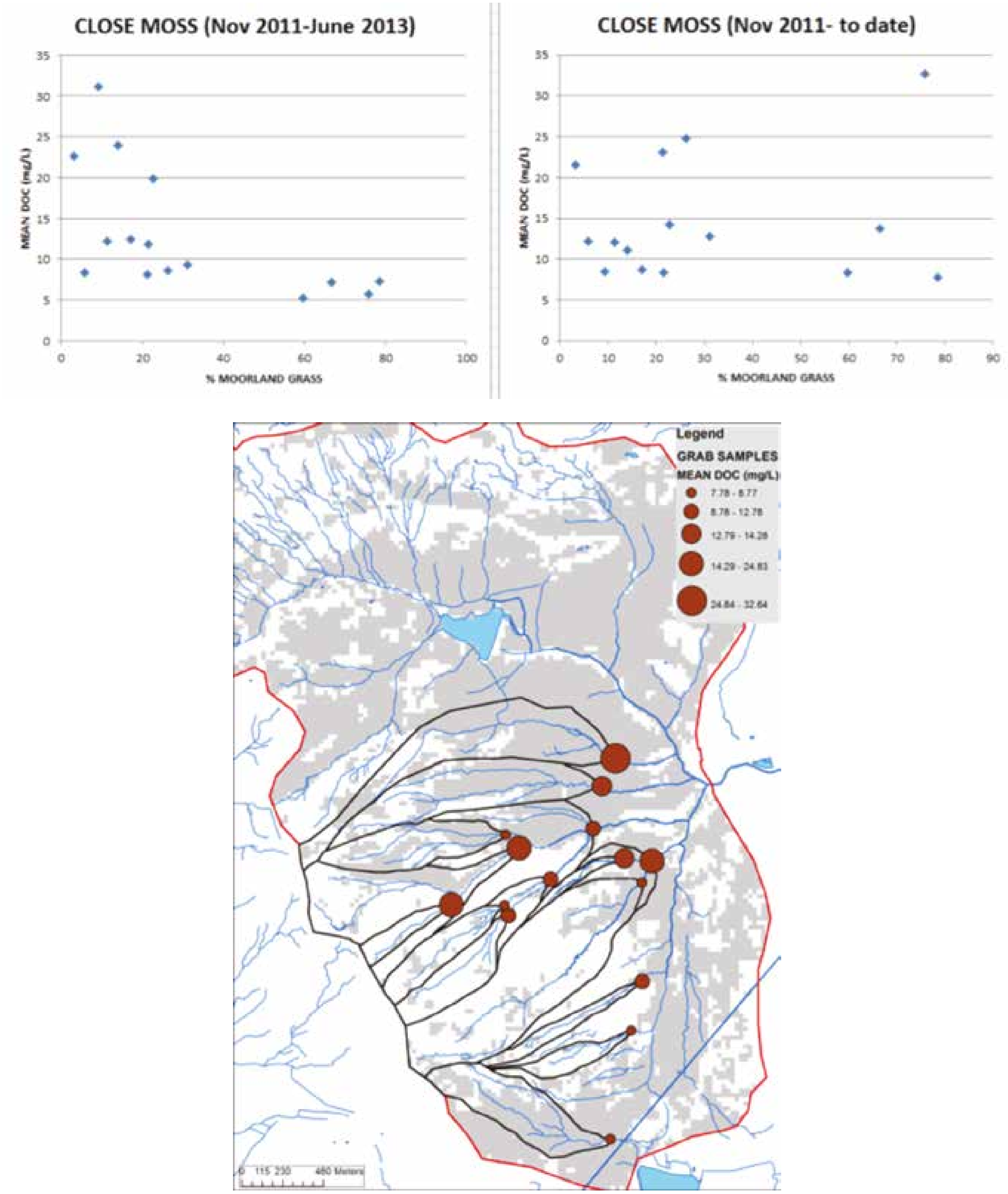
In summary, *Molinia* does not contribute significantly to peat accumulation because it has a high rate of litter decomposition compared to *Sphagnum* and Ericaceous species, though it is not clear whether the oxygen status of all situations is comparable, as decomposition is more inhibited in stagnant environments.

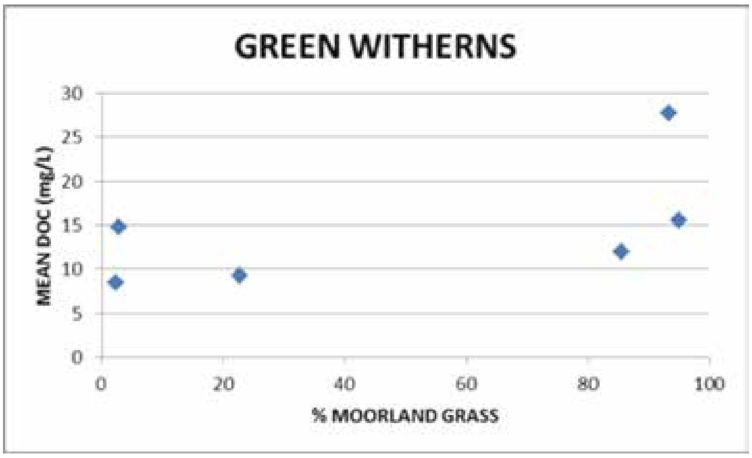
Contrarily, the two papers looking at DOC examined in this review are either equivocal or suggest that *Molinia*-dominated vegetated material gives rise to only low quantities of DOC, despite the high rate of decomposition and the aeration of peat by its deep-penetrating roots. Consequently, the exudates that contribute to DOC may not be detected by the soil water samplers near the surface which is where most of the roots of Ericaceous species are found.

Local studies of DOCs in stream water under AMP5[3] have also yielded equivocal results about the comparative release of DOCs under different dominant plant covers. The concentration of DOC in stream water was measured at points in two catchments, Green Withens and Close Moss[4]. The graphs showing DOC concentration and sample locations are shown for Close Moss in Figure 4 and for Green Withens in Figure 5. While the plots for Close Moss for the earlier dates show an inverse relationship between DOC release and *Molinia* cover, it is not so clear from the more recent data. With so few samples and without statistical analysis it is difficult to interpret the Green Withens data, but the scatter suggests the converse to the Close Moss site, with a slight increase in DOC release associated with increasing cover of *Molinia*.

Based on these conclusions the dominance of potable water catchments by *Molinia caerulea* does not pose a threat to the quality of the supply of raw water to Yorkshire Water's treatment works.

Figure 4. Analysis of DOC in stream waters from the Close Moss catchment, south of the M62.





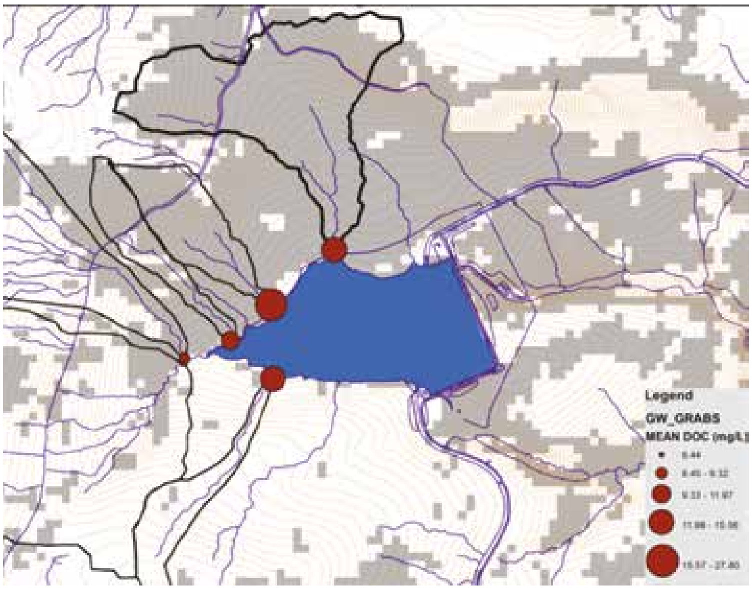


Figure 5. Analysis of DOC in stream waters from the Green Withens catchment, north of the M62.

The context for Molinia – Yorkshire Water's priorities for managing upland catchments

While the evidence suggests that *Molinia* dominance on the blanket mire does not compromise water quality, there are no longer any doubts about the issues arising from bare and eroding peat. This is not only due to the release of DOC but also the erosion of peat which fills up water storage space in reservoirs. As a consequence Yorkshire Water is supporting the stabilisation of bare peat through revegetation.

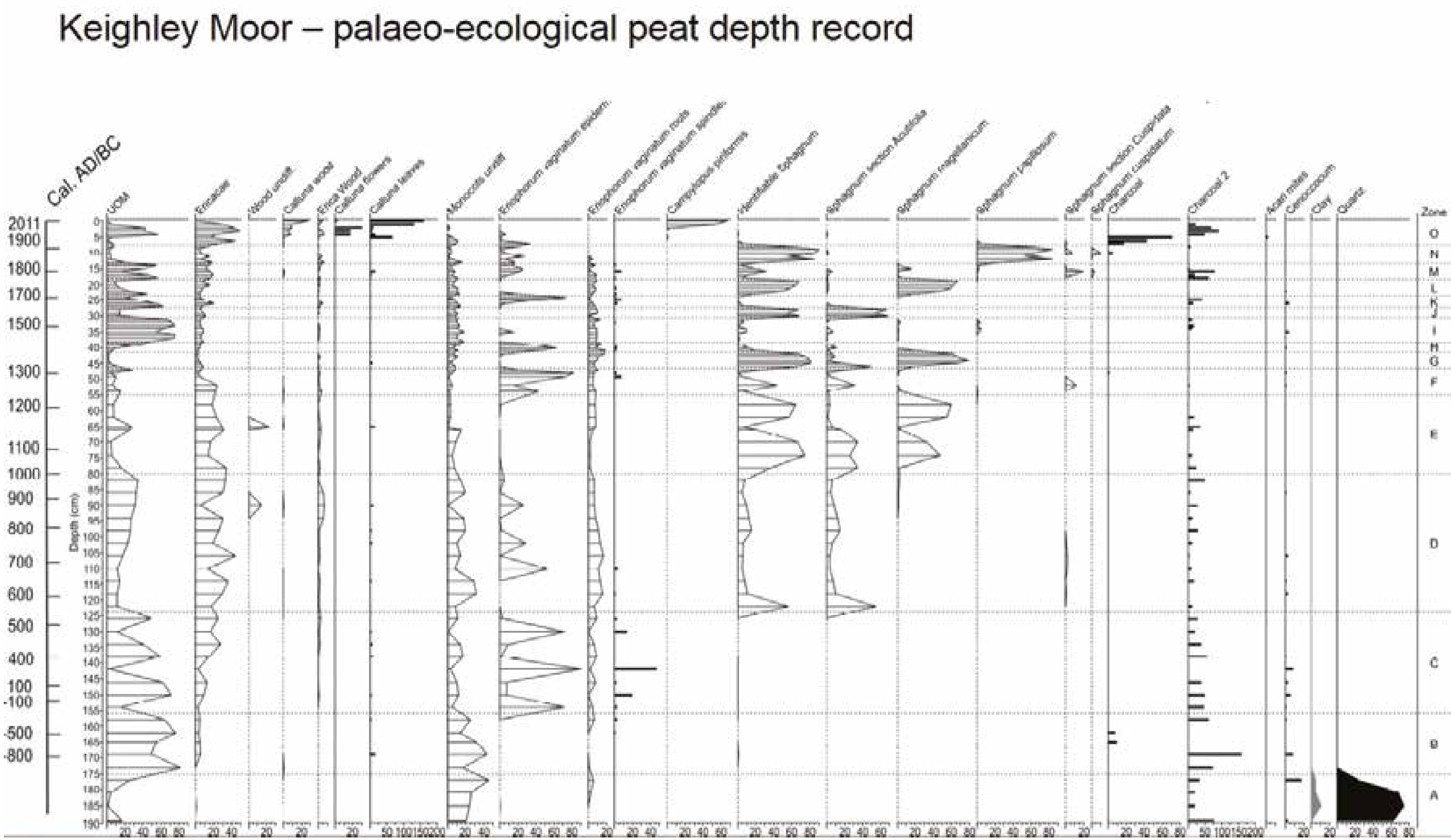
There is an action plan for each moor (Figure 6). On Keighley Moor Yorkshire Water has filled 5000 bags with mown heather, which has been used on peatland restoration work in Nidderdale. A programme has just started to establish *Sphagnum* moss in some of the cut areas in order to extend the dominance of this peat forming species, targeting areas that are known to be sources of colour.

Figure 6. Approaches to the improvement of the vegetation on deep peat within catchments managed by Yorkshire Water. Top left: Involving science in the discussion of options. Top right: Blocking ditches to raise the water level and prevent peat from oxidising. Bottom left: Harvesting and spreading heather brash to revegetate bare peat and improve dwarf-shrub heath vegetation. Bottom right: Encouraging the growth of Sphagnum moss to encourage new peat formation, atmospheric carbon capture, and to prevent the release of DOC.

In other less sensitive areas the cut areas will be left to recolonize. In time it is hoped to demonstrate that the wetter areas deliver as many, if not more grouse than the more traditional burns.

Evidence is key in changing behaviours and perceptions. A peat core from Keighley Moor (Figure 7) presents a compelling case that what we see today (80% plus heather coverage) has only been there for the last 150 years. The preceding 3000 years have been dominated by wetter conditions with more peat building mosses and sedges.

Figure 7. Macrofossil diagram for KMRC master core. Peat components are derived from averaged quadrat counts under low-power magnification (x10). Leaf counts are a breakdown of the % Identifiable Sphagnum and consist of proportions based on a random selection of leaves (100 per sample interval where possible) identified at high magnification (x400). Bar graphs are absolute counts. For charcoal, Charcoal 1 represents an absolute count of charcoal pieces. Charcoal 2 is the percentage of the entire sample when there are too many pieces to count. UOM is Unidentified Organic Matter; it can be used as a surrogate for the degree of decomposition, and ties in roughly with the degree of humification (A. Burrell pers. comm.).



Notes

[1] Dissolved organic carbon (DOC) is a broad classification for organic molecules of varied origin and composition within aquatic systems. The "dissolved" fraction of organic carbon is an operational classification. Many researchers use the term "dissolved" for compounds below 0.45 micrometers, but 0.22 micrometers is also common, saving colloidal for higher concentrations. A practical definition of dissolved typically used in marine chemistry is all substances that pass through a GF/F filter. The recommended measure technique is the HTCO technique after filtration on pre-combusted glass fiber filters, typically GF/F filters. (*Source: Wikipedia*)

[2] Hydrophobic organic material is harder to remove with the coagulants used at the treatment works. If it is not removed it can react with chlorine (used for disinfection) to form carcinogenic disinfection by-products such as tri-halomethanes.

[3] Asset Management Plan phase 5. A Regulator approved Customer-funded plan for the water industry.

[4] Close Moss is also the location for the *Molinia*-dominance work described by Underdown & Meade in this volume.

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Long-term observations of *Molinia caerulea* (Purple Moor-grass) dominated Blanket mire in the West Pennine Moors and statutory designation.

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Introduction

This paper is not based on an exact scientific methodology but rather on observations of trends and changes in vegetation in the West Pennine Moors (WPM) over the last forty years.

The West Pennine Moors lies between the Lancashire towns of Blackburn, Chorley, Bolton and Haslingden and is the western half of the Forest of Rossendale. With its counterpart, the Forest of Bowland to the north of the River Ribble, the two comprise broad western extensions to the main Pennine ridge. The name West Pennine Moors was coined around 1975 (LCC, 1976) as a prelude to the adoption of a Local Plan for the area (LCC, 1986) to cover recreation, conservation and development. The area involved a partnership of Lancashire County Council, Greater Manchester Council and North West Water Authority (NWWA), covered parts of six District Councils, and functioned much as a second tier 'national' park. This holistic approach to countryside management was dealt a severe blow, arguably resulting from the political ethos of the Thatcher premiership, through the abolition of GMC in 1986 and finally with the privatisation of NWWA in 1995. Current cuts in local government, alongside the business function of United Utilities plc (as the major land owner) have in the author's opinion, led to the near demise of the integrated countryside management of the WPMs as set out forty years ago.

Establishing a case for statutory designation

In the early days of the Nature Conservancy in the UK, south Lancashire was situated between its regional offices in South Lakeland and Shropshire. At the same time leading academic institutions tended to focus upland research in the Peak District, the Lake District and Snowdonia, rather than the Lancashire uplands, evident in mapping of data to define NVC Communities (Rodwell, 1991), (Rodwell, 2006) and published works (Tallis *et al*. 1997; Tallis, 1965; and Tallis, 1969).

When it came to the designation of the South Pennines Site of Special Scientific Interest (SSSI), the boundary was very much guided by the territories of upland breeding birds (Brown & Shepherd, 1990) and this was subsequently adopted for the Special Protection Area (SPA). The WPMs, being generally lower in altitude and consequently having comparatively more varied vegetation, is less favourable to upland waders such as Golden Plover *Charadrius morinellus*. However, it was and remains more suitable for Short-eared Owl *Asio flammeus*; regrettably all the four breeding pairs were missed during the 1990 survey, carried out as the precursor of SSSI designation.

Figure 1. Plateau blanket mire vegetation, Anglezarke Moor, West Pennine Moors.

The existing SPA boundary was followed when the opportunity arose to propose a habitat-based South Pennines Special Area of Conservation (SAC) designation.

By the mid-1990s it had become recognised by ecologists working in local government, privatised utilities and NGOs in Lancashire and Greater Manchester, that the WPMs blanket bog habitat was in far better condition than elsewhere in the South Pennines (Figure 1), despite parts appearing to be dominated by *Molinia caerulea* (Purple Moor-grass). Their views were supported by the Local Team of English Nature; however, following the South Pennines designations there were allegedly insufficient resources to undertake the necessary survey work. This situation remained until the matter was taken up by LCC's Ecologist through the West Pennine Moors Area Management Committee (AMC), who resolved in November 2003:

'To engage with regional agencies and present a case for improved conservation status for the WPM and greater legislative protection for threatened species and habitats'.

With funding through the WPMs Conservation Budget and voluntary support, work to survey, collect and collate data commenced in 2004 and was completed in 2007 with the production of the *West Pennine Moors: A Conspectus for Statutory Designation* (Jepson, *et al.*, 2007). This document comprised two parts, the text detailing how and why the area qualified for designation; and numerous distribution maps for key species and habitats. Although made available to Natural England (English Nature's successor) in 2007, limited action followed, despite the verbal acknowledgement that the area qualifying for designation for both habitats and birds. Indeed it was further acknowledged that the area qualified as an SPA. However, further surveys were undertaken in 2012 through Natural England but, in the author's opinion, various policy-based obstacles persisted and there followed numerous missed deadlines for designation. It has still not been designated as an SSSI though its case for designation has not been challenged.

West Pennine Moors – General Statistics

The WPMs covers an area of 230 km^2 comprising 71 km^2 of open moorland. At its closest the WPMs is situated circa 25 km from the Lancashire coast and receives an annual rainfall greater than 1300 millimetres. Almost 40 km^2 of the moorland is blanket bog within the altitudinal range of 300 m – 400 m, with the lowest on Withnell Moor at 240 m and the highest on Winter Hill at 456 m. Average peat depth range between 2.5 – 3 m, with the deepest recorded over 5 metres. Of this *Molinia caerulea* dominates 707 ha (18.5%), whilst *Molinia* mosaic/transitional stands cover an additional 680 ha (17.8%).

Sphagnum moss species in the WPMs

Across the WPMs, including areas of *Molinia*-dominated mire, field surveys undertaken between 2000 and 2010 revealed a general *Sphagnum* diversity of 7 to 9 species per one kilometre square, with at least two such square containing 11 species. *Sphagnum* species recorded growing on blanket mire within the WPMs are listed in Table 1.

Table 1. List of Sphagnum species growing in association with blanket mire in the West Pennine Moors.

Scientific Name	Common Name
Sphagnum capillifolium ssp. rubellum	Red Bog-moss
Sphagnum cuspidatum	Feathery Bog-moss
Sphagnum denticulatum	Cow-horn Bog-moss
Sphagnum fallax	Flat-topped Bog-moss
Sphagnum fimbriatum	Fringed Bog-moss
Sphagnum flexuosum	Flexuous Bog-moss
Sphagnum magellanicum	Magellanic Bog-moss
Sphagnum palustre	Blunt-leaved Bog-moss
Sphagnum papillosum	Papillose Bog-moss
Sphagnum russowii	Russow's Bog-moss
Sphagnum squarrosum	Spiky Bog-moss
Sphagnum subnitens	Lustrous Bog-moss

Molinia caerulea, 'Friend' or 'Foe'

Molinia caerulea (Purple Moor-grass)-dominated moorland is generally viewed as a habitat of little value to nature conservation and more generally as a threat to moorland habitats, particularly as there may have been an associated loss of dwarf-shrub/ericaceous plant cover. This is well exemplified by the statement *'Molinia* encroachment has been viewed as a major threat to moorland conservation in the UK and elsewhere in Europe' (Marrs *et al.* 2004). However, this rather generic statement needs teasing out to assess its relevance to the blanket mire component of 'moorland' and how it relates to the definition of 'active bog' applied to upland and lowland ombrotrophic bogs in the EU Habitats Directive (EU, 1996).

The natural habitat is blanket mire[1] over most of the Pennine uplands, including the WPMs. It is a very different habitat from upland heath, often a near monoculture of *Calluna vulgaris* (Heather), a type much favoured in the management of moorland for Red Grouse.

A distinction is made between peat that is not still accumulating or possibly degrading, and that in which there is still a net increase. JNCC (2005) follows the EU (1996) in defining 'Active' 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 circumstances, together with heather *Calluna vulgaris* and other ericaceous species'.

The definition includes two statements that are of particular significance for the WPM and each warrants very careful interpretation:

- vegetation that is normally peat-forming; and
- inclusion of Purple Moor-grass *Molinia caerulea* in certain circumstances.

In the author's opinion, *Molinia,* like any other plant material, will form peat where the conditions are sufficiently anoxic. This is where the water table is at or near the surface and the dead foliage is allowed to accumulate[2]. This process is often prevented by drainage, grazing and burning. New peat is usually found by rummaging beneath the thatch of dead leaves, where the underlying ground is moist; this is certainly the case in locations in the WPMs (Figure 2). Provided this initial peat formation by *Molinia* litter is sustained by waterlogging, a stand of Purple Moor-grass is indicative of habitat recovery after past mismanagement.

Another argument in favour of *Molinia* contributing to favourable condition on blanket mire is the way in which its tussocks provide a suitable microclimate for the establishment of *Sphagnum* mosses. This has been observed to take place on the WPM for over the preceding forty years.

Figure 2. (left) Incipient peat formation beneath the thatch of Molinia caerulea (Purple Moor-grass) foliage, West Pennine Moors

Evidence for the role of *Molinia caerulea* in the recovery of degraded blanket mire

Bromiley Pasture, on the flank of Anglezarke Moor, Lancashire, (Figures 3 – 7b), is an appropriate example and case study, though it is by no means unique. Here, using a topographic typology (JNCC, 1994) the extensive area of *Molinia*-dominated peat forms watershed mire contiguous with the saddle mire across the head of the Belmont valley. Where the water table is at or near the surface, *Sphagnum* mosses flourish between mature *Molinia* tussocks and beneath its canopy of leaves (Figures 4a and 4b). Observations suggest that a humid environment for growth is maintained beneath the thatch. Even in high summer during moderate periods of drought, night-time condensation on *Molinia* foliage is substantial and serves to maintain a degree of humidity. Further, in the absence of inhibiting fires the *Sphagnum* hummocks grow to over a metre across, to overtop the *Molinia* tussocks and reduce its foliage to scattered culms (Figure 5).

Figure 3. Bromiley Pasture case study, an extensive area of Molinia-dominated blanket mire across the head of the Belmont valley, 2015, West Pennine Moors

Figure 4a. (left) Sphagnum (Bog-moss) between Molinia caerulea (Purple Moor-grass) tussocks and beneath its foliage, Bromiley Pasture, West Pennine Moors

Figure 4b. (right) Sphagnum papillosum growing up through Molinia caerulea (Purple Moor-grass) Bromiley Pasture, West Pennine Moors

Figure 5. Molinia caerulea (Purple Moor-grass) reduced to scattered culms in Sphagnum (Bog-moss) carpet, Bromiley Pasture, West Pennine Moors

Figure 6. *Vaccinium oxycoccus* (Cranberry) on hummock of *Sphagnum papillosum* within *Molinia caerulea* (Purple Moor-grass) blanket mire, Bromiley Pasture, West Pennine Moors

Alongside with the decline of *Molinia* dominance, *Vaccinium oxycoccus* (Cranberry) can colonise and spread across the hummocks of *Sphagnum papillosum* (Figure 6). Seedlings of ericaceous dwarf-shrubs follow, including *Erica tetralix* (Cross-leaved Heath). However, all too often this succession is halted, albeit temporarily, by wildcat fires, although the larger *Sphagnum* hummocks are capable of surviving if the burn is not too hot. It is only after such fires that the size and extent of the *Sphagnum* hummocks growing within the *Molinia* tussocks becomes evident (Figure 7a and 7b). In this sheltered environment *Sphagnum* hummocks have been found to measure a metre across, some coalesce to form hummocks with a spread of 3 metres.

Figure 7a. (left) Extent of *Sphagnum* (Bog-moss) hummocks visible after wildcat fire across *Molinia caerulea* (Purple Moor-grass) Blanket mire circa 2007, Bromiley Pasture, West Pennine Moors

Fugure 7b. (right) Damage to individual *Sphagnum* (Bog-moss) hummock following wildcat fire circa 2007, Bromiley Pasture, West Pennine Moors

Without the intervention of fire or grazing, the author's observations would suggest that succession from dominant *Molinia* is not towards the NVC M20 *Eriophorum vaginatum* blanket and raised mire (Rodwell, 1991) so widespread in the Pennines. Rather, given the general abundance of *Sphagnum papillosum* and certain ericaceous species, succession is towards the M18 *Erica tetralix-Sphagnum papillosum* raised and blanket mire, with the *Erica tetralix* sub-community of the M19 *Calluna vulgaris-Eriophorum vaginatum* blanket mire in some instances representing a transitional stage or an intermediary climax community.

Successional linkage between M25 and M18 or M19a communities may be reinforced by a reversal of this succession in Marshaw Clough in the Bowland SSSI and SPA (Figure 8). In the mid-1970s this broad upland clough was near wilderness, its moorland flanks and valley dominated by extensive M18 *Erica tetralix-Sphagnum papillosum* raised and blanket mire community (Figure 9).

Figure 8. Habitat degradation, Marshaw Clough in the Bowland SSSI and SPA, through the disruption of hydrology by the construction of an access track and overgrazing by sheep.

Figure 9. Example of mire vegetation, tentatively referable to M18 Erica tetralix-Sphagnum papillosum raised and blanket mire, which existed prior to the construction of the track and its consequential hydrological impacts, Marshaw Clough in the Bowland SSSI and SPA.

As part of the blanket mire macrotope, hillside flushes supported scarce species such as *Myosotis stolonifera* (Pale Forget-me-not) and its newly described hybrid *M. x bollandica, Eriophorum latifolium* (Broad-leaved Cotton-grass), *Neotia cordata* (Lesser Twayblade) and *Anagalis tenella* (Bog Pimpernel)[3]. In the late 1980s a track was consented along the valley flank to provide access to the fell tops for Grouse management. This truncated the drainage, robbing the mires below of water, and over the same period the intensity of sheep grazing increased significantly.

The result has been the loss the M18 mire community and *Sphagnum* to be replacement by heavily grazed *Molinia* tussocks, on which there are localised vestiges of *Erica tetralix* (Cross-leaved Heath). Degradation has taken place leading to a community referable to a poor variant of the M25 *Molinia caerulea-Potentilla erecta* mire community (Figure 10), along with the loss of the flush habitats impacted upon by the track.

Figure 10. Degradation to a poor variant of the M25 Molinia caerulea-Potentilla erecta mire community from a species-diverse M18 Erica tetralix-Sphagnum papillosum raised and blanket mire, Marshaw Clough in the Bowland SSSI and SPA.

While there is rarely any records or documentation of past activities leading to the contemporary extent of dominant *Molinia*, (notwithstanding the examples cited by Anderson, 2016, in these Proceedings), the most likely causative activities leading to habitat change in Marshaw Clough are documented here.

The Re-wetting Option

Various techniques have been tried to reduce the dominance of *Molinia caerulea* including heavy grazing, ground disturbance, the use of herbicides, burning and re-seeding; many of these were investigated by Marrs *et al.* (2004) and are further described in these Proceedings. Observations in the WPMs over nearly forty years underpin the author's long-held opinion that hydrology is the key to habitat restoration on deep peat. Re-wetting the peat through the blockage of drains and 'grips', constructed many years ago, and the cessation of burning, are both crucial. If the peat is sufficiently moist at the surface, *Sphagnum* colonisation can be rapid. With the re-wetting of Aushaw Moss, a formerly totally dry bog in the WPMs, the result was numerous bog pools. Within three years many had become well colonised by the aquatic bog-moss *Sphagnum cuspidatum*, despite it not having been present before the formation of the pools.

Under a thatch of dead *Molinia* foliage, where the peat remains sufficiently moist for much of the year, *Sphagnum* recovery appears to occur spontaneously. This can involve several species, the first typically being *Sphagnum fallax, S. fimbriatum*, and then *S. subnitens, S. palustre* (the hummock forming variety), *S. papillosum* (most importantly) and *S. capillifolium*.

While the above observations should ideally be underpinned by long-term research, the lack of it should not preclude action on the ground to restore blanket bog by re-wetting, as there are several other environmental gains, such as reduced fire risk, flood alleviation, improved water catchment control and water quality. In the author's opinion, based on the observations described above, the role of *Molinia* needs to be re-evaluated and the part it can play in bog restoration recognised. Habitat restoration working though 'natural' processes is more likely to deliver success than short term 'fix-it' intervention techniques such as harrowing or the widespread application of herbicide. Restoration of peat hydrology should be the priority, the rest will follow with time. In this respect in terms of habitat condition assessment, *Molinia*-dominated mire with an understory containing frequent *Sphagnum* or where there is evidence of peat formation, should not be regarded as Unfavourable Condition, but at the very least, be in a state of Unfavourable but Recovering.

Notes

[1] The term blanket mire for upland bogs is preferred by the editor because not all of it is strictly ombrotrophic and some parts are more fen-like, being sustained by water that has infiltrated and run through the peat, or which has had contact with non-peat soils. See Tallis *et al*., 1997, Introduction.

[2] See Anderson (2016) in these Proceedings for a description of the relationship between waterlogged peat and the growth of *Molinia caerulea*.

[3] See Anderson (2016) in these Proceedings over historic species diversity of upland habitats.

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Molinia management and birds

David O'Hara, RSPB Dove Stone Site Manager

Introduction

The uplands of the UK are of international importance for their moorland breeding birds. *Molinia*-dominated vegetation is locally abundant in the moorlands of Britain, particularly in the west, and on the degraded peatlands of the south Pennines. It tends to occupy a lower altitude zone than the Cotton-grass plateaux bogs. Though in most cases a degraded form of a formerly richer vegetation community, a number of bird species are associated with *Molinia*. Of particular note are Curlew *Numenis torquata* and Short-eared Owl *Asio flammeus*. What management will best meet the needs of these and other species, and do these birds benefit from aims to restore more diverse peatland vegetation communities?

Figure 1. A monoculture of Molinia. Photo: David O'Hara

Molinia on moorland – extensive on former blanket bog, and part of a wider mosaic of moorland edge vegetation

To set the context in which stands of *Molinia* and birds are perceived, more extensive examples tend to be found on degraded blanket bog, formerly *Sphagnum*-dominated peatlands, which are often still relatively waterlogged, depending on the impact of drainage or erosion. These deep peats indicate a long history of active peat formation, primarily formed of *Sphagnum* species. Historic atmospheric pollution, burning and overgrazing has severely depleted the abundance of *Sphagnum* mosses, and often reduced all bryophyte abundance. In the worst cases there is little but a mono-culture of *Molinia*, with dense dead material (Figure 1). On moorland edges there tends to be a greater range of vegetation types, driven by soil type, slope and drainage, and here *Molinia* can dominate shallow peats that were formerly more diverse wet heaths (Rodwell, J. (Ed) *et al.* 1991-2000). Restoring these habitats has two key aspects – the return of *Sphagnum*-dominated vegetation on peatland, and more diverse wet heath vegetation, which will include *Sphagnum* among a richer flora.

Figure 2. Curlew. Photo: Tim Melling

The birds of *Molinia* and their habitat needs

The Curlew (Figure 2) is undoubtedly one of our most iconic upland birds, and very much associated with moorland edges and in-bye pastures. A long-term European decline has been mirrored by UK decline of 42% between 1995 and 2008, with losses around the periphery of their range and in the southern uplands of Scotland, Ireland and Wales. Between 19 and 28% of the global population of Curlew is found in the UK, so as a nation we have a considerable responsibility for the species (Balmer *et al.,* 2013. Hayhow *et al.,* 2015). Extensive mono-cultures of *Molinia* are unlikely to provide optimum habitat for Curlew – various studies of birds with precocial[1] chicks that leave the nest immediately have noted that dense vegetation stands hinder chick movement, and may reduce access to insect food and can lead to chilling in wet weather. A mosaic of shorter and longer vegetation has been suggested as ideal for Curlew (Pearce-Higgins & Grant, 2006).

The other key bird in conservation terms associated with *Molinia* is the Short-eared Owl, another species that has declined in both Europe and the UK, though trends are difficult to ascertain. For the Short-eared Owl, life revolves around its main food supply – the Field Vole, *Microtis agrestis* (often called Short-tailed Field Vole). Whilst un-managed stands of *Molinia* are very dull in terms of botanical diversity, they can provide good habitat for voles, which benefit from a litter layer for their concealed runs (Harris & Yalden, 2008). Field Voles have boom and bust population cycles, and the Short-eared Owl (Figure 3) population follows its prey; the owls are mobile on at least a regional level, with populations fluctuating with food supply. Anecdotally, some extensive *Molinia* areas tend to have breeding birds present in most years; through lean vole years there may be one pair, and in boom years there may be three or four pairs in the same area; likewise brood size will vary markedly with food supply.

Figure 3. Short-eared Owl chicks awaiting their next vole. Photo: Irena Tomnakova

The most widespread bird of the uplands is the Meadow Pipit *Anthus pratensis*. Densities between 18 and 55 pairs / km^2 have been reported for acid moorland (Cramp *et al.,* 1988). A 39% decline in Meadow Pipit numbers has been recorded since 1970, primarily a loss from farmland habitats (Hayhow *et al.,* 2015). Though neither spectacular nor iconic, it is a mark of spring to find their neat grass-lined nests under a tussock, with 4 or 5 brown eggs, as the adult flits away from close to your feet. Meadow Pipits are important for other species; the Cuckoo *Cuculus canorus* lays its eggs in their nests in the uplands, and when Cuckoos were commoner, one study found that a fifth of nest failures in Meadow Pipit was due to Cuckoo occupancy (Coulson, 1956). Meadow Pipits are the commonest prey species for Merlin *Falco columbarius* in the UK, making up 50% and 80% of prey brought to nests in two studies (Sale, 2014). For Hen Harriers *Circus cyaneus* Field Voles and Meadow Pipits also make up an important part of their diet.

On extensive deep peat areas, Golden Plover *Pluviaris apricaria*, the most typical breeding wader of blanket bog, may be a potential breeder if the vegetation is open and relatively short, but deep tussocky areas of *Molinia* are avoided. Red Grouse *Lagopus lagopus* will almost certainly be present, but dense *Molinia* will be of little value. Most *Molinia* areas will be below the plateau bogs favoured by Dunlin *Caladris alpina*.

Tending more to the moorland edges, and mosaics with rush pasture and heath, birds that may occur include Snipe *Gallinago gallinago,* Whinchat *Saxicola rubetra,* Stonechat *Saxicola rubicola,* Reed Bunting *Emberiza schoeniclus*, Ring Ouzel *Turdus torquatus*, and localised in England the Twite *Carduelis flavirostris*. Black grouse *Tetrao tetrix,* is one of the most charismatic species of moorland fringes, but has been lost from much of its former range. None of these species are associated particularly with *Molinia,* and all should benefit from more diverse wet heath and peatland vegetation communities. Localised species such as Twite and Black Grouse will only benefit if restoration is close to existing populations.

Managing *Molinia*-dominated habitats to benefit birds

Looking at this range of bird species and their relationship with *Molinia*, it becomes apparent that not many are benefitting from mono-cultures of dense vegetation. Even for the voles which do enjoy dense vegetation, the aim might be to ensure that lightly managed stands are retained, which supports a vegetation thatch at ground level, rather than a need for extensive dense *Molinia*.

There is a question about on what scale we should think about structural diversity. Traditionally burning has often been used to create blocks of different age and structure on moorland, but burning perpetuates a mono-culture and is damaging to bryophytes (Rodwell, 1991) and lowers the water table on peatland (Brown *et al.,* 2015). Wet bryophyte-rich vegetation is a key target for restoration, and therefore burning should not be a part of the routine management.

Cutting may be used to break up dense swards, and there have been a number of initiatives to break up and diversify dense *Molinia* using varying combinations of burning, glyphosate application and flailing followed by seed introduction. Caution should be exercised around intensive management that is removing much of the vegetation structure, particularly where owls are present.

Especially on deeper peat sites, time should be allowed for bryophyte recovery and the introduction of *Sphagnum* may even be considered. From our experience at Dove Stone, *Sphagnum* appears to benefit from the shelter of dense vegetation in wet situations, possibly related to enhanced humidity amongst vegetation. Again, our experience at Dove Stone shows that once *Sphagnum* begins to become locally more dominant, vegetation structure can begin to open up relatively quickly; certainly within a five to ten year timescale.

A patchwork of more intensive management may be part of the restoration process, but overall, light grazing densities are of key importance in supporting diverse vegetation and maintaining higher vole populations in grassland (Harris & Yalden, 2008). Cattle grazing regimes provide probably the most natural approach to diversifying vegetation structure. Restoring structural and species diversity should benefit a range of species, including one of our moorland priority species, Curlew, but also provide an improved habitat for Snipe, Whinchat, Meadow Pipit, and help with wider conservation of such species as Merlin and Cuckoo (Pearce-Higgins & Grant, 2006).

Invertebrate abundance matters

Craneflies, *Tipulid* spp, are often the most important food supply for many moorland birds (Cramp *et al.,* 1998). Research (Carrol *et al.,* 2015) shows that a high water table helps summer survival of cranefly eggs and larvae, so work to restore water tables and make peat wetter by blocking drainage grips and erosion gullies will be beneficial. This study gave evidence that for Golden Plover, Dunlin and Red Grouse the abundance of adult cranefly emergence in spring affects chick survival rates and subsequent breeding population the following spring. Increasing *Sphagnum* abundance will also be beneficial, as this will help retain water and keep conditions moist through dry spells; again, studies have shown that cranefly eggs and larvae will survive summer droughts better when protected by *Sphagnum* (Carrol *et al.,* 2015).

Figure 4. Marsh Violet, a component of a richer wet heath flora, has increased under light sheep grazing; it is the food plant of the Dark Green Fritillary caterpillar. Photo: David O'Hara

Figure 5. The Dark Green Fritillary butterfly, which has recently colonised this area at Dove Stone, the RSPB United Utilities Partnership in the Peak District. Photo: David O'Hara

From *Molinia* to something richer

To develop richer moorland habitats for plants and birds needs a combination of extensive grazing regimes, water table restoration, reducing burning, tackling vegetation mono-cultures that are a product of management, and considering the role of scrub and natural woodland in our upland landscape. Beginning to transform mono-cultures of *Molinia* to more diverse bog, wet heath or rush/heath, willow and birch scrub communities has the potential to benefit a range of birds and invertebrates declining in the uplands (Figures 4 & 5 show Marsh Violet and Dark Green Fritillary butterfly).

Although quite intensive management may be part of the restoration process, in many cases the benefits of less intensive management, reduced grazing and burning pressure, can quite quickly result in biodiversity gains, and particularly a richer flora can begin to emerge, and with it associated invertebrate diversity. Many bird species can potentially benefit, particularly from increases in invertebrate abundance. The challenge is to make fundamental changes across landscapes, and to pro-actively pursue the best management for individual sites.

Notes

[1] Chicks that leave the nest before they are fully fledged.

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Molinia on the Marsden Moor Estate

Molinia and much 'moor' besides; an introduction to the National Trust's Marsden Moor Estate

Members of the Survey Team, the National Trust, Marsden Moor Estate

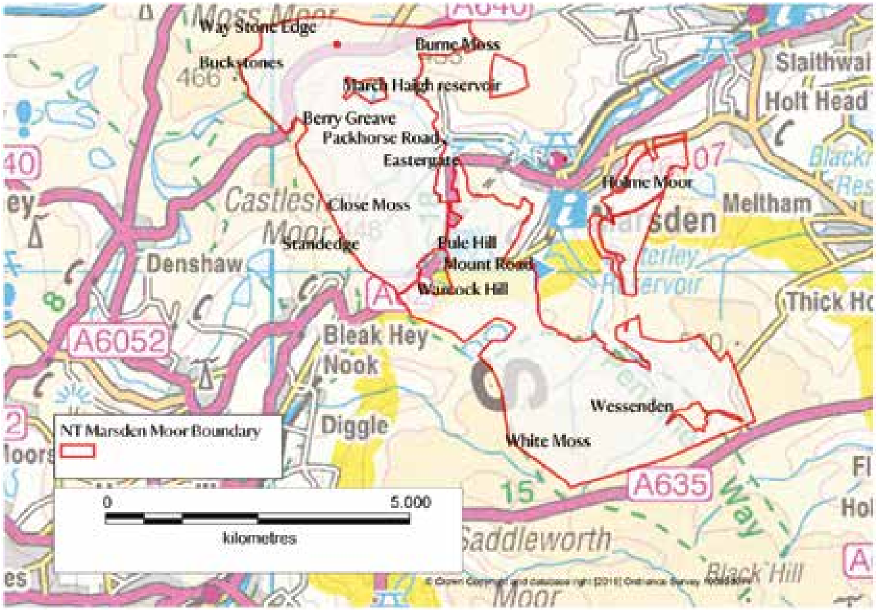

Figure 1. Outline map of the Marsden Moor Estate

Introduction

Marsden Moor Estate comprises 2,301 hectares of moorland, which was transferred to the National Trust (NT) on the 30th June 1955.

The estate is situated at the head of the Colne Valley in West Yorkshire (Figure 1) and in its southern area encompasses the most northerly part of the Peak District National Park. It is also covered by the South Pennines and North Peak Environmental Sensitive Area, with the majority of the estate now subject to Higher Level Stewardship (HLS) agreements with Natural England and the grazing commoners.

Located on the backbone of the Pennines, the estate is subject to relatively high levels of rainfall and is often cooler than the lower level conurbations of Huddersfield and Oldham. The wet, cool climate is the reason why characteristic peat bog and mire habitats have developed.

Hydrology

Gentle slopes, associated with the acidic substrate and the wet weather, averaging 1600mm rain per year at the top of the moor, have provided ideal conditions for the establishment of one of the oldest and thickest blanket bogs in England. From the Pennine watershed, streams and catch drains flow to east and west, filling the reservoirs of Yorkshire Water and United Utilities.

Topography and Geology

Marsden Moor is an area of upland moorland characteristic of the bleak and desolate country of the Central Pennine Ridge. The property comprises a gently undulating moorland plateau dissected by a series of steep-sided valleys which are locally described as cloughs; the variations in topography and vegetation create a distinctive and attractive landscape (Panorama from Buckstones Edge, Figure 2). The altitudinal range is from about 250 metres at the foot of Holme Moor, east of Marsden, to about 480 metres along Way Stone Edge, which marks the northern margin of the estate.

Figure 2. Panorama from Buckstones Edge.

A composite picture taken in November 2015 looking west-south-west. March Hill is in the centre distance with the vegetated land slips on shale substrate. March Haigh Reservoir is to the far left. Bracken (brown) covers the slopes. Clearly shown are: Molinia-dominant areas, significant areas of bracken, two types of acid grassland, one being dominated by Mat-grass Nardus stricta, the other Common Bent – Sheep's Fescue Agrostis capillaris-Festuca ovina, and a glimpse of dwarf-shrub heath on the right-hand side. (Photograph by Alan Stopher)

The property is underlain by Namurian Millstone Grit rocks of the Carboniferous Period, mainly Kinderscout Grit. These are extensively covered by peat, but are exposed in deeply incised stream valleys, on steep slopes where boulder screes are locally present, and where quarrying has taken place. These screes are comprised mainly of mudstones and shales, with beds of sandstone and grit.

Most of the property is covered by thick, very acid, raw peat soils allocated to the Winter Hill Association. There is considerable variability in the peat depth, typically about 1.5 or 2 metres on plateau areas but infrequently as high as 4 metres and some areas are entirely devoid of peat. Coarse, loamy, very acid soils of the Belmont Association are present in some marginal areas. These have a wet peaty surface horizon and a thin iron-pan, and have developed on bedrock. Soils of the Wilcocks 1 Association are present very locally in some marginal areas. These acid, loamy soils, with impeded drainage, have developed on Glacial Drift. There is a single geological SSSI and two Local Geological Sites on the estate.

Vegetation and Plant Communities

On the gently undulating plateau, the dominant vegetation is that typical of blanket bog or marshy grassland with a network of natural drainage channels.

Better-drained soils on the steeper or lower slopes also support acid grassland, grass-heath, bracken and flush communities. The plateau is crossed by a series of very steep-sided stream valleys (cloughs) which contain a range of habitats including flushes and sheltered rocky crags.

The vegetation over most of the site is composed of a very narrow range of species, however the proportions of these species vary considerably between habitat types. These dominant species are Hare's-tail Cotton-grass *Eriophorum vaginatum*, Common Cotton-grass *Eriophorum angustifolium*, Purple Moor-grass *Molinia caerulea*, Mat-Grass *Nardus stricta*, Wavy Hair-grass *Deschampsia flexuosa*, Crowberry *Empetrum nigrum*, Heather *Calluna vulgaris*, Bilberry *Vaccinium myrtyillus*, Bracken *Pteridium aquilinum* and the moss *Polytrichum commune*. Other species, such as Cross-leaved Heath *Erica tetralix,* contribute only a minor role in the vegetation or are restricted to small features of the site such as flushes. Other characterisitic dwarf-shrub of blanket bog habitat species such as Cowberry *Vaccinium vitis-idaea* and Cloudberry *Rubus chamaemorus* are rare.

Blanket Bog

In terms of the Phase 1 habitat classification used in the 2004 survey (Allen *et al*., 2005), blanket bog covers a large proportion of the estate. It is one of the most interesting ecological features of the area as it is one of the driest blanket bogs in the United Kingdom being close to the edge of its geographical range.

It is unclear which limited areas of the blanket bog are still active in terms of peat deposition; large areas are in a degraded state. There are erosion gullies and, despite considerable restoration efforts, bare patches of peat, and *Sphagnum* moss, which should be common, is only present in small amounts.

Dwarf-shrub Heath

Away from the 'degraded blanket bog' of the plateau, the 2004 survey (Allen *et al*, 2005) describes much of the estate as comprising a mosaic of heathland and acid grassland. The most prevalent dwarf-shrub heath species are Heather *Calluna vulgaris* and Bilberry *Vaccinium myrtillus*. Some areas have good heather cover mainly due to re-vegetation works and stock exclusion. Large areas could be described as 'white moor', a type of grassy moorland dominated by *Molinia caerulea*. Some flushes hold diverse botanical assemblages and are of regional significance, containing species such as Round-Leaved Sundew *Drosera rotundifolia*, Bog Asphodel *Narthecium ossifragum*, and a notable diversity of sedges and *Sphagnum* mosses.

Sphagnum mosses

These are a key component in the creation of peat and were a significant part of the vegetation on the moor in the past. Today, such mosses are thinly distributed (less than 1% on many areas of the plateau), and mostly found in the gulleys rather than on the plane and gently sloping surface of the mire (Gully on Wessenden Moor, Figure 3). The demise of *Sphagnum* on the Pennines is well-documented and much work is being done to try and re-establish it.

Species present currently include: **Common -** *S. fallax, S. fimbriatum*; **Frequent** - *S. palustre, S. papillosum, S. subnitens, S. capillifolium* subsp. *Rubellum*; **Local/occasional -** *S. capillifolium, S. cuspidatum, S. squarrosum*; **Rare** - *S. molle, S. denticulatum, S. inundatum, S. magellanicum.*

Figure 3. Gully on Wessenden Moor

A gulley formed by the collapse of the peat strata on the north side of Wessenden Moor viewed looking north. Yorkshire Water's Blakeley Reservoir is in the distance towards Marsden. The dominant Calluna is typical of well-established dry heath which has not been affected by burning. Sphagna are well established in the gulley along with other mosses. Voids in the peat are clearly visible. (Photograph from National Trust Marsden Moor Estate collection)

Trees

As a moorland estate with a history of grazing, Marsden Moor has few trees. Mainly scattered and self-seeded birch and rowan, they can be found on the sides of the steep cloughs including Butterley, Blake and Blakely Cloughs, with a few odd saplings (mainly birch) next to footpaths.

As a rule trees are not encouraged on the moorland plateau. Selective planting in the cloughs seeks to increase diversity of habitat; it aims to be sensitive to any importance of existing vegetation and adds value as nesting bird habitat.

Bracken

Bracken is an integral part of the flora of Marsden Moor. Several large patches exist across the estate. These are mainly on the southwest side of Pule Hill, above March Haigh reservoir and within Oakner and Long Cloughs. It is an important component of the habitat required by Twite *Carduelis flavirostris*.

Purple Moor-grass

Molinia caerulea is the dominant vegetation cover to the east and south of March Haigh extending down to the A62 and reaches near 100% cover in places. It is thought that this extensive area of *Molinia* has become dominant due mainly to uncontrolled summer fires, too much winter grazing and the negative effects of air pollution. In the past there have been some unsuccessful attempts at changing the grazing regime to manage *Molinia*. Over the last decade, there has been an increasing awareness of the spread or increasing dominance on sections of the estate, possibly linked to reduced grazing. The extent of its spread at Berry Greave is discussed in the conference paper by Underdown and Meade. *Molinia* also shows some dominance around Pule and Warcock Hill and to the south-east of Mount Road though it tends to be less tussocky than in other areas of the Estate.

In 2002, in the area south of Mount Road, it was noted that the high grazing pressure was keeping the *Molinia* in check but has also inhibited the growth of any dwarf-shrubs.

Molinia is also present throughout and reaching dominance in some areas of Holme and Binn.

Rhododendron

Rhododendron self-seeds across the estate from neighbouring land. It is an invasive species and is discouraged on the moorland by cutting and pulling seedlings.

Fauna

Mammals

Marsden Moor with the northern Peak District and Saddleworth is the only area in England where the Mountain Hare *Lepus timidus* is resident. Also present are Brown Hare *Lepus capensis*, Red Fox *Vulpes vulpes*, Field Vole *Microtus agrestis*, Stoat *Mustela erminea*, Weasel *Mustela nivalis*, and Roe Deer *Capreolus capreolus*. Field Vole is important as the food source for the Short-eared Owl *Asio flammeus*. The presence of the invasive American Mink *Mustela vison* means that Water Vole *Arvicola terrestris* is scarce.

Birds

The whole of the estate is within the South Pennines Special Protection Area (SPA) and as such the assemblage of breeding birds on the moorland is of international significance and must be taken into account in any land management decisions.

The estate is home to the rare Twite *Carduelis flavirostris*, known locally as the Pennine Finch. Populations numbers have declined by 90% in the last 15 years with only around 100 breeding pairs left, most of which live in the South Pennines. It is estimated that 10% of these breed on NT land at Marsden. This has implications for management of bracken beds on the moor where the Twite are known to nest.

Other breeding birds of importance on Marsden Moor are Short-Eared Owl, Golden Plover *Pluvialis apricaria*, Curlew *Numenius arquata*, Skylark *Alauda arvensis* and Meadow Pipit *Anthus pratensis*.

Historic land use and management

There are several series of shooting butts on the estate indicating historic use as a grouse moor. Historically, it is almost certain that there would have been substantial peat cutting although specific records of its location and extent are not available.

From the late 18th Century until the late 19th Century the construction of the canal tunnel and three subsequent railway tunnels through Standedge and under Marsden Moor has left spoil heaps, air shafts, quarry inclines and other archaeological features (shafts, inclines and spoil heaps near Standedge, Figure 4).

Over a similar period the importance of the Pennine watershed for water supply has resulted in the construction of reservoirs firstly for supplying the canal and latterly for the public water supply. A number of catch-drains and associated structures have been built and maintained within what is now the Marsden Moor Estate since the Huddersfield Waterworks Act of 1871.

In the 19th century, there was a legal challenge to the right to use the ‘Packhorse Road’ across the estate; prior to the second half of the twentieth century, public access to these moors was very limited. Since the mid twentieth century, public access has been extensive.

Figure 4. Shafts, inclines and spoil heaps near Standedge

Winter view of some of the historic engineering features on the Marsden Moor Estate between the foot of Pule Hill and Standedge Cutting looking west-south-west. The two shafts on the right and the distant block-like remains of the Redbrook Engine House mark the line of the canal tunnel which is paralleled by three railway tunnels. To the left of the Engine House are spoil heaps mainly excavated during the construction of the dual track rail tunnel in the 1890s. Even now little vegetation grows on the spoil. Down the centre of the picture is the incline used to bring stone for construction down from Pule Hill quarry behind the photographer. In the left middle distance is the dam of Redbrook reservoir. (Photograph by Alan Stopher)

For many years the estate was grazed by sheep and Commoners' rights to it cover large parts of the estate. Grazing levels on the Marsden Moor Estate were high as late as the 1980s with visible signs of over-grazing (Anderson et al, 1989); experimental exclosures were established from 1988 onwards and overall levels have been progressively reduced since then. Over recent years, at least 6 registered commoners have continued to exercise their grazing rights; currently there is only a very small amount of summer sheep grazing. There are however plans to reintroduce a limited amount of controlled grazing by cattle and sheep in connection with the HLS agreements – a partnership between the National Trust and commoners.

Over recent decades, there have been periodic fires across sections of the estate, some deliberate and some accidental; the estate is vulnerable to such occurrences, being crossed by several major roads and with a high level of public access from neighbouring areas of high population. Specific causes, where known, are very varied; the last two significant fires were caused by the exhaust of an (unauthorised) quad bike and an occurrence when estate workers on an adjoining estate were undertaking 'controlled burning' but then had to deal with a medical emergency. In the 1970s, there was a deep-seated peat fire on Pule Hill; most of the fires are fast-moving across the surface vegetation and do not ignite the peat.

Recent interventions

A full chronicle of the management of the estate since transfer to the National Trust is beyond the scope of this paper. In its stewardship of the estate, the Trust balances a number of objectives, in seeking to ensure that the land designated as SSSI (much also SAC and SPA) moves towards favourable condition and also in relation to other objectives regarding public and community access and enjoyment. (National Trust, 2014).

From the 1970s onwards, there has been a drive to restore the blanket bog areas. In the initial period, the principal focus was on dealing with extensive areas of bare peat which were present at that time on the moorland plateau and combating the continuing erosion of peat on the plateau and in gullies. By the turn of the twentieth century, there was increasing attention to the reintroduction of *Sphagnum*.

Some of the interventions used in the last decades are:

Bracken cutting – this ceased in 2009 after discussion with the RSPB over the importance of the bracken beds for nesting Twite. It was agreed that the extent of bracken existing at that time would be maintained as 'base-line' but that any further expansion would be managed. The bracken has been monitored since then and it is only spreading in a limited number of locations.

Damming of gullies – over 500 wooden dams have been constructed in gullies at Buckstones and many heather dams placed in gullies on White Moss, all with the aim of inhibiting peat erosion, re-establishment of plant communities and moorland re-wetting. The high energy associated with the run-off of surface water means that many have needed repair.

Brash-spreading – this has been undertaken on areas including White Moss and Buckstones over a number of recent years with the aim of re-establishing heather and other plants on areas of bare peat. The extent of areas of bare peat have been reduced, with some variability in results probably linked to specific locations (e.g. angle of slope) and the timing/condition of brash spread.

Tree planting – In an attempt to create some shelter and wildlife corridors within the valleys, tree planting has taken place in Oakner Clough, Long Clough and Redbrook Clough and Haigh Clough. Species planted include oak, alder, rowan and birch.

Cotton-grass plug planting – localised areas of White Moss and Buckstones have received plug plants and there has been some early success in re-establishing vegetation on bare peat with some variability linked with specific location conditions.

Spreading of a grass, lime and fertiliser mix – Large areas of White Moss, Wessenden and Way Stone have had this mixture spread in collaboration with Moors for the Future and Yorkshire Water as part of a project to reduce peat erosion and re-establish plant communities. There are indications of interim success in the stabilisation of peat pans; the Moors for the Future Science Team is involved in monitoring and evaluating the impact of various treatments.

Localised reintroduction of *Sphagnum* – trials on White Moss have attempted to reintroduce *Sphagnum* through the planting of small plugs and spreading of blended 'soup' or gel beads.

Sheep exclosures – as sheep-grazing has now virtually disappeared on the Estate, the temporary exclosures to protect dwarf-shrubs have in many cases been removed.

Figure 5.
Mowing Molinia

Mowing of dominant Molinia south of Haigh Clough and west of Eastergate Bridge in October 2013. (Photograph from National Trust Marsden Moor Estate collection)

MoorLIFE2020 – This new five year project (Moors for the Future Partnership, 2015) aims to protect Active Blanket Bog within the South Pennine Moors SAC which includes Marsden Moor. It involves stabilisation of bare peat and halting peat erosion, restoration of hydrological integrity, increasing the heterogeneity of vegetation, managing invasive species such as Rhododendron, increasing the diversity and quantity of *Sphagnum* moss. Activities include monitoring of environmental conditions, vegetation surveys and fencing of commons to support low density cattle grazing.

***Molinia* Management** – Management plans over this period have made some limited reference to *Molinia*; until recently, it has not been a major focus of restoration efforts. Two areas of about a hectare each just south of Mount Road were flailed in 2002. Some of the area was then spread with *Calluna vulgaris* seed. In 2013 and 2014, there was further pilot work involving mowing stands of dominant *Molinia* below Buckstones House and on the slopes between Close Moss and Eastergate (Figure 5, Mowing *Molinia*) This was part of the SITA supported Bog Diversity Project.

There has been recent funding approved for a 4 year programme of mowing of dominant *Molinia* and the introduction of controlled grazing by cattle (National Trust, 2015). The aim of the programme is to 'improve the condition and cover of grazing suppressed dwarf-shrub on dry heath, blanket bog and wet heath' including increasing the number and diversity of species.

Meanwhile, pilot work is being undertaken to examine how best to reintroduce *Sphagnum* where scarce or absent in *Molinia*-rich areas; one trial site is at Burne Moss on the Marsden Estate (see conference paper by Fawcett and Pilkington).

Conclusion

Over the last 30 or 40 years, there has been significant attention to and an increasing understanding of the moorland habitats of the estate and about the longer and shorter term changes affecting that environment and the habitats, plant communities and wildlife it supports. There have been several restoration programmes, aimed particularly at protecting and restoring the blanket bog habitat. The restoration programmes have built partnerships and brought in significant resources. There has also been an increasing awareness of the impact, sometimes intended but not always foreseen, of changes in land management as well as the impact of other occurrences such as wild fires. Within this broader picture, there is now an awareness of the apparent increase in areas of *Molinia* dominance over recent decades. It is an issue which will merit continuing monitoring and attention, and management which fits into a broader strategy for protecting and enhancing the natural environments and habitats of the estate.

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R. Allen, G. Barker, C. Ellen, P. Brash & A. P. Foster (2005); National Trust Nature Conservation Evaluation, Marsden Moor, West Yorkshire 2004 Survey

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Molinia caerulea: changes over a quarter century on blanket mire peat

A project undertaken by the National Trust's Marsden Moor Survey Group of volunteers

Written by Andrew Underdown and Roger Meade

Abstract

During 2015, a project was started on the Marsden Moor National Trust estate to examine whether *Molinia* had become more prevalent since the 1980s. The project focused on a 20 hectare site known as Berry Greave and used evidence from aerial photographs and vegetation surveys, including new fieldwork. The project concluded that *Molinia* had become more dominant over most of the study area and was linked to changes in the representation of other plant species. The paper reviews the methods used and speculates on possible explanations for the changes.

The Project Team

This project was taken forward by a group of National Trust volunteers, linked to the Marsden Moor National Trust estate. Known as the 'Survey Group', they support the Trust's conservation efforts by a weekly session of surveying and monitoring of the moor generally and of restoration sites in particular. Priorities are set by the Trust's rangers at Marsden.

Background to the study

The Survey Group and the ranger team were aware of 1980s surveys and aerial photos which seemed to show smaller areas of *Molinia* dominance than at present. If this could be established as a fact, it would describe a baseline condition that management should aim to re-instate, in that it would have supported a greater diversity of plant species than the current monoculture of dense tussocky *Molinia*. Thus it was important to establish whether these large areas of *Molinia* dominance were of longstanding or had developed more recently.

At this stage, the Survey Team was only partially aware of the possible drivers for *Molinia* dominance, and the need to know more provided a strong local incentive for this conference and helped to determine the variety of papers it has included. As things stood, a number of explanations were possible. For example, is the apparently quick resurgence of *Molinia* after wild fire compared with other species instrumental in the observed changes (Figure 1). This was recognised as but one possible factor and there could have been many others at work over such a long period.

Figure 1. Two weeks after fire close to Cupwith moor, April 2015. Foreground shows charred heather and bilberry, rear ground shows rapid new growth from charred Molinia tussocks

Aims of the study

Berry Greave was chosen as the study site, a bounded area of approx 60 hectares where *Molinia* appeared to have spread or become more dominant since the 1980s (Figure 2). The area was selected because it was accessible and changes were easy to observe on photographs and plans as it was adjacent to March Haigh reservoir.

The following aims were identified for the study:

- Establish whether *Molinia* had spread and/or become more dominant across the site;
- Documenting how other vegetation may have changed;
- Give a tentative account of how or why these changes have happened.

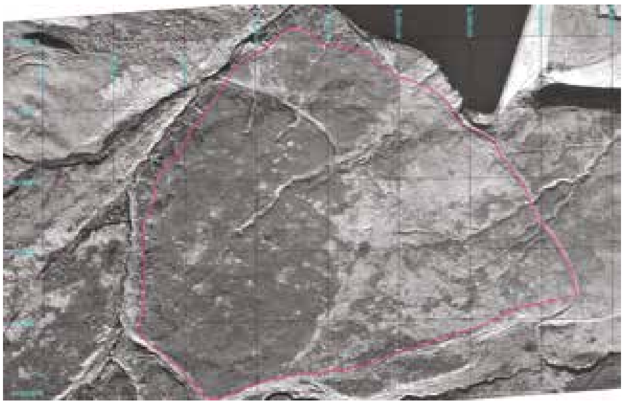


Figure 2. Berry Greave in the 1980s: Aerial photograph of Berry Greave, October 1988. Red line shows boundary of study area

Interpretation of aerial photographs and earlier vegetation surveys

As a baseline for 1988, an aerial photograph captured in the late autumn of that year (Figure 2) showed a range of tones from almost white to almost black. The extreme white was taken to represent a monoculture of dominant *Molinia* and the much darker areas to represent other vegetation, such as dwarf-shrub heath. An intermediate state was recognisable and this was interpreted as dwarf-shrub heath with a strong representation of *Molinia*. These classes are plotted onto the aerial photograph in Figure 3. The image was registered to British National Grid using known reference points and MapInfo software to assist subsequent ground-truthing and comparisons with the present-day. The interpretation suggested that, in 1988, *Molinia* was dominant on the east side of the site but largely absent from the west with the exception of two lines of *Molinia* corresponding to deep transverse gullies.

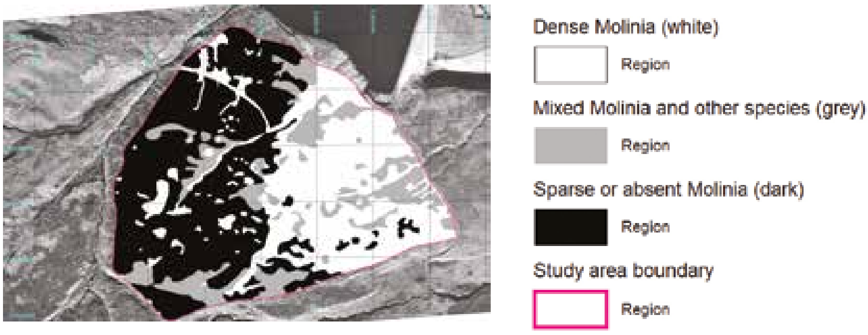


Figure 3. Interpretation of Molinia cover classes at Berry Greave on 1988 greyscale aerial photograph

In addition to the aerial photographs, there were two vegetation surveys on the files from this same period. These were both surveys of the whole National Trust estate, of which the study area in Berry Greave was only about 2.4%. The more detailed of these surveys had been undertaken in 1989 by Penny Anderson Associates who had access to the 1988 aerial photographs (Anderson *et al.*, 1989). Figure 4 is derived from an annotated vegetation map given in that report. On the west of the study area, the map shows *Molinia* dominance only along the deep gullies; most of the west of the study area is shown as dominated by Hare's-tail Cotton-grass *Eriophorum vaginatum*. It also shows that *Molinia* is co-dominant with Hare's-tail Cotton-grass across the east side of site.

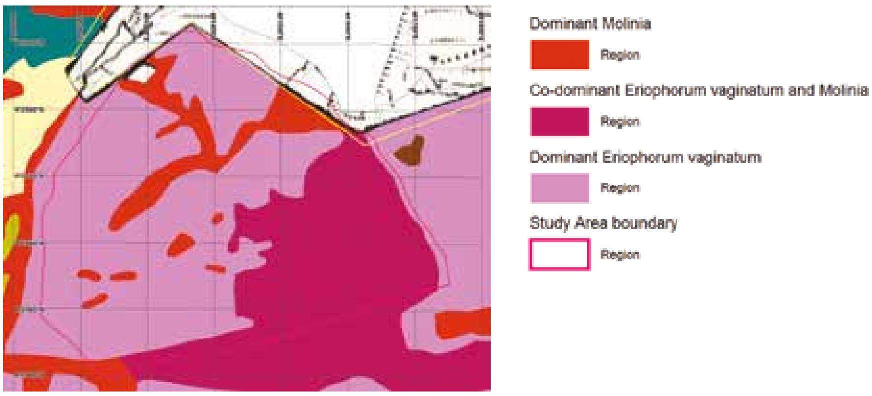


Figure 4. Vegetation categories at Berry Greave as interpreted from a 1989 habitat map showing dominant plant species (Anderson et al., 1989)

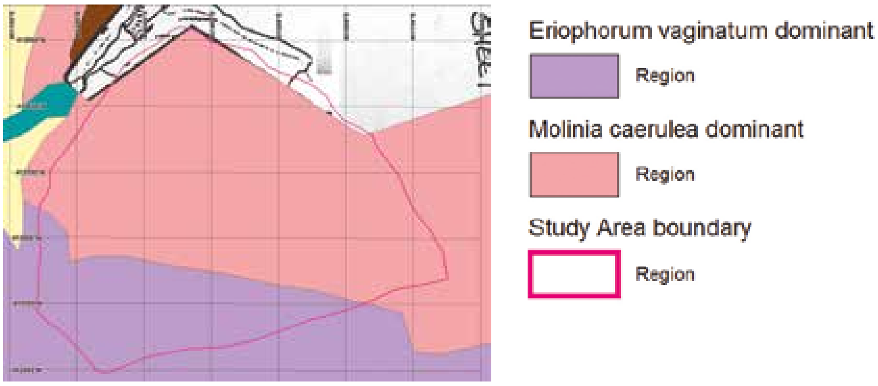


Figure 5. Vegetation map of Berry Greave from 1987 survey (NT, 1988)

Another survey from the same era (1987) by an in-house National Trust survey team (NT, 1988) also includes a vegetation map for Berry Greave (Figure 5). This has little in common with Figures 3 and 4; on balance, the aerial photograph and Anderson *et al.* (1989), even though there was linkage between the two, were taken to be better representations of the status of *Molinia* at Berry Greave in the late 1980s.

A more contemporary photographic image and its interpretation

A colour aerial photograph of 2009 was available for comparison with the 1988 image (Figures 2 and 3), and was converted to monochrome using Adobe Photoshop software. Editing the image in this way provided one that was more easily interpreted as *Molinia* cover and would make comparison with the monochrome 1988 image more valid (Figure 6). Polygons were drawn around areas of similar image intensity and interpreted as shown in the legend (Figure 7). From a comparison of Figures 3 and 7, if the interpretation of the image is correct, *Molinia* has spread over almost the whole of Berry Greave in the 21 years between 1988 and 2009.

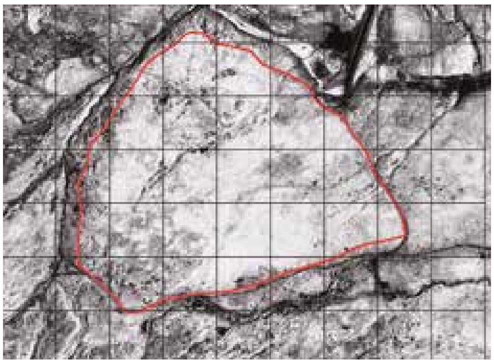


Figure 6. Colour aerial photograph of Berry Greave 2009 converted to monochrome for comparison with Figure 2

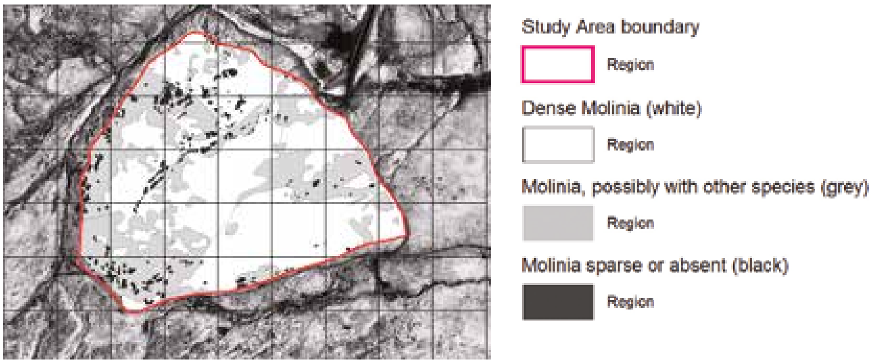


Figure 7. Interpretation of Molinia cover, Berry Greave, on 2009 aerial photograph using cover-class polygons

2015 Fieldwork Survey

Without a more recent aerial photograph the only option for ground-truthing was to make the assumption that comparatively little change would have occurred over the six years since 2009. A survey was carried out by a small team of volunteers in May-June 2015. The team examined 132 large quadrats (5mx5m), at 50 metre intervals across the whole Berry Greave site and at 25 metre intervals in the central portion. For each quadrat, the team estimated the proportion of *Molinia,* its tussock height and also recorded the second and third most common species present. The information collected has been displayed in five maps and one table to describe the distribution of these plant species. Some of the maps are supplemented with photographs to illustrate the nature of the plant cover. They are: cover classes for *Molinia* (Figures 8 & 9), Hare's-tail Cotton-grass *Eriophorum vaginatum* (Figures 10 & 11), Common Cotton-grass *Eriophorum angustifolium* (Figures 12 & 13), Bilberry *Vaccinium oxycoccos* (Figure 14), *Sphagnum* moss species (Figure 15) and other species in Table 1.

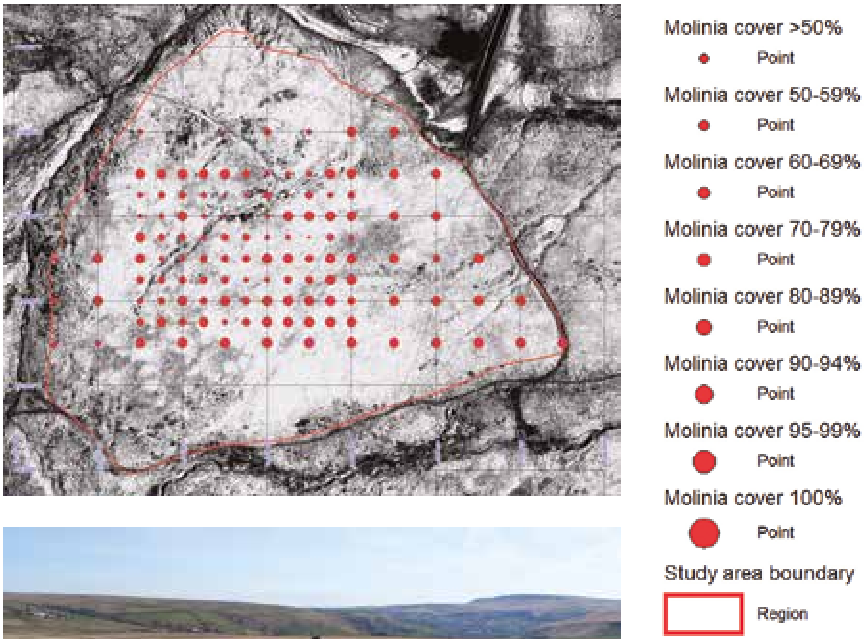


Figure 8. Cover classes of Molinia from 2015 field assessment on 2009 aerial photograph

Note: The size of the red circles should be interpreted in order of size on the figure and separately on the legend as those in the legend are all larger than their analogues on the figure.

Figure 9. Highly tussocky Molinia to the east of site with member of survey team, to provide a visual picture of what 'Molinia dominance' means in this setting.

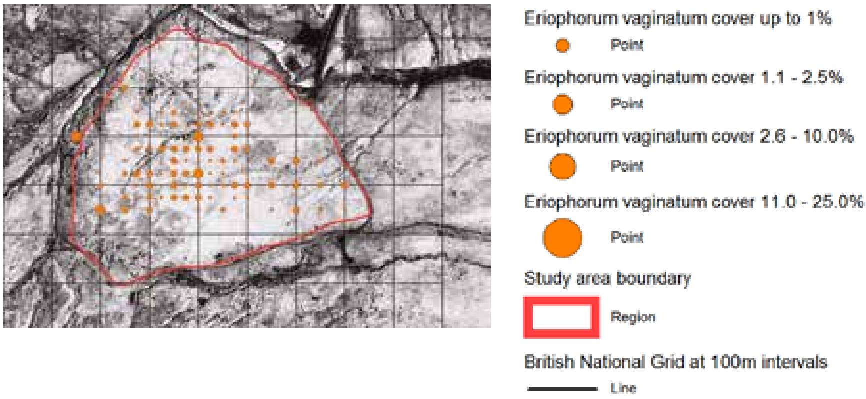


Figure 10. Cover classes of Eriophorum vaginatum from 2015 field assessment on 2009 aerial photograph

Figure 11. Illustrating the presence of Hare's-tail Cotton-grass in parts of the site where it was most strongly represented, often interwoven in the Molinia tussocks. This degree of frequency is far below co-dominance.

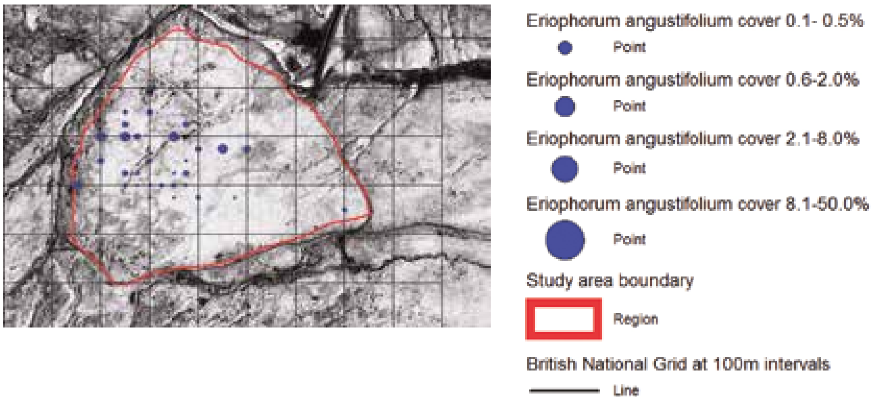


Figure 12. Cover classes of Eriophorum angustifolium from 2015 field assessment on 2009 aerial photograph

Figure 13. Common Cotton-grass in areas of least tussocky or non-tussocky Molinia

Figure 14. Cover classes of Vaccinium myrtillus from 2015 field assessment on 2009 aerial photograph, present as small islands

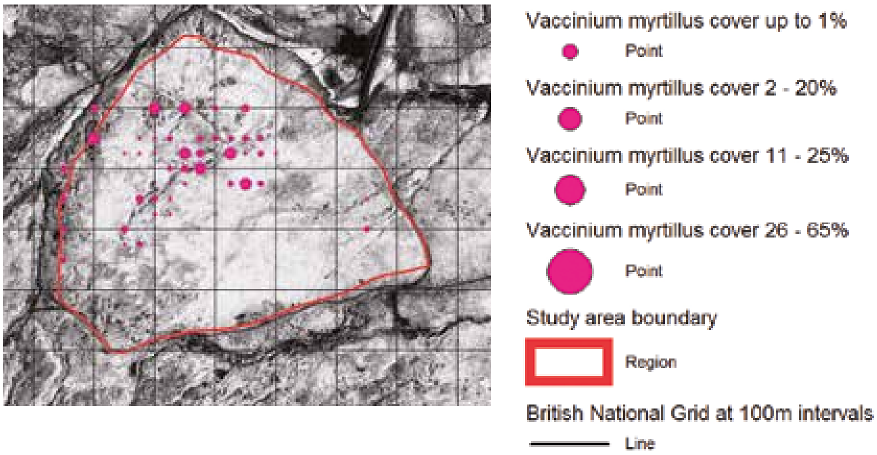
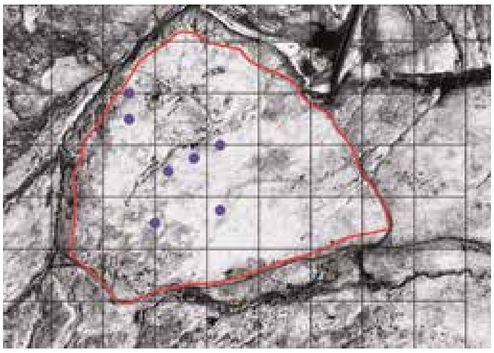


Figure 15. Cover classes of Sphagnum moss species from 2015 field assessment on 2009 aerial photograph. Each point indicates presence at a cover value between 0.5 – 2.0%



The key conclusion of the fieldwork was that *Molinia* had become dominant (>90%) across most of the west of the plot and that the initial interpretation of the 2009 aerial photo was sound. Referring back to evidence from the 1980s, which cannot now be tested by 'ground-truthing', *Molinia* had replaced Hare's-tail Cotton-grass which had previously been dominant on the west of the site (Anderson *et al.*, 1989) and co-dominant on the east. *Molinia* had remained dominant in the gully areas.

Hare's-tail Cotton-grass was the second most prevalent species after *Molinia*, but only three quadrats in the SW corner of the site recorded it at cover values above 10%. About a quarter of quadrats found cover in 2.6 to 10% range.

Common Cotton-grass was observed in only a small number of quadrats in areas where *Molinia* was least tussocky.

After Hare's-tail Cotton-grass, Bilberry was the next most constant species. It was present in over 30% of quadrats but mostly in very small amounts. However, in 5% of quadrats, it was present in proportions above 10%. These small islands of Bilberry were sometimes surrounded by areas of highly tussocky *Molinia*.

The survey found very small quantities of *Sphagnum* moss species in a small number of quadrats. The only species recorded other than as the genus was *Sphagnum subnitens*, though *S. fimbriatum, S. fallax* and very occasionally *S. papillosum* are known to occur in the area.

Table 1. *Plants found within quadrats but not plotted separately as in Figures 8-15*

Species	Common name	Records	% cover range
Calluna vulgaris	Ling	4	1.0-10.0
Deschampsia flexuosa	Wavy Hair-grass	4	1.0-2.0
Dryopteris dilatata	Broad buckler fern	1	<1.0
Empetrum nigrum	Crowberry	2	0.5-1.0
Polytrichum commune	Common haircap	3	0.1-5.0

Table 1 shows that other species, such as *Calluna vulgaris* and *Polytrichum commune*, were also present but only in a very small proportion of quadrats.

The survey team was concerned that, because of time of year, their fieldwork might have failed to observe other species, especially other grasses such as Wavy Hair-grass *Deschampsia flexuosa* or Sheep's Fescue *Festuca ovina*. However, a return visit in early September confirmed that other grass species were present in negligible proportions (<0.1%).

Depth of peat at Berry Greave

Peat depth measurements were taken on 20 coordinate points (Figure 16). The average depth of peat recorded was about one metre.

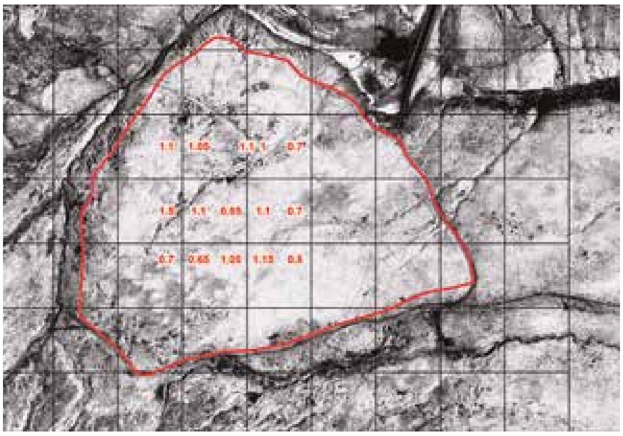
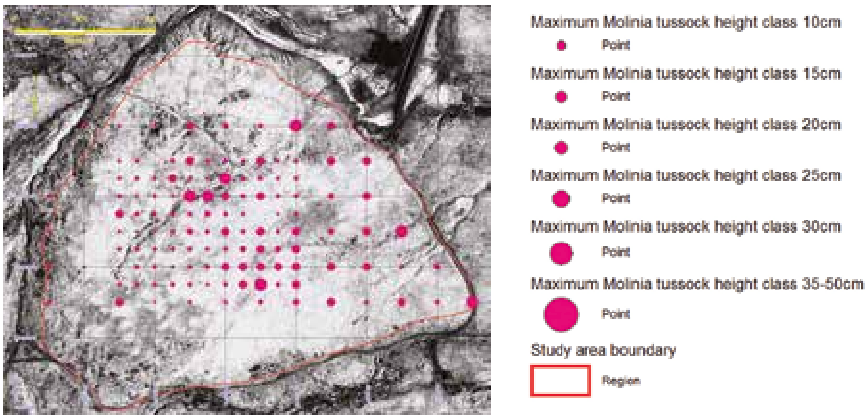


Figure 16. Measured peat depths in metres superimposed on the 2009 aerial photograph

Formation of tussocks by *Molinia*

The range of tussock height was recorded by measuring a small number of tussocks in each quadrat and plotting the estimated mid-height for each (Figure 17). It was anticipated that high tussocks would be found in the areas of long established *Molinia* in the east. As high tussocks were also found in the more recently-colonised west of Berry Greave and shorter ones in the east, tussock height is not necessarily related to the age of the plant. The height of tussocks is likely to be determined by other factors such as angle of slope, the standing water level and its fluctuation.

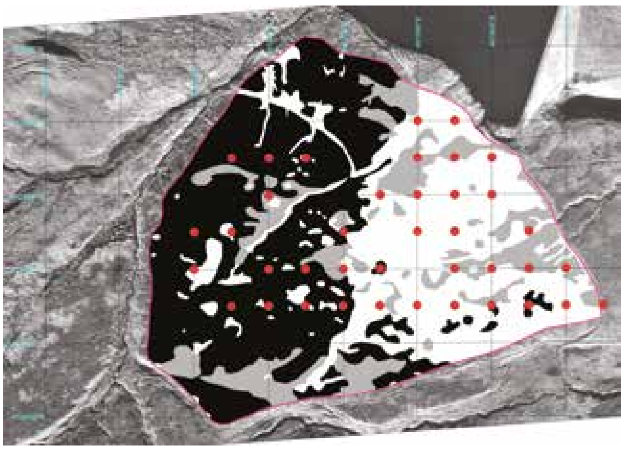
Figure 17. Molinia tussock height classes on the 2009 aerial photograph



Conclusions

The findings are summarised in Figure 18 as the 100% cover points from the 2015 survey plotted on the interpreted 1988 aerial photograph. They present a contemporary picture of 100% *Molinia* dominance across most of the study area and that it is likely to be far more extensive now than in 1988. A thick layer of *Molinia* litter was noted during the survey, suggesting the area has not been burned for several years. Such a build-up is likely to prevent other species establishing or developing between the tussocks. If the increase in *Molinia* cover in the study area is typical of the wider peatland it suggests this species will continue to extend its range at the expense of other species, including the *Sphagnum* mosses that contribute to the definition of Favourable Condition.

Figure 18. 2015 survey of Molinia on interpreted 1988 aerial photograph. Red circles show where 100% cover of Molinia was recorded in 2015; the legend to the background white, grey and black polygons is given for Figure 3.



A number of questions arise from this type of interpretation of old aerial photographs and surveys. Apart from the possible use of peat stratigraphy, it is one of the few lines of evidence available and in this case both have been helpful in drawing reasonable conclusions. Not all lines of evidence coincided, and in such cases it is important to understand the time available and the rigour with which historic surveys were undertaken and the degree to which aerial photographs were used to inform or replace actual field recording. This is not to denigrate the field recorders; surveys have to be carried out within the available budget and this may not always allow for full and careful checks on interpretations.

The ground-truthing of the 2009 aerial photograph in this survey was an essential element and provides a baseline for future monitoring. It could have set up permanent quadrats that could be re-recorded in the future, and this would give a comparatively unequivocal measurement of change.

Issues and questions raised by the survey

An understanding of how *Molinia*-dominated blanket mire fits into our national nature conservation values is perhaps the most important prerequisite for management, the second is the knowledge of how to change the vegetation from one condition to another. A close third is establishing the 'reference condition', that which is either original or optimal for the site in nature conservation terms. All these factors underpin judgements about what work should be undertaken, how much money should be spent, and the risks involved.

In this context it is important to know that *Molinia* has spread over the last 20 to 25 years at Berry Greave, and that another type of vegetation, more valued for nature conservation, used to be present. It leads on to speculation as to why this has occurred, such as changes in grazing (or lack of grazing), wild fire events and/or change in climate patterns or pollution levels. Discussion at the September 2015 'Managing Molinia' Conference drew attention to likely high levels of grazing by sheep in the earlier part of the period, followed by dramatically lower levels and, more recently, complete removal of sheep.

Without intervention it is likely that the trend will continue and that *Molinia* dominance will further increase, though there will be small residual populations of alternative species, such as Hare's-tail Cotton-grass. Once highly tussocky *Molinia* has become dominant, it seems likely to stay that way unless there is some intervention or external change. In successional terms, in may represent a 'still-stand' community. Whatever the future management, the extent of *Molinia* dominance should be recorded and monitored.

References

Anderson, P. A., Radford, E. & Mackenzie, S. 1989. Marsden Moor Estate: Moorland Erosion, Its Extent, Cause and Restoration; Penny Anderson Associates, report to the National Trust.

National Trust Survey Team, 1988. Biological Survey, August 1987. NT internal report.

Field visit 16 September 2015: Introduction to Burne Moss

Emma Fawcett, Natural England

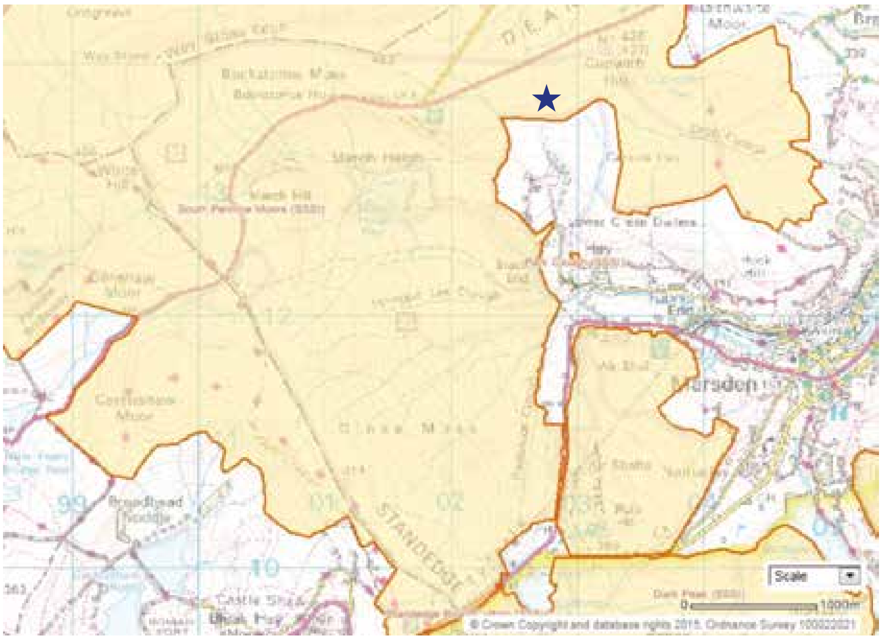


Figure 1. Part of the SSSI close to Marsden with the location of Burne Moss. Red line is SSSI boundary; blue star is Burne Moss and site for Sphagnum introductions.

South Pennine Moors SSSI is designated for its moorland habitats and associated breeding bird assemblage. The site forms part of the South Pennine Moors SAC (SAC Documentation) and the whole of the South Pennine Moors Phase 2 SPA (SPA Information). The SAC is primarily designated for its blanket bog, with heathland habitats. Sessile oak woodland is also a feature but this is not found within the northern section of the SAC boundary. The SPA is designated for the Annex 1 species Golden Plover and Merlin, and an associated upland breeding bird assemblage.

The National Trust's Marsden Moor Estate north (Pule Hill to Buckstones Moss) falls within the SSSI. The area has recently come into a Higher Level Stewardship agreement between Natural England (NE), the Marsden Commoners and the National Trust (NT). It is part of a wider partnership with adjacent moorland owners/commoners to improve the condition of the site in a co-ordinated approach; the NT has worked as a central facilitator in this. This work has tied in closely with Yorkshire Water Services (YWS) Longwood Catchment Project. The aim of these agreements and partnerships has been to restore the blanket peat through re-vegetation and gully blocking, and to diversify the moorland vegetation and its structure by re-introducing grazing with native cattle breeds at key location which are dominated by grasses and cotton-sedges.

The moorlands in this area are especially important for the remaining Twite *Carduelis flavirostris* colonies, found in both bracken beds and mature heather, and Golden Plover *Pluvialis apricaria*. Merlin *Falco columbarius* are known to nest in the vicinity. In 2014 Natural England commissioned an upland breeding bird survey over the whole SPA; the appended table shows numbers and trends for some of the species. The South Pennine Moors SSSI (Table 1) has a good history of bird surveys, using a consistent methodology, allowing comparisons with data gathered in 1990 and 2004.

The area around the A58, M62 and Marsden Moor have a high frequency of wildfires which has led to areas of bare peat and dominance by graminoids, predominantly *Molinia*. The moorlands in this area are primarily water catchment so the range of potential restoration techniques is limited. NT, YWS and NE formed a partnership, working with Moors for the Future, to look at diversifying *Molinia*-dominated swards using *Sphagnum* mosses (Pilkington, in these Proceedings). These trials have been split over three areas of moorland, to reduce fire risk to the experiment, one of which is located on the NT land at Burne Moss.

Table 1. South Pennine Moors SSSI/SPA Phase 2 Breeding Bird Survey: numbers of pairs and population trends. (Courtesy of Keystone Ecology).

Species	1990	2005	2014	Recorded population change 2005-2014	Likely SSSI population trend 2005-2014	Regional population trend	RSPB 2014 population changes		RSPB 2014 Population change period
Black-headed Gull	1	3	2	-33%	Stable	Unknown	32%	26%	1986-2013, 2000 - 2013
Canada Goose	10	41	144	251%	Increase	186%	54%		1995 -2012
Carrion Crow	NS	472	14	-97%	Decrease	69%	95%	17%	1970-2012, 1995-2012
Common Sandpiper	19	35	28	-20%	Stable	Unknown	-48%	-36%	1970-2012, 1995-2012
Cuckoo	NS	13	20	54%	Stable	-63%	-62%	-49%	1970-2012, 1995-2012
Curlew	295	461	456	-1%	Stable	24%	-62%	-43%	1970-2012, 1995-2012
Dipper	2	4	9	125%	Increase	Unknown	-32%	-17%	1970-2012, 1995-2012
Dunlin	52	34	46	35%	Increase	Unknown	Unknown		
Golden Plover	263	229	259	13%	Stable	Unknown	-6%		1995-2012
Grasshopper Warbler	NS	2	3	50%	Stable	Unknown	-6%		1995-2012
Great Crested Grebe	NS	NS	1	-	-	Unknown	8%		1995-2012
Greylag Goose	NS	8	32	300%	Increase	867%	293%		1995-2012
Grey Partridge	NS	7	4	-43%	Decrease	-64%	-91%	-56%	1970-2012, 1995-2012
Grey Wagtail	NS	11	11	0%	Stable	Unknown	-60%	-32%	1970-2012, 1995-2012
Kestrel	NS	4	14	250%	Increase	-44%	-48%	-35%	1970-2012, 1995-2012
Lapwing	41	115	133	15%	Stable	9%	-64%	-42%	1970-2012, 1995-2012
Linnet	NS	87	40	-54%	Decrease	-6%	-57%	-25%	1970-2012, 1995-2012
Little Owl	NS	3	1	-67%	Decrease	Unknown	-60%	-51%	1970-2012, 1995-2012
Little Plover	2	5	4	-20%	Stable	Unknown	Unknown		
Long-eared Owl	NS	NS	1	-	-	Unknown	Unknown		
Mallard	1	5	46	820%	Increase	33%	97%	17%	1970-2012, 1995-2012
Merlin	NS	NS	13	-	-	Unknown	Unknown		
Oystercatcher	0	7	27	286%	Increase	208%	-13%		1995-2012
Peregrine	NS	NS	3	-	-	Unknown	-20%		1995-2012
Pied Wagtail	NS	17	21	24%	Stable	-21%	23%	-11%	1970-2012, 1995-2012
Redshank	36	20	12	-40%	Decrease	Unknown	-44%		1995-2012
Ringed Plover	0	2	3	50%	Stable	Unknown	Unknown		
Reed Bunting	12	96	164	71%	Increase	25%	-41%	14%	1970-2012, 1995-2012
Red-legged Partridge	NS	2	10	400%	Increase	15%	-19%	19%	1970-2012, 1995-2012
Raven	NS	2	9	350%	Increase	Unknown	18%		1995-2012
Ring Ouzel	NS	14	2	-86%	Decrease	Unknown	Unknown		
Short-eared Owl	3	9	10	11%	Stable	Unknown	Unknown		
Snipe	40	89	100	19%	Increase	1%	11%		1995-2012
Stonechat	NS	39	42	8%	Stable	Unknown	-3%		1995-2012
Tawny Owl	NS	NS	1	-	-	Unknown	-35%	-25%	1970-2012, 1995-2012
Teal	1	2	8	300%	Increase	Unknown	Unknown		
Tree Pipit	NS	NS	2	-	-	Unknown	-71%	5%	1970-2012, 1995-2012
Tufted Duck	NS	NS	5	-	-	Unknown	64%	1%	1970-2012, 1995-2012
Twite	219	57	34	-40%	Decrease	Unknown	Unknown		
Wheatear	27	25	20	-20%	Decrease	68%	2%		1995-2012
Whinchat	25	22	9	-59%	Decrease	Unknown	-55%		1995-2012
Whitethroat	NS	1	2	100%	Stable	10%	13%	55%	1970-2012, 1995-2012
Wood Warbler	NS	NS	1	-	-	Unknown	-66%		1995-2012
Wren	NS	293	285	-3%	Stable	-2%	21%	-3%	1970-2012, 1995-2012
Willow Warbler	NS	NS	68	-	-	0%	-36%	0%	1970-2012, 1995-2012

Table 2. Full names of birds cited in Table 1.

English common name	Binomial
Black-headed Gull	Larus ridibundus
Canada Goose	Branta canadensis
Carrion Crow	Corvus corone
Common Sandpiper	Actitis hypoleucos
Cuckoo	Cuculus canorus
Curlew	Numenius arquata
Dipper	Cinclus cinclus
Dunlin	Calidris alpina
Golden Plover	Pluvialis apricaria
Grasshopper Warbler	Locustella naevia
Great Crested Grebe	Podiceps cristatus
Greylag Goose	Anser anser
Grey Partridge	Perdix perdix
Grey Wagtail	Motacilla cinerea
Kestrel	Falco tinnunculus
Lapwing	Vanellus vanellus
Linnet	Carduelis cannabina
Little Owl	Athene noctua
Little Ringed Plover	Charadrius dubius
Long-eared Owl	Asio otus
Mallard	Anas platyrhynchos
Merlin	Falco columbarius
Oystercatcher	Haematopus ostralegus
Peregrine	Falcus peregrinus
Pied Wagtail	Motacilla alba
Redshank	Tringa totanus
Ringed Plover	Charadrius hiaticula
Reed Bunting	Emberiza schoeniclus
Red-legged Partridge	Alectoris rufa
Raven	Corvus corax
Ring Ouzel	Turdus torquatus
Short-eared Owl	Asio flammaeus
Snipe	Gallinago gallinago
Stonechat	Saxicola torquata
Tawny Owl	Strix aluco
Teal	Anas crecca
Tree Pipit	Anthus trivialis
Tufted Duck	Aythya fuligula
Twite	Carduelis flavirostris
Wheatear	Oenanthe oenanthe
Whinchat	Saxicola rubetra
Whitethroat	Sylvia communis
Wood Warbler	Phylloscopus sibilatrix
Wren	Troglodytes troglodytes
Willow Warbler	Phylloscopus trochilus

Managing habitat and vegetation: blanket mire and dwarf-shrub heath

Problems with *Molinia caerulea* in the restoration of lowland peat bogs – Manchester Mosses Special Area of Conservation (SAC)

Paul Thomas, Natural England

Background

The Manchester Mosses SAC is managed by Cheshire Wildlife Trust, Lancashire Wildlife Trust and Warrington Borough Council Rangers as part of a wider partnership working together to enhance and promote the Great Manchester Wetlands. The SAC is made up of 3 relict bog sites Astley and Bedford Mosses Site of Special Scientific Interest (SSSI), Holcroft Moss SSSI and Risley Moss SSSI with a combined area of 193ha. All 3 sites are fragments of a much larger peatland complex, Chat Moss, that once covered large areas of the Mersey Valley. In the 1990s peat mapping for the Northwest Wetland Survey put the extent at about 3500ha (Hall et al., 1995, Leah et al., 1997).

Functionally the Manchester Mosses are lowland raised bog at an elevation of 21m above sea level. The bogs initially developed within discrete basins and then, between 5000 and 1000 BC, there was a rapid phase of peat formation and adjacent land was engulfed by paludification[1]; this resulted in the landscape being blanketed in bog. With the arrival of the railways in 1830, the area was opened up through conversion to agriculture and large scale peat cutting. As a consequence, much of the bog habitat was lost and the three SSSIs represent the biggest surviving fragments of this habitat. These relict sites are part of the wider paludified landscape rather than from terrestrialisation of original basins and this has consequences for the hydrology.

Each SSSI within Natural England's remit is required to have a condition target against which it is monitored on a regular basis. This sets out what the composition of the plant community should be and hence what is wanted in terms of favourable condition within the Lowland Raised Bog habitat. For the three Manchester Mosses SSSIs the National Vegetation Classification (Rodwell (Ed.), 1991) was used to determine "favourable condition". Rodwell (Ed.) (1991) describes M18 *Erica tetralix – Sphagnum papillosum* raised and blanket mire as the typical plant community of Lowland Raised Bog. In this community a high cover of *Sphagnum* mosses would be expected[2] with at least two of the following species constant and with a combined cover greater than 20%: *Sphagnum capillifolium, S. magellanicum, S. papillosum, S. tenellum*, with *Sphagnum cuspidatum* at least occasional. We would also expect for at least three of *Calluna vulgaris, Erica tetralix, Eriophorum angustifolium, E. vaginatum* and *Trichophorum cespitosum* to be constant, with a combined cover not exceeding 80%. When measured against this target in 2003, Manchester Mosses were dominated by *Molinia caerulea* (Purple Moor Grass), with past attempts at restoration all slipping back to *Molinia* dominance (Thomas & Walker, 2004), and thus in unfavourable condition.

Holcroft Moss Case study – Treatment of *Molinia* with heavy sheep grazing.

Grazing on this site started in 1998 with the aim of removing the dense thatch of *Molinia* and making space for more typical bog plants (Waring, 2004). Up to 80 sheep were used to graze part of the site (7.4ha). This level of grazing was maintained until 2009. The 2009 condition assessment noted that this management had been successful in reducing the cover of *Molinia* but that the sheep were becoming a problem in their own right by preventing the spread of *Sphagnum*, Cranberry *Vaccinium oxycoccos* and other species and producing obvious signs of enrichment.

Unfortunately, despite over 10 years of heavy grazing, no net positive outcome was seen in the bog vegetation. This site has never been cut for peat but there are deep drainage channels at the edges of the SSSI which result in water loss due to a large hydraulic gradient. Plastic sheet piles were installed around the site in the 1990s to hold the water in, but this was ineffective because their length stopped short of the bottom of the peat, underlying clay and sand so water could seep beneath. This meant the peat mass continued to dry out and has promoted *Molinia* dominance; in this instance *Molinia* is a symptom of low summer water levels.

The recognition of over-grazing and on-going low water levels resulted in a change in management. Sheep numbers were reduced down to 18 over 18.1 ha, and perimeter ditches were blocked. This management has been effective and the moss is recovering, with an increase in *Sphagnum* and both Common and Hare's-tail Cotton-grass cover and some recovery of Cross-leaved Heath and Cranberry. However, with the changes in hydrology and grazing taking place at the same time, it is not possible to show which management intervention has been the most significant at this site.

Astley Moss Case study – Stressing *Molinia* by raising the water-table

The vegetation and hydrological circumstances at Astley Moss was very similar to those at Holcroft Moss. Restoration works by the Lancashire Wildlife Trust have been ongoing since the early 1990s (Rowell, 1990) and have concentrated on the blocking of internal ditches. This has been successful in raising the water levels and allowing a relict bog community to survive within the old peat cuttings. However, outside of this area, the majority of the moss suffers from wide fluctuations in the water table, especially in summer (White *et al.*, 1992). This left the site managers fighting a constant battle against scrub encroachment, and large parts of the site were still dominated by *Molinia*.

The ditches on the edge of this moss are up to 3m deep and water could often been seen seeping out of the peat along the sides of the ditches. Unlike Holcroft Moss, it was not possible to block all the ditches at the edge of the moss due to the potential impact on adjacent agricultural land. Even where a lagg fen buffer had been created, ground level differences resulting from past peat cutting still resulted in large hydrological gradients so water is still lost from the higher areas.

To restore the hydrology of the site, Lancashire Wildlife Trust, supported by Natural England, installed plastic piling to cut the site off from the influence of external drainage. This piling was keyed into the underlying clay and the piles formed the core of a peat bund (Figure 1), and this has vastly improved the effectiveness of the bund compared to those installed at Holcroft Moss. Further peat bunding has also been constructed within the moss to slow the flow of water away from higher areas (the remains of the old peat cuttings) and, where land was available, "lagg fen" buffers have been created by backfilling the ditches and blocking land drains.

This management approach has been very successful and large areas of *Molinia*-dominated vegetation have been transformed to a cover of *Sphagnum* mosses and Cotton-grasses (Figures 2 and 3).

Figure 1. Installation of plastic piles as part of bund creation on land adjacent to Astley Moss. The works created a new "lagg" fen to reduce the hydrological gradient off the moss so helping re-wet the core of the bog.

Figure 2. The core of Astley Moss in 2007 before re-wetting with a Molinia-dominated sward.

Figure 3. Change in the vegetation after re-wetting in 2010 with Sphagnum mosses and both Common and Hare's-tail Cotton-grass becoming dominant.

Risley Moss Case study – Treatment of *Molinia* on a complex site with a long history of "conservation management".

Risley Moss SSSI has been heavily modified in the past by large scale peat extraction by the British Moss Litter Company. Peat extraction destroyed the natural surface of the bog and replaced it with an undulating surface of high baulks, deep-cut pits and drains. In 1939 construction of the Risley Royal Ordnance Factory started and most of what is now the new town of Birchwood was developed. Part of the moss was within the boundary fence of the factory and was used for testing of small munitions and smoke bombs, as well as waste tipping.

The factory closed shortly after the end of the Second World War in 1946 and large quantities of waste was dumped on the moss during decommissioning. This included clay from demolished bunkers, ash, clinker, pyrotechnic waste and munitions. In 1976 the old factory and moss were acquired for development as a New Town (Warrington) with the moss being selected for development as a nature reserve. Survey information from this time shows that the moss was *Molinia*-dominated with small wet pools in some of the deeper peat cuttings which supported Cotton-grass and relict bog species such as Cranberry and *Sphagnum papillosum* (Meade, 1977). The dry nature of the majority of the moss and the dominance of *Molinia* resulted in regular fires at this time. This was of a major concern to the site manager given the proximity of the site to the new and planned residential areas.

So in 1978, as part of the first phase of works on the nature reserve, a security and fire-break ditch was constructed around the moss at a time when the science of bog hydrology was relatively young. This ditch ranged from 5-10m wide and up to 2m deep and was divided into sections by metal sheet piling dams. The choice of metal sheet piles for the dams was unfortunate because, in the acid environment of the moss, they rusted away, resulting in a massive water loss from large parts of the site.

The moss was notified as an SSSI in 1986. Between 1994 and 1999 a large scale re-wetting project was undertaken in conjunction with the clearance of the pyrotechnic residues, which involved the construction of bunds to form a series of terraced lagoons; the surface peat and vegetation was removed and used to form bunds, control pipes were installed to allow water levels in the newly created lagoons to be controlled and toxic waste was removed. A second smaller series of re-wetting works was undertaken in 2002.

Despite large-scale hydrological improvement, many of the gains were lost due to a lack of site management continuity. Many of the bunds were constructed from surface peat with a high proportion of old *Molinia* tussocks and over time this resulted in widespread leakage problems. In 2007 much of the site was dry and *Molinia* was dominating the less successful scrapes. Also, there had been an increase in birch scrub cover and, in some cases, the development of W4 *Betula pubescens* – *Molinia caerulea* woodland on the former open habitat. It was clear from this assessment that, although very low-lying parts of the site were on the road to recovery, 60% of the site was still failing its favourable condition targets and continuing to dry out.

Figure 4. Newly re-wet woodland on the edge of Risley Moss, where all the ditches and field drains have been blocked and a more natural hydrology restored to help keep the adjacent mossland remain wet.

With the drive to secure management to deliver favourable condition on SSSIs and the obligations to restore the SAC back to 'vegetation normally capable of peat formation within 30 years', action was needed to re-wet the full extent of the remaining mire. To this end, Warrington Borough Council entered into a Higher Level Stewardship agreement to undertake a further phase of re-wetting between 2011 and 2015. This work was informed by the 2010 condition assessment which identified the location of lost water level controls and leaks. Within this project, major leaks on the site were identified and works put in place to address the problems that resulted from earlier works (such as leaking dams and fire ditches), as well as dealing with historical drainage issues missed during the earlier works. Another key factor was to protect the bog improvements achieved under previous phases and extend the conditions for it to spread.

As part of the re-wetting work it was critical to understand the hydrological functioning of the bog, the way the land has been modified in the past and how these relate to the notified features of the SSSI and SAC. One good example of this is Unit 3 (Figure 4); this area of the moss sits on deep peat but does not support open lowland raised bog habitat, being largely dominated by birch woodland. This area presented a problem that was highlighted in the 1999 condition assessment:

"Unfavourable – No change. This unit is still mainly under trees. Likelihood of return to raised bog is greater than for Unit 1 but it would take a huge effort to remove all the woody vegetation."

Key to making a decision about the condition and future of this area was historic information on how this area was modified in the past. Old Ordnance Survey maps show that the land had been farmed since the mid-1800s, and then in the 1940s was heavily modified by tipping from the Royal Ordnance factory. This historic use means that the unit is unlikely to recover directly to lowland raised bog but it is still important for the site's notified breeding bird assemblage. Hence, the unit was we re-classified as supporting lagg fen woodland and the breeding bird assemblage only, removing the need to restore to bog habitat.

Thanks to the re-wetting works large parts of the moss are now so wet as to be inaccessible. The available aerial photographs pre-date the works so it is difficult to get a clear picture of how habitats are developing across the site and where there still may be a need to augment the management. Technology has helped here and small unmanned aerial vehicles are being used to collect up-to-date photographs. These flyovers have been very effective at showing the effects of rising water levels and the expansion of *Sphagnum* cover. They have also highlighted areas where there are further problems, such as the areas next to the woodland where water levels are still low. Looking at the photography and, having knowledge of the history of Unit 3, allowed the 'problems' to be found and resolved. A quick follow-up investigation on the ground discovered that all the old tile drains within the woodland (dating back to farming in the 1800s) were still active and needed blocking.

Warrington Borough Council successfully secured SITA[3] funding and a project to wet up the woodland was completed over the winter 2014-15. As well as creating 10ha of wet woodland (Figure 4), this work raised water levels on the moss and has started to waterlog the *Molinia*-dominated vegetation on the adjacent moss (Figure 5).

Figure 5. Sphagnum moss spreading out from flooded peat cuttings on to the Molinia-dominated ridges at Risley Moss. This is after leaks were fixed and adjacent wet woodland provided a buffer, which resulted in raised water levels across the moss.

Conclusion

The Manchester Mosses have developed a long way towards eventual favourable condition, and are much wetter than they were ten years ago. The cover of positive indicators such as *Sphagnum* mosses and both Common and Hare's-tail Cotton-grass have increased at the expense of *Molinia*. However, the sites still fail the condition assessment targets for the cover of *Sphagnum*. *Sphagnum papillosum* and *S. magellanicum* are rare and the sites are still dominated by what are widely considered to be typically poor-fen species such as *S. fallax* and, *S. fimbriatum*. It is going to take a long time to get the mosses back to favourable condition, but looking at photos of this area they are already successfully restored to their early 20th century state, a very positive trend.

Notes

[1]Peat formation.

[2]As required by the condition assessment method.

[3]'SITA Trust is an ethical funding organisation dedicated to making lasting improvements to the natural environment and community life. A not-for-profit company, the Trust is a registered and accredited environmental body that operates under the Landfill Communities Fund, distributing money donated by SITA UK.' Quote from the SITA website (Ed).

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Generic approaches for the restoration of *Molinia*-dominated moorland

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Abstract

This paper considers a range of methods for the control of *Molinia* and the re-establishment of a more mixed vegetation. It discusses herbicide use, prescribed burning, sheep grazing and species additions. It suggests prescriptions for applied vegetation management.

Introduction

Molinia caerulea (L.) Moench is a problem species because it can be dominant over large areas of upland Britain; in some places policy-makers and land managers would prefer a more diverse vegetation type with a greater dwarf-shrub heath component. Our contention is that *Molinia* control cannot be considered in isolation and must be carried out in an integrated way that encompasses restoration of the desired vegetation outcome. This paper will look at some ways that this can be done, it reflects a great deal of research carried out in the late 1990s and early 2000s, funded by Defra, and carried out by scientists at the University of Liverpool and the Heather Trust. It supplements a great deal of practical experience of restoring diversity in upland moorlands. Hereafter, *Molinia caerulea* (L.) Moench and *Calluna vulgaris* (L.) Hull will be referred to by their generic names.

The academic research part of the work covered four main topics, these were testing:

- Control methods (grazing, burning and herbicide application) on *Molinia* performance and vegetation recovery on *Molinia*-dominant and mixed *Molinia*-dwarf-shrub heath vegetation (Todd *et al*., 2000; Marrs *et al*., 2000, 2004).
- Effectiveness of graminicides – herbicides that selectively affect grasses on *Molinia* and *Calluna* (Milligan *et al*., 1997, 1999, 2003a; Marrs *et al*., 2000).
- The effectiveness of weed-wiping technology to control/reduce *Molinia* (Marrs *et al*., 2000; Milligan *et al*., 2003b).
- Integrated control/restoration methods (sheep grazing, cutting frequency, graminicide application and *Calluna* brash addition) on *Molinia*-dominated land effectiveness of (Milligan *et al*., 2004).

It was supplemented by a parallel track of long-term series of practical control methods continuously refined by Geoff Eyre over a twenty-year period.

Note throughout this work, we strived to carry out the research to the highest standards of rigour and this included the statistical analyses. Accordingly, in order to meet the strict assumptions of the statistical tests used (Sokal & Rohlf, 1969), we transformed the raw data either to its logarithm ($\log_e(x+1)$) or if a percentage to an angular transformation using the arcsin transformation arcsin(sqrt(x%/100)). These data are discussed here.

Testing the effects of grazing, burning and herbicide application on Molinia performance and vegetation recovery

In this study we tested a range of management treatments to reduce *Molinia* and encourage the development dwarf-shrub heath in two regions (northern part of the Peak District, referred to hereafter as North Peaks and Yorkshire Dales). In each region, the same experiment was carried out on two types of moorland vegetation (*Molinia*-dominated 'White' moorland and a mixture of *Molinia* and *Calluna vulgaris* 'Grey moorland'). Burning, grazing and herbicide (glyphosate) treatments were applied in factorial combination at each of the four sites (two regions x 2 moor types). The responses of both vegetation and individual species were assessed throughout. In addition, on the 'White' moors, two techniques for *Calluna* re-establishment were investigated; these were (1) removal of *Molinia* litter by raking and (2) application of *Calluna* seed. A third pair of experiments in Exmoor were discounted because of wildfire damage caused by vandalism.

The only treatment that had consistent effects in the univariate analyses was glyphosate application, which had similar effects on *Molinia* cover and vegetation height at all study sites (Figure 1).

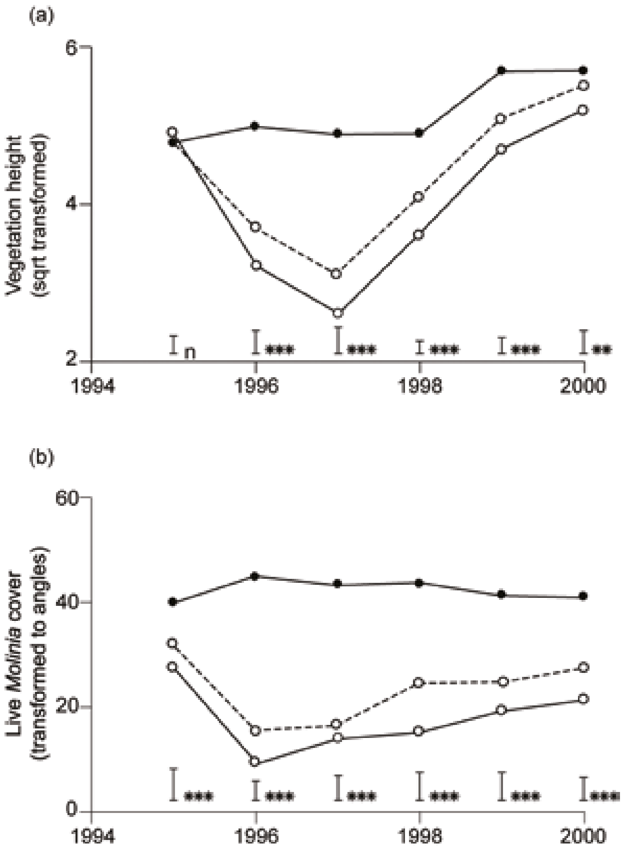


*Figure 1. Effects of glyphosate application on (a) vegetation height, and (b) live Molinia cover in moorland dominated by Molinia caerulea between 1995 (year of application) and 2000: as there was no significant interaction between herbicide treatment and region the data shown are pooled across all four experimental sites (2 regions x 2 moors types): Herbicide treatments: closed symbols = unsprayed control, open symbols = sprayed, dashed line = 0.27 kg ai ha^{-1}, solid line = 0.54 kg ai ha^{-1}. Pooled treatment means (n=48) are presented with vertical bars representing the LSD (P < 0.05) and significance is denoted: n=P>0.05, *=P<0.05, **=P<0.01, ***=P<0.001 (abstracted from Marrs et al., 2004).*

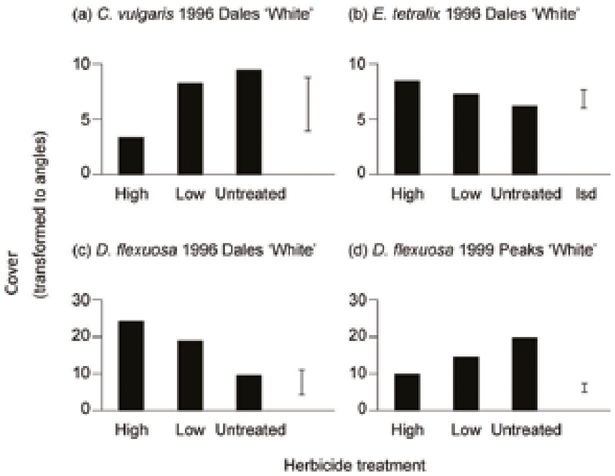


Figure 2. Examples of significant species responses to glyphosate treatment: (a) Group 1: Calluna, cover reduced by herbicide; (b) Group 2: E. tetralix, cover increased by herbicide, and (c,d) Group 3: D. flexuosa, a species with conflicting responses at different sites or in different years. See text for further explanation. Herbicide treatments: control = unsprayed control, low = 0.27 kg ai ha^{-1}, high = 0.54 kg ai ha^{-1}. Pooled treatment means (n=12) are presented with the LSD (P<0.05) represented as a vertical bar (abstracted from Marrs et al., 2004).

There was little difference between the use of low and high glyphosate application rates (0.27 and 0.54 kg ai^{1} ha^{-1}). There was little impact of herbicide use on other moorland species. Some species were affected on some sites in some years, but there were no consistent effects (Figure 2). Tentative identification of species that responded positively, negatively and erratically to glyphosate application was made.

Greater *Calluna* seedling densities were found initially in plots where herbicide was applied, the *Molinia* litter was removed and seed was added (Figure 3). However, after the initial colonisation, *Calluna* seedling densities reduced as the *Molinia* recovered. This indicates that disturbance, seed addition and follow-up management is needed for successful *Calluna* establishment.

In terms of *Molinia* control and subsequent restoration of dwarf-shrubs, there was marked variability of response between "apparently similar" vegetation types in different regions. There were abrupt temporal changes taking place some years after treatment application and a significant length of time was required for change to be detected. Managers need to obtain a greater knowledge of initial floristic composition before starting the restoration process, be prepared to accept multiple outcomes of response (acid grassland *versus* dwarf-shrubs), be prepared for a long-term monitoring process and perhaps the inclusion of additional treatments for continued *Molinia* control (application of selective graminicides) and dwarf-shrub restoration (disturbance and seed addition treatments).

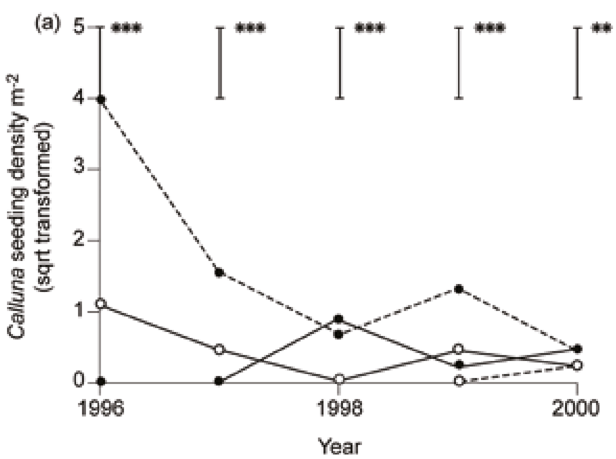


*Figure 3. Effects of removal of litter by raking and application of Calluna seed on Calluna seedling establishment on 'White' moorland dominated by Molinia between 1996 (year of treatment) and 2000. Litter removal treatments: dashed line = no removal, solid line = litter removed; seeding treatments: open symbols = unseeded, closed symbols = seeded. Pooled treatment means (n=36) are presented with vertical bars representing the LSD (P < 0.05) and significance is denoted: n=P>0.05, **=P<0.01, ***P=< 0.001 (abstracted from Marrs et al., 2004).*

Table 1. Dose-response relationships for Molinia treated under controlled conditions with resultant equations, r2, P values and estimated (ED50 kg ai ha^{-1}) (abstracted from Milligan et al., 1999).

Herbicide	y †	Equation fitted	r2	P	ED50 (kg ai ha-1)
Glyphosate	DWS	= 1.12 + (- 0.0601) * (dose)	0.68	0.001	0.46
	DWR	= 1.46 / (1+ (exp(0.67 * 0.03))*(dose$^{0.67}$))	0.89	0.050	0.41
	Flower	= k /(1+(exp(b * g))*(dose ^{b}))	0.94	0.001	0.55
	FT	= 13.90 /(1+(exp(2.71 *-1.18))*(dose $^{2.71}$))	0.89	0.001	0.62
	FT-IT	= 10.30 /(1+(exp(13.24 * 0.56))*(dose $^{13.24}$))	0.44	0.001	0.67
Clethodim	DWS	= 0.29+(-2.11)*(dose)	0.21	0.001	-
	DWR	= 0.29+(-0.97)*(dose)	0.11	0.004	-
	Flower	-	-	-	-
	FT	= 3.64+(-1.714)*(dose)	0.16	0.001	-
	FT-IT	= 1.80+(-1.00)*(dose)	0.11	0.001	-
Cycloxydim	DWS	= 2.43+(-0.84)*(dose)	0.08	0.051	-
	DWR	= 1.25+(1.75)*(dose)	0.22	0.001	-
	Flower	= 10.35 + (-8.94)*(dose)	0.40	0.001	-
	FT	= 17.75 + (-10.83 * dose)	0.23	0.001	-
	FT-IT	= 11.52 + (-11.44 * dose)	0.30	0.001	-
Fluazifop-P-	DWS	= 2.54 + (-1.29)*(dose)	0.23	0.001	-
butyl (120)	DWR	= 1.40 + (-0.16)*(dose)	0.00	0.621	-
	Flower	= 12.98+ (-5.32)*(dose)	0.13	0.014	-
	FT	= 17.20 + (-4.21)*(dose)	0.03	0.193	-
	FT-IT	= 9.95 + (-3.48)*(dose)	0.03	0.215	-
Fluazifop-P-	DWS	= 2.75 + (-0.71)*(dose)	0.19	0.002	-
butyl (250)	DWR	= 1.21 + (-0.76)*(dose)	0.04	0.151	-
	Flower	= 15.18 + (-5.61)*(dose)	0.27	0.001	-
	FT	= 22.00 + (-6.26)*(dose)	0.14	0.008	-
	FT-IT	= 15.28 + (-8.08)*(dose)	0.28	0.001	-
Quizalofop-	DWS	= 0.45 + (-0.55)* Ln(dose)	0.56	0.001	0.18
ethyl	DWR	= 0.97 + (-1.92)* Ln(dose)	0.19	0.002	-
	Flower	= 11.74 + (-3.28)* Ln(dose)	0.51	0.001	1.2
	FT	= 4.51 + (-2.69)* Ln(dose)	0.50	0.001	0.28
	FT-IT	= -0.82 + (-2.30)* Ln(dose)	0.58	0.001	0.10
Sethoxydim	DWS	= 2.25 /(1+(exp (0.85 * 0.74))*(dose $^{0.85}$))	0.87	0.001	0.39
	DWR	= 1.29 + (-0.08) * (dose)	0.00	0.520	-
	Flower	= 2.01 + ((-3.00) * Ln (dose)	0.56	0.001	-
	FT	= 21.63/(1+(exp (1.71 *-1.25)) * (dose $^{1.71}$))	0.70	0.001	0.37
	FT-IT	= 10.96/(1+(exp (3.05 * 1.36)) * (dose $^{3.05}$)	0.86	0.001	0.49
Tralkoxydim	DWS	= 2.78 + (-0.75)*(dose)	0.06	0.083	-
	DWR	= 1.34 + (-0.22)*(dose)	0.02	0.284	-
	Flower	= 12.20 + (-0.55)*(dose)	0.00	0.808	-
	FT	= 15.27 + (-0.40)*(dose)	0.00	0.893	-
	FT-IT	= 9.61 + (0.18)*(dose)	0.00	0.949	-

† DWS = Dry weight of shoots (g); DWR = Dry weight of roots (g); FT = Final tiller number; FT - IT = Final tiller number minus initial tiller number; Flower = number of seed heads.

Table 2. Dose-response relationships for Calluna treated under controlled conditions with resultant equations, r2 and P values and the estimated ED50 (kg ai ha^{-1}) (abstracted from Milligan et al., 1999).

Herbicide	y	Equation fitted	r2	P	ED50 (kg ai ha^{-1})
Glyphosate	DWS	= 2.79 + (-0.63) * (dose)	0.21	0.001	-
	FFSH	= 3.77 + (-1.56) * (dose)	0.50	0.001	0.450
	FTL	= 100.01 + 192.72 * 0.15E-12 dose	0.78	0.001	0.048
	FTL-ITL	= 12.30 + 235.24 * 0.15E-12 dose	0.65	0.001	0.025
Clethodim	DWS	= 3.66 + (-0.62)*(dose)	0.02	0.202	-
	FFSH	= 10.50 + (-1.63)*(dose)	0.02	0.235	-
	FTL	= 234.50 + (-113.13)*(dose)	0.13	0.001	-
	FTL-ITL	= 141.75 + (-94.07)*(dose)	0.13	0.001	-
Cycloxydim	DWS	= 3.91 + (0.57)*(dose)	0.02	0.250	-
	FFSH	= 11.33 + (1.32)*(dose)	0.01	0.339	-
	FTL	= 234.92+ (-3.87)*(dose)	0.00	0.877	-
	FTL-ITL	= 135.20 + (-5.82)*(dose)	0.00	0.778	-
Fluazifop-P-	DWS	= 3.82 + (0.06)*(dose)	0.00	0.632	-
butyl (125)	FFSH	= 11.32 + (0.11)*(dose)	0.00	0.786	-
	FTL	= 274.04 + (0.71)*(dose)	0.00	0.946	-
	FTL-ITL	= 186.57 + (-2.12)*(dose)	0.00	0.822	-
Fluazifop-P-	DWS	= 4.01 + (-0.10)*(dose)	0.03	0.122	-
butyl (250)	FFSH	= 11.92 + (-0.28)*(dose)	0.03	0.140	-
	FTL	= 285.57 + (-11.66)*(dose)	0.04	0.031	-
	FTL-ITL	= 201.92 + (-11.57)*(dose)	0.05	0.017	-
Quizalofop-	DWS	= 3.44 + (0.04)*(dose)	0.00	0.932	-
ethyl	FFSH	= 9.96 + (-0.64)*(dose)	0.00	0.591	-
	FTL	= 247.43 + (-84.92)*(dose)	0.06	0.006	-
	FTL-ITL	= 153.45 + (-68.21)*(dose)	0.04	0.020	-
Sethoxydim	DWS	= 3.93 + (-0.38)*(dose)	0.03	0.153	-
	FFSH	= 11.86 + (-1.20)*(dose)	0.03	0.133	-
	FTL	= 265.10 + (-26.57)* (dose)	0.02	0.144	-
	FTL-ITL	= 179.45 + (-20.69)*(dose)	0.01	0.203	-
Tralkoxydim	DWS	= 4.04 + (-0.10)*(dose)	0.00	0.507	-
	FFSH	= 12.22 + (-0.52)*(dose)	0.02	0.254	-
	FTL	= 322.05 + (-48.12)*(dose)	0.14	0.001	-
	FTL-ITL	= 216.76 + (-42.41)*(dose)	0.15	0.001	-

† DWS = Dry weight of shoots (g); FFSH = Final fresh weight (g); FTL = Final total shoot length (cm); FTL-IT = Final shoot length minus initial shoot length (cm).

Given that *Molinia* is perceived to be increasingly dominant in upland moorland communities at the expense of dwarf-shrub heath, dose-response experiments were used to assess the efficacy of six graminicides against the non-selective glyphosate on both *Molinia* and *Calluna* and to calculate effective doses(ED_{50}). Graminicides are herbicides that are intended only to affect grasses, glyphosate is a herbicide that affects all species, grasses and dicotyledons alike (Naylor, 2002). A range of measures were used to assess ED_{50}. Plants were grown under laboratory conditions and increasing doses of herbicide sprayed using a precision sprayer.

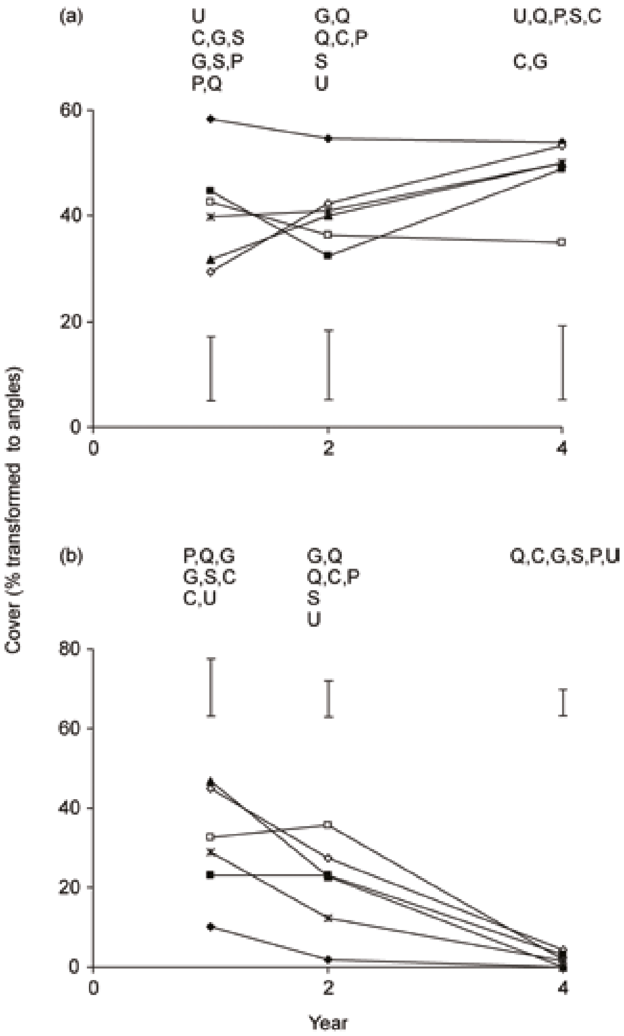
Results were highly variable, indicating the great morphological plasticity both species, and this made determination of an ED_{50} difficult. Indeed, where estimation was possible there was a high degree of variation in the different estimates of ED_{50} depending on the parameters measured. Of the graminicides, quizalofop-ethyl and sethoxydim, reduced *Molinia* sufficiently to allow calculation of an ED_{50} and hence showed promise for field applications (Table 1); the other four were less effective. Glyphosate reduced *Molinia*, and was the only herbicide that affected *Calluna* sufficiently to allow the calculation of an ED_{50} (Table 2).

Field experiments were then set up in both *Molinia and Calluna*-dominated areas at Ramsgill Bents, North Yorkshire. In each area twelve plots (1 m x 2 m) were set up in each of three replicate blocks; the twelve herbicide treatments (6 herbicide treatments (5 herbidices + untreated) x 2 doses) were then assigned randomly within each block. The five herbicides used and their application rates (Table 3) were selected on the basis of a combination of ED_{50} values obtained for *Molinia* and *Calluna* (Milligan *et al*., 1999) and the respective manufacturer's guidelines. A double dose (2 x chosen application rate) was also included to test if this could produce more effective control (Table 3). Taken together the results suggested that quizalofop-ethyl and propaquizafop caused adequate reductions of *Molinia* and yet did not damage *Calluna* and other moorland species such as *Eriophorum vaginatum* (L.) (Figures 3 & 4). However, in the following year, live *Molinia* percentage cover was not non-significantly different from untreated plots, suggesting that follow-up herbicide applications may be necessary to ensure more permanent levels of *Molinia* control.

Table 3. The selective herbicides assessed for their efficacy for controlling Molinia on Calluna-dominated moorland; the doses used in this study are also shown (abstracted from Milligan et al., 2003a).

		Application rate (kg ai ha^{-1})	
Active ingredient	**Commercial product (kg ai $litre^{-1}$)**	**Low dose**	**High dose**
Glyphosate	Roundup Biactive (0.36)	0.54	1.08
Cycloxydim	Laser (0.2)	0.24	0.48
Quizalofop-ethyl	Pilot (0.5)	0.125	0.25
Propaquizafop		0.15	0.30
Sethoxydim	Checkmate (0.19)	0.048	0.09

Figure 4. Effects of five herbicides on the cover of (a) live and (b) dead Molinia on Molinia-dominated moorland at Ramsgill Bents over a three year period, year 1= 4 weeks after treatment. Means (n = 6) plotted are arcsin transformed and are presented along with the Least Significant Difference (LSD, P < 0.05) for each year as a vertical bar. The LSD gives an estimate of the minimum difference needed between means to be significantly different.



The letters in horizontal lines above each year represent the significant groups in a Duncan's multiple range test. Hence in (a) in Year 1 there are four groups (1) U (least affected), (2) C, G, S, (3) G, S, P and (4) P, Q (which showed the biggest reduction). Note a treatment can be in two groups.

Treatment key: C = cycloxydim (solid square), G= glyphosate (open square), P=propaquizafop (triangle), Q=quizalofop-ethyl (open diamond), S=sethoxydim (star), U=untreated plots (solid diamond) (abstracted from Milligan et al., 2003a).

Testing the effectiveness of weed-wiping technology

Where it is agreed there is a need to control *Molinia*, and that herbicides might play a part in the management strategy, there is the potential to minimize environmental damage to other species if the herbicide could be applied by topical means, i.e. directly to the target plant without the use of sprays. This study, therefore, assessed the potential glyphosate application by weed wiper to *Molinia* whilst leaving other species unharmed.

Field test using tracers

Herbicide depositions patterns from both a weed wiper and spray applications were made on both 'white' and 'grey' moorland using tartrazine, as an artificial tracer. Three herbicide treatments were compared to untreated controls: (a) single pass of weed wiper; (b) double pass of weed wiper and (c) spraying with conventional boom.

Wiping was carried out using a 'Rotowiper' (Cobhasa Limited) with a Flojet 2100 self-priming pump, pulled behind an ATV[2]. The wiper was set *ca.* 25 cm above ground level on 'white' sites and 20 cm above ground level at 'grey' sites. Application volumes were estimated in test runs over 'white' moorland to be *ca.* 87 litres ha^{-1}. Spraying was carried out with a knapsack sprayer with an application volume of 170 litres ha^{-1}.

At the ‘white’ site, there were no significant differences in the amounts of tartrazine deposited by the three herbicide application techniques ($P=0.58$). However, there were significant differences between the amounts deposited throughout the vegetation sward (Figure 6a; $P<0.05$); all application techniques deposited greater amounts of tartrazine in the uppermost layers (20-30cm and +30cm) compared to the lowest layer (0-10 cm). In contrast, at the ‘grey’ sites spraying and wiping twice applied significantly more tartrazine onto the graminoid fraction than a single wipe (Figure 6b, $P<0.05$). Spraying deposited more tartrazine in the upper most layers whilst wiping deposited greatest amounts in the 10-20 cm layer ($P<0.01$). However, significantly more tartrazine ($P<0.01$) was deposited onto the ericaceous species by spraying than either of the two wiping treatments (Figure 6c).

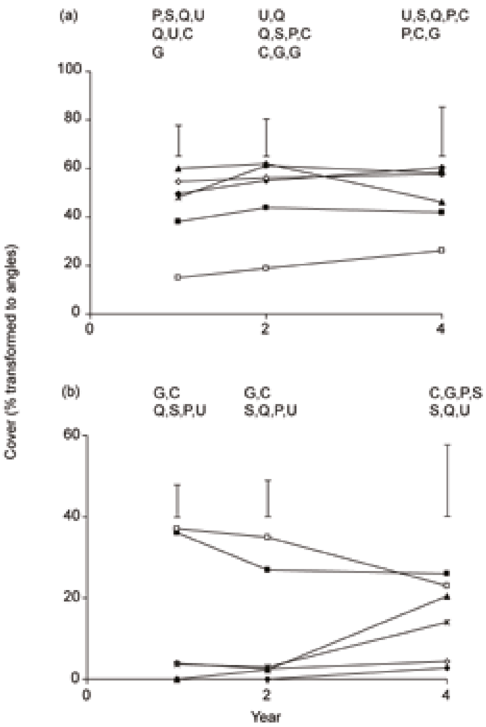


Figure 5. Effect of five herbicides on the cover of (a) live and (b) dead Calluna cover on Calluna-dominated moorland at Ramsgill Bents over a three year period, year 1= 4 weeks after treatment. Means (n = 6) plotted are arcsin transformed and are presented along with the Least Significant Difference (LSD, P < 0.05) for each year as a vertical bar. The LSD gives an estimate of the minimum difference needed between means to be significantly different.

The letters in horizontal lines above each year represent the significant groups in a Duncan’s multiple range test. Hence in (a) in Year 1 there are three groups (1) P,S, Q, U (least affected), (2) Q, U, C (3) G (which showed the biggest reduction). Note a treatment can be in two groups.

Treatment key: Treatment key: C = cycloxydim (solid square), G= glyphosate (open square), P=propaquizafop (triangle), Q=quizalofop- ethyl (open diamond), S=sethoxydim (star), U=untreated plots (solid diamond) (abstracted from Milligan et al., 2003a).

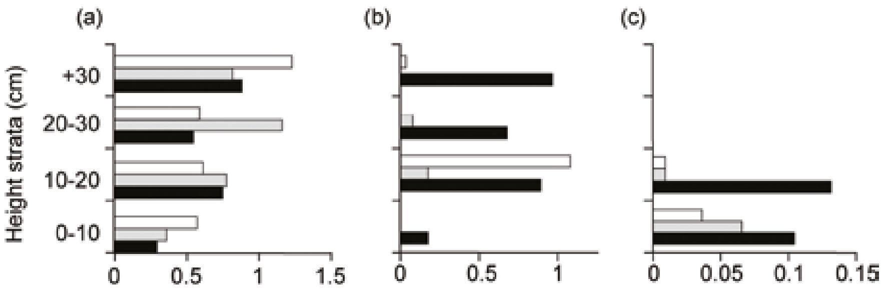


Figure 6 Tartrazine deposited (mg g^{-1}) by spraying (clear), and by single wipe (grey) and double wipe (black) application from a weed wiper in (a) graminoids on ‘white’ moorland, (b) graminoids on ‘grey’ moorland, and (c) ericoids on ‘grey’ moorland (abstracted from Milligan et al. (2003b).

Lab tests using glyphosate

Molinia tussocks were collected and grown under glasshouse conditions. Increasing concentrations of glyphosate were then either sprayed using a Mardrive Precision Sprayer or applied using a sheepskin paint roller to mimic the action of the weed wiper. Glyphosate was applied at the following rates: 0, 0.03, 0.07, 1.44, 2.88 and 5.76 kg ai ha^{-1} to cover the manufacturer's recommended range (0.72-2.16 kg ai ha^{-1}). Spraying glyphosate onto *Molinia* plants significantly reduced the dry weight of roots and shoots and fresh weights more than wiping (Table 4). However, there were no main treatment differences between the two application techniques on tiller number, but was a significant interaction between the treatments and doses used – as the glyphosate concentration increases the reduction in control produced by wiping declines (Figure 7). The standard errors on these data were large, indicating the highly variable response of *Molinia* to glyphosate.

Table 4. Relative efficacy of spraying and weed wiper herbicide application techniques as indicated by differences in various parameters of Molinia growth. S=sprayed, W=wiped; mean values ± SE (n = 15) are presented (abstracted from Milligan et al., 2003b).

Plant Parameter		Dose					
		0	0.30	0.07	1.44	2.88	5.76
Shoot dry wt (g)	S	0.44±0.04	0.15±0.03	0.17±0.01	0.15±0.03	0.14±0.02	0.17±0.02
	W	0.50±0.05	0.30±0.03	0.39±0.07	0.30±0.04	0.23±0.02	0.23±0.03
Root dry wt (g)	S	0.26±0.03	0.16±0.03	0.19±0.02	0.17±0.02	0.13±0.02	0.11±0.01
	W	0.29±0.04	0.28±0.03	0.30±0.03	0.29±0.03	0.19±0.02	0.22±0.03
Final – initial fresh wt (g)	S	1.45±0.21	0.140.05	0.23±0.08	0.27±0.14	0.19±0.14	0.10±0.03
	W	1.32±0.04	0.93±0.03	0.92±0.17	0.53±0.11	0.36±0.06	0.29±0.09
Final – initial tiller number	S	1.87±0.50	0.67±0.67	0.13±0.09	0	0.13±0.13	0.07±0.07
	W	1.73±0.31	1.06±0.55	1.34±0.48	0.34±0.16	0.07±0.07	0.27±0.15

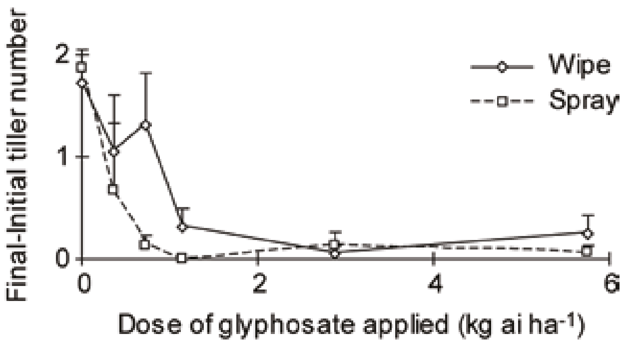


Figure 7. Effect of increasing dose of glyphosate applied by spraying or weed wiping on the difference in tiller number in Molinia. Mean numbers (±SE, n=15) are presented (abstracted from Milligan et al. (2003b).

Field tests using glyphosate

In July 1996 glyphosate (Roundup) was also applied to an area of 'white' moorland at Ramsgill Bents, North Yorkshire using both the Rotowiper (as detailed previously) and a knapsack sprayer at application rates equivalent to 0.54 and 1.08 kg ai ha^{-1} (low and high respectively). Four weeks after treatment in 1996 the percentage of live *Molinia* cover (%) was assessed in wiped and untreated plots. No significant differences were found between the wiped plots and the untreated plots (mean *Molinia* cover for control plots (±SE) = 73.22±2.75, glyphosate-wiped plots at high-dose = 54.50±1.30, low-dose = 60.50±2.30, P=0.18) and no significant difference was found between the high and low doses used (P=0.28). On return in 1997, no significant differences were recorded (mean cover on control plots 58.21±1.12, plots treated with low doses of glyphosate = 52.51±1.63, high doses = 53.65±2.96).

Testing the effectiveness of integrated control/ restoration methods on *Molinia*-dominated land

In an attempt to develop management strategies to control *Molinia* and restore *Calluna* moorland, here weed control and restoration treatments were combined into an Integrated Land Management Strategy to provide a more sympathetic approach than previous prescriptions. The following treatments were applied in factorial combination to a *Molinia*-dominated moorland in the Yorkshire Dales: grazing (ESA prescription level *versus* no grazing), cutting (0, 1, 2 & 3 cuts), ± graminicide application and ±*Calluna* brash addition. The response of the vegetation was assessed for four years. These data were analysed using a combination of univariate and multivariate analysis of variance based on constrained ordinations but combined with bivariate standard deviational ellipses.

The only treatment that had consistent effects in the univariate analysis of variance was cutting, where there was increased bare ground, reduced vegetation height, increased species diversity and reduced *Molinia* cover. Cutting three times had the greatest effect, maintaining a reduced *Molinia* cover until the fourth year (Figure 8). The multivariate analysis showed that there were important community-level interactions, but these are complex but they are fully discussed in Milligan *et al.* (2004). Grazing generally produced vegetation which had a greater moorland species complement. Where grazing was restricted the vegetation had a greater component of *Molinia* and other acid grassland species. The most effective treatment was the grazed plots, cut thrice, which maintained a low *Molinia* cover for longest and had less variation in moorland species into the fourth year. Graminicide and brash application had marginal effects on species composition, but the best plots were those given herbicide alone, or in combination with brash addition.

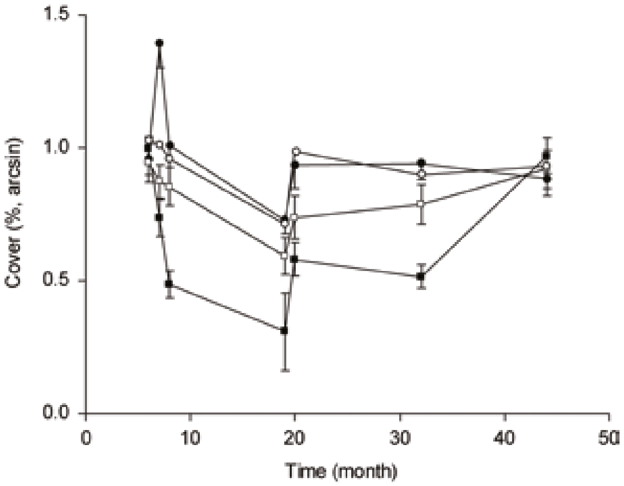


Figure 8. Effects of cutting once, twice or thrice compared to uncut controls on Molinia cover at Ramsgill Bents over a four year period; mean values ± SE are presented of arcsin transformed data.
Key:
uncut = ○
cut x1 = ●
cut x2 = □
cut x3 = ■
(abstracted from Milligan et al., 2004).

These results contrast with other studies, where non-selective herbicide treatment and *Calluna* addition were required to obtain *Molinia* control and *Calluna* regeneration. However, great variation has been found between sites, and managers should be prepared to tailor Integrated Land Management Strategies for their own site. This is likely to require a good knowledge of the initial floristic composition, seed banks and experimentation.

Towards an integrated land management approach

The scientific work detailed here is only part of the story; it has been augmented by a huge amount of practical research and development by land managers particularly Geoff Eyre. Taking scientific work and the practical approaches together, the authors suggest the following:

‘White’ moorland, land dominated by *Molinia*

Here a four-fold approach should be used:

a. **Reduce the *Molinia* cover.** This can be done in two ways either mechanically or using a herbicide/burning strategy. With cutting (Figure 9c), either three cuts of a standard agricultural cutter are suggested, or once with a heavy-duty “jungle-buster”; the aim is to smash up the tussocks and leave a good seed bed for the establishment of other species. With the herbicide/burning strategy experience suggests that the high rate of glyphosate (6 litres Roundup/ha) in mid-summer (July-August) gives good initial knockdown. Thereafter, it is important to remove the resultant dry thatch by summer-prescribed burning preferably in late-August to end of September. This requires an out-of-season burning licence, but burning at this time has the benefit that the sprayed areas is usually very dry and burns easily while the surrounds are much wetter making it is easier to control the fire.

Figure 9. Examples of large-scale techniques used to increase Calluna cover on land previously dominated by Molinia (a-c) and the end result being managed by prescribed burning (d) (Photos G. Eyre MSc).

b. From a practical point of view the spray/burn approach is much quicker and cheaper to implement (Fig 9b); with spraying you can easily spray 40 ha (100 acres) per day at between £74-£124 per ha (£30 - £50 per acre). With cutting it depends on the number of cuts and the equipment available, clearly the first cut will take most effort but subsequent cuts will require less effort. Three cuts with a standard cutter 100hp tractor usually averages around 0.40 ha (1.0 acres) per day (0.30ha (0.75 acres) for the first cut, 0.40ha (1 acre) the second cut, 0.61 ha (1.5 acres) third cut) so it actually totals 3.25 acres per treatment; the cost of a tractor for 19.5 hrs cutting @ £40 per hour = £780 per ha (£316 per acre). Two cuts with a heavier duty tractor (150+ Hp) with heavy-duty flail does 0.30 ha (0.75 acres) first cut, 0.50 ha (1.25 acres) second cut, or 0.91 ha (2.25 acres) per day taking 10.5 hrs @ £65 per hour = £683 per ha (£276 per acre). One negative consequence is that the cutting procedure can compact the peat and encourage rush growth that has to be weed-wiped later at additional cost!

c. **Seeding with an appropriate seed mixture**. In the early days on *Molinia* control only *Calluna* was used, usually by the addition of cut brash from an adjacent moorland. Now, there is the potential to spray or spread harvested seed from a range of species and locations (Figure 9c,d), as well as having the option to include *Sphagnum* L. species. This can be done at any time of year but experience shows that the period between December and April gives good results.

d. **Sheep grazing should be controlled** for a period of two years – this allows developing seedlings to become established.

e. **Monitor the response and adapt the management.** If the *Molinia* is increasing again and affecting the establishment of other species spray with an appropriate graminicide to keep it in check. Either Pilot or Laser can be used here. Graminicide choice may of course vary depending on the species to be controlled.

'Grey' moorland, land with mixed Molinia/dwarf-shrub heath cover

Here it is more difficult but there are at least three options:

a. **Spray the vegetation with a graminicide.** This will reduce the *Molinia* somewhat at least in the short term allowing other species to increase. It must be accepted that any one-off treatment will at best give two years suppression. If glyphosate is used in place of graminicides there will be damage to the dwarf-shrub heath. Overall spraying and reduced grazing plus the addition of extra required seed/*Sphagnum* can also provide good results.

b. **Weed-wipe the vegetation with glyphosate.** This will also reduce the *Molinia* but could also affect some other species, especially if the non-target species are tall.

Figure 10. Examples of Calluna moorland restoration on land previously dominated by Molinia (Photos G. Eyre MSc).

(a) Dense Molinia

(b) Before (left) and after treatment (right) – what can be achieved)

(c) Moorland vegetation restored on dense Molinia

(d) Moorland vegetation restored on dense Molinia

Overview

The decision whether to control *Molinia* or not is a strategic management decision made for any given moor. Assuming that the decision is to control *Molinia* and restore some other vegetation type then it is suggested that focussed management be implemented as suggested here – think big and get stuck in (Figures 9 & 10).

We thank Defra for funding much of the scientific work and the following for planning and executing the lab and field work: Dr Anna Milligan, Dr Pam Todd and Penny Anderson Associates, supervisors – John Phillips and Dr Phil Putwain, and assistance with data analysis – Dr Emma Cox, Dr Jamshid Ghorbani and Dr Mike Le Duc. Suzanne Yee redrew the figures.

Notes

[1]Active ingredient

[2]An **all-terrain vehicle** (**ATV**), also known as a **quad**, **quad bike**, **three-wheeler**, **four-wheeler**, or **quadricycle** is defined by the American National Standards Institute (ANSI) as a vehicle that travels on low-pressure tires, with a seat that is straddled by the operator, along with handlebars for steering control. As the name implies, it is designed to handle a wider variety of terrain than most other vehicles. Although it is a street-legal vehicle in some countries, it is not street-legal within most states and provinces of Australia, the United States or Canada. (*Source: Wikipedia*)

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Molinia reversion on Derwent & Howden Moor: Looking at the techniques and results of restoring *Molinia*-dominated blanket bog and dry heath

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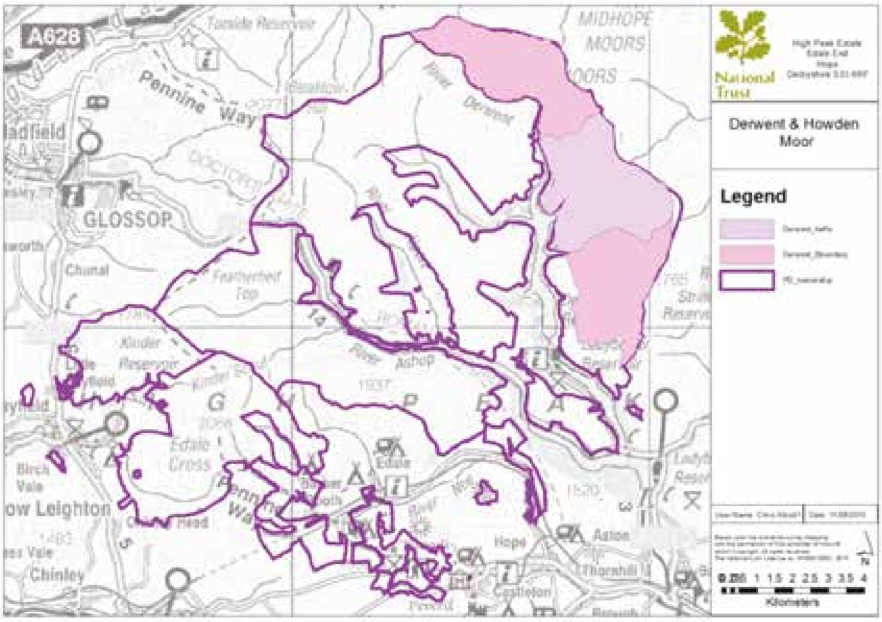


Figure 1. Location of the National Trust property at Derwent and Howden Moor

Background

This presentation and report are based on work conducted by Geoff Eyre and The National Trust on Derwent and Howden Moors between 1989 and 2000. This work was documented by Penny Anderson Associates Ltd in 2000 when an assessment was made on the effectiveness of the different techniques used. For a full account see PAA (2001).

Site History

The Kinder Scout and Bleaklow part of the Peak District National Park is within visiting distance of millions of people in the north of England and is used by many of them for informal recreation. A substantial part of it (10000ha) is owned by the National Trust and is a Site of Special Scientific Interest (SSSI), Special Area of Conservation (SAC) and Special Protection Area (SPA). Part of it, known as the Upper and Nether Heys, Derwent and Howden Moor (Figure 1), has been owned by the National Trust since 1952.

As is shown in the following illustrations, much of the study area is covered by dense tussocky Purple Moor-grass *Molinia caerulea*, subsequently referred to as '*Molinia*'. It has not always been this way; old maps show that in 1912 (Moss, 1913), much of it was dominated by Hare's-tail Cotton-grass *Eriophorum vaginatum*, and that heather, acid grassland with Mat-Grass *Nardus stricta* and even scrub were also common (Figure 2).

The moorland was managed for Red Grouse *Lagopus lagopus* until about 1930. Grazing intensity increased from 1940 and there was frequent burning to improve palatability and early growth for sheep and it is thought that *Molinia* dominance emerged between then and the early 1980s. Annual spring burning stopped in 1984 but the sheep stocking rate remained high until the Environmentally Sensitive Areas Scheme (ESA) began in the early 1990s. The light-coloured unbroken cover of *Molinia* is clear on Figure 3, an aerial photograph dated 1983. Polygons have been traced on Figure 4, a 1991 aerial photograph, showing the extent of dominant *Molinia*, though some parts are still dominated by *Eriophorum vaginatum*, *Nardus stricta* and Bracken *Pteridium aquilinum*. Approximately 90% of the study area is occupied by *Molinia*.

As is evident from the SPA designation and within the SSSI description, the land is not only important for its plant-dominated habitats. The structure provided by the plants is made use of by internationally important populations of Golden Plover *Pluvialis apricaria* and is locally important for Short-eared Owl *Asio fammeus*, Skylarks *Alauda arvensis* and Meadow Pipits *Anthus pratensis*. Dominant tussocky *Molinia* is not the preferred habitat for these species.

There were early trials of *Molinia* control under the ESA scheme in 1989 and in a restoration project that ran from 1992 to 2000 under the management of The National Trust's tenant Geoff Eyre; it was evaluated by Penny Anderson Associates (PAA) in 2000.

What led to the *Molinia* dominance?

A combination of old surveys and aerial photographs (Figures 1-4) show that the cover and extent of *Molinia* did increase between 1912 and the 1980s. The change can be tentatively attributed to what is known to have occurred, which is regular burning of the vegetation and the introduction of an increasing number of grazing animals. While these could be responsible, it is also important to consider that additional drainage may have occurred, rainfall patterns may have changed, and above critical loads of nitrogen and sulphur compounds have been deposited on the south Pennines, exacerbated in terms of quantity by its precipitation in the higher rainfall experienced in the uplands.

Managing the *Molinia*

In 1989 the ESA was launched by MAFF. The scheme for the South Pennine moors aimed to "create a mixed moorland vegetation which is of benefit to wildlife and biodiversity, enhances the carrying capacity for sheep grazing and for grouse, provides access for recreation and is attractive in appearance". One of the main objectives was to reverse the decline in heather cover by reducing winter stocking and providing funding to restore 1% per year over the 10 years of the scheme.

Figure 2. Derwent and Howden Moor and surrounding area, 1912 (Moss, 1913)

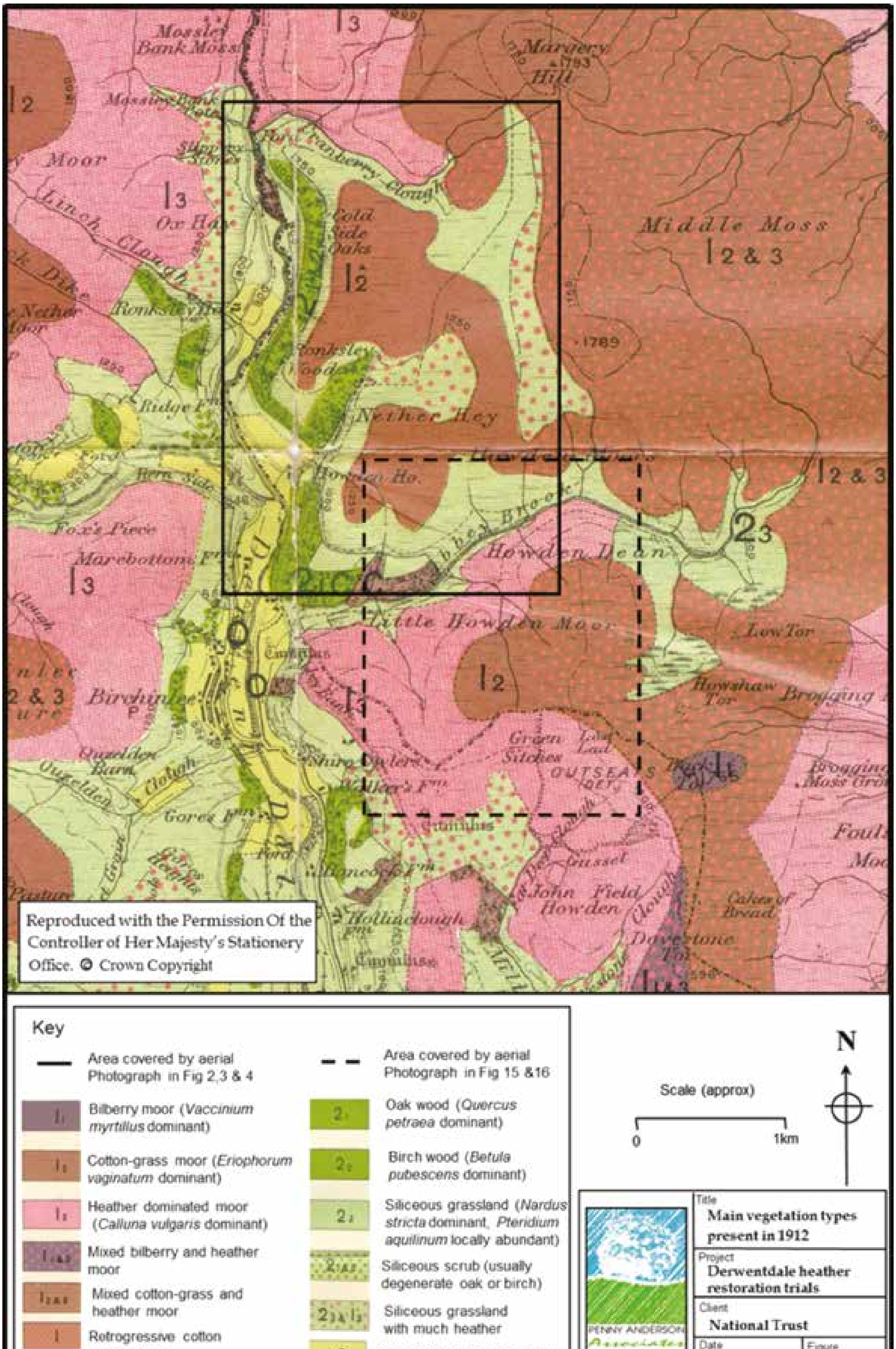
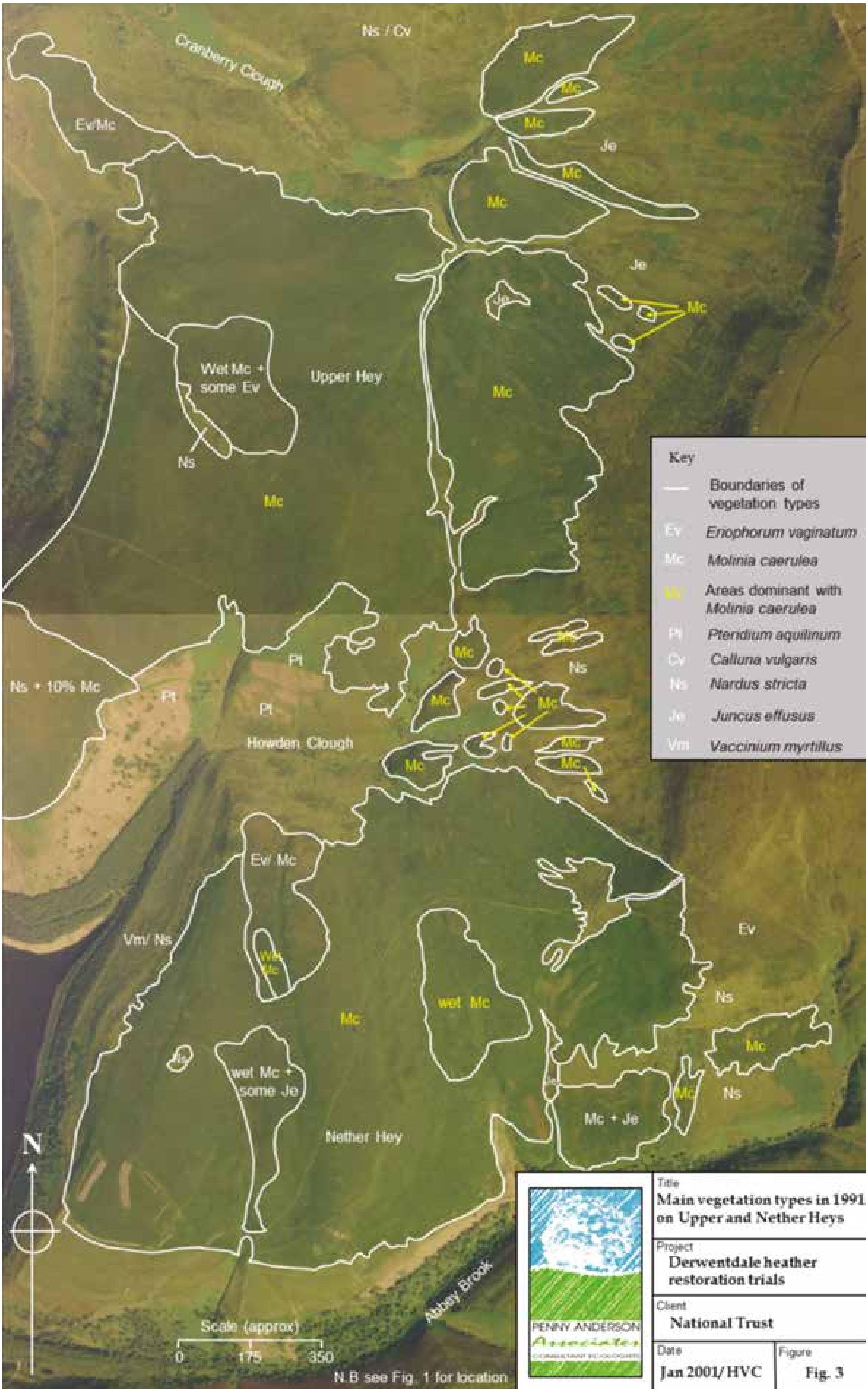


Figure 3. Aerial photograph of Derwent and Howden Moor 1983, Molinia is the lighter coloured areas of the moor top.

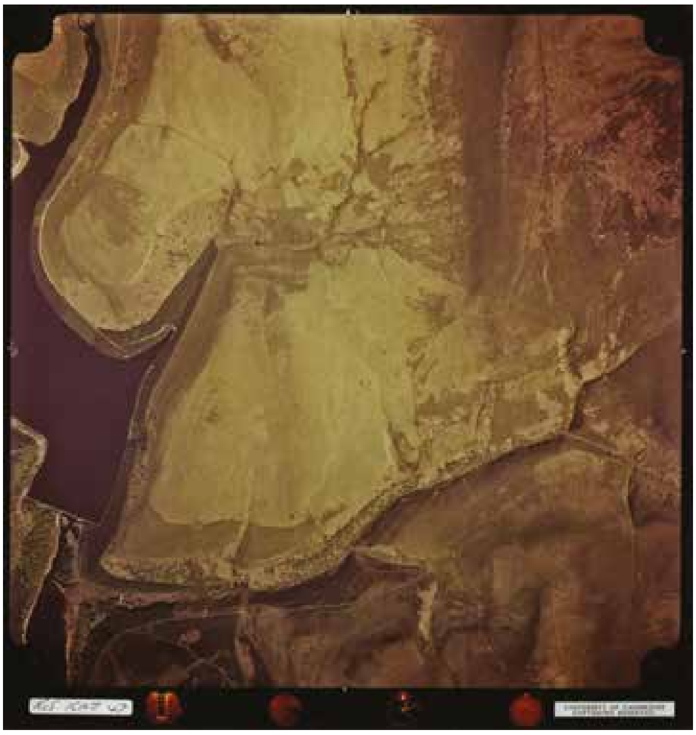


In 1989 the first trials began looking into how this could be achieved. Initially the first investigations on Upper and Nether Heys were undertaken by The National Trust. The first step in the restoration programme was to investigate the seed bank. The National Trust took samples in 1988-9 from near Cogman Clough and Abbey Bank, but no heather seedlings established. Following this a scarifier (a Glentanner) was used to turn over the turf, but again no heather seed established from these trials at various depths suggesting that the amount of viable heather seed left in the soil was so low that natural regeneration would not be successful. The priority, therefore, was to remove the *Molinia* tussocks along with the accumulation of dead litter that blanketed the soil surface, to provide a suitable surface for seed establishment when added.

Following these early trials a partnership project was developed between English Nature and the three ESA beneficiaries (National Trust, Geoff Eyre (Shoot tenant) and Peter Fryer (Grazing tenant). In 1994 the Upper & Nether Hey restoration Project began which saw common agricultural techniques successfully applied to moorland restoration in an attempt to replace the *Molinia* dominant vegetation with heather-dominated dwarf-shrub heath.

The main period of large-scale restoration began in 1994 and ran over a 6-year period. The work was undertaken by Geoff Eyre, hired contractors and National Trust estate workers. The main methods used included cutting, herbicide application, burning, adding heather seed and reducing and manipulating the grazing. Areas for different treatments were selected primarily for ease of access and to avoid wet areas. Trials were based on Geoff Eyre's earlier experience of these same restoration goals in controlling tussocky *Molinia* vegetation on High Moor near Macclesfield Forest (Anderson *et al.*, 1997).

Figure 4. Derwent and Howden moor in 1991, an aerial photograph on which the dominant plant species have been mapped.



In all, 40 treatment plots were selected and subjected to a variety of different treatment combinations which varied in the number of cuts, amount of herbicide applied, method and number of herbicide applications, quantity and method of heather seeding and treatment of seeds, duration and presence of grazing and burning practice. Helicopter hydroseeding was also used on drier, steeper slopes.

The principal restoration techniques set out to provide a suitable seed bed for heather establishment, break the dormancy of heather seed, identify suitable seed application techniques and manipulate grazing so that heather could successfully re-colonise.

The dominance of *Molinia* was broken using herbicide application (glyphosate & other graminicides) or repeated cutting. This was followed on some sites by burning to destroy the dense thatch of dead litter left behind. After the successful establishment of a suitable seed bed, heather seed was spread using a variety of methods which included trials into breaking its dormancy using combinations of smoke and chemicals. Both treated and untreated seed was used and seed was repeatedly spread between 1995 and 1999 thus giving a back-up for successful germination over a period of years. Grazing was managed by either fenced or unfenced plots and untreated areas were used as control plots to see the effect of the treatments.

Evaluation

The trials ended in 2000 at which point Penny Anderson Associates Ltd were asked to evaluate the success of the different treatments. Thirty 0.1m^2 random quadrats were recorded per plot for 18 plots during August 2000. Both number of species and percentage cover were recorded. Mosses and lichens were also recorded as were presence and percentage cover of litter and bare ground. In addition general conditions including structure and height of vegetation were recorded. Some statistical analysis was attempted although this was limited mainly to changes in species composition between treatments.

Effectiveness & end results

It was clear from the control plots (both grazed and ungrazed) that the "Do Nothing" option resulted in *Molinia* remaining the dominant species and that adding seed only resulted in very few new heather plants. The most successful new establishment came from the combination of pre-treated and untreated seed, still effective even at seed rates as low as 17.3kg/ha. Excluding sheep from plots proved essential to successful heather establishment during the trials but it was acknowledged that reduced stocking rates and careful shepherding might also have the potential to secure similar results. Helicopter seeding on steeper slopes was not very effective but this was likely due to the effects of grazing.

The most efficient treatment was to apply glyphosate in August and burn off litter in the following March, at the same time as excluding sheep. However this might not always be the most appropriate technique, especially close to water courses and sensitive areas. Glyphosate application did not seem to adversely affect the establishment of vegetation whereas other graminicides, although effective, were not suitable because they were not approved for use on moorlands and were expensive.

Breeding bird surveys conducted in 1993 recorded Short-eared Owl and Golden Plover using the site. A repeat survey in 1997 found Merlin (*Falco columbarius*), Lapwing (*Vanellus vanellus*) (possibly 4 pairs), Curlew, Grey Partridge (*Perdix perdix*), Red Grouse, and many skylarks, as well as short-eared owls and golden plovers. A further survey in 1999 found a similar assemblage including meadow pippits, Red Grouse, and an increase in Curlew and short eared owls. Mountain Hare numbers were also seen to increase. This improvement in wildlife was attributed to the changes in vegetation structure, the increased range of plants supporting an enhanced invertebrate biodiversity, and the improved accessibility of the vegetation.

Lessons learnt

The trials favoured heather which was part of the ESA prescription to bring heather-dominant vegetation back to the moors. Later work after the main trials (into the 2000s) did include other dwarf-shrubs (Bell Heather *Erica cinerea*) and also *Sphagnum* species although this work has not been well-documented (Geoff Eyre, pers. comm.). The current condition over much of the original treatment area now resembles dwarf-shrub heath where there is shallow or deeper peat.

Stock exclusion proved to be vital in successful seedling establishment and the conclusions reached were that fenced plots should have been established at the start rather than as a reaction to damage from grazing. Grazing exclusion continued until the end of the ESA scheme in 2012.

Other potential grazing regimes were ignored during these trials. Cattle grazing, mixed with sheep, has been shown to have positive effects on the control of *Molinia* and also helps to establish and maintain a more varied vegetation structure and diversity than just sheep alone (Upland Grazing Project, Evans *et al*, 2015).

PAA (2001) also acknowledged the need to apply more structured and scientific approach to this type of trial in order to determine the complex interrelations between different treatment types. Long term monitoring of the outcomes of the trials is also something that was neglected after the trials, potentially losing important information about how the restored vegetation has developed and the impact on wildlife.

Current & Future management

The ESA scheme ended in 2012 and in 2013 The National Trust entered into a new Higher Level Stewardship agreement (HLS) for a ten year period. At the same time the Trust also launched the High Peak Moors Vision and Plan, a 50 year initiative which aims to be a model for future upland moorland and moorland fringe management that delivers excellent landscape scale conservation and restoration; is rich in wildlife and cultural heritage; and provides excellent access, sustainable livelihoods and wider public benefits. Management of the area will be based on constructive, forward looking partnerships with tenants, communities, organisations and users.

Geoff Eyre remains the shooting tenant, and the management of Old House Farm is currently in-house with The National Trust. The priority for Derwent and Howden Moors is to increase diversity of blanket bog vegetation, dwarf-shrubs and *Sphagnum* wherever possible. The Trust is currently managing the upper and Nether Heys with a combination of cattle and sheep grazing and is keen to establish cutting as an alternative to traditional burning. In tandem with this the Trust is also developing a management plan with clear targets and measurable milestones which will be subject to long term monitoring.

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Cutting *Molinia* to improve habitat for Golden Plover, Abergwesyn Common Sharing experience: An account of management techniques used and a critique of their usefulness

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Introduction

Abergwesyn is located in the middle of Wales in an area known as the Elenydd, sometimes referred to as the Roof of Wales with spectacular far-reaching views, but it is remote with uninterrupted access and difficult terrain (Figure 1). The National Trust (NT) acquired the Abergwesyn Commons in 1984 from ESJ and WN Legge-Bourke, Glan Usk Estate. It was bought to protect this upland area from afforestation and at that time to continue allowing public access, a key part of the benefit to the nation. The property now represents a major resource for biodiversity and archaeology, carbon storage, water (quality and retention). It comprises 6,677.44 hectares (16,500 acres) of upland moorland, lying between 250 - 641 m above sea level and extends westwards for 12 miles, from just south of Rhayader to the Irfon Valley adjacent to the Tywi Forest and Llyn Brianne Reservoir. All the holding is common land and grazed mainly by sheep, but with some ponies and cattle. It is one of the largest commons in central Wales situated in the heart of the Cambrian Mountains and represents *circa* 12% of the total NT ownership in Wales and almost 3% of all land in NT ownership in the UK.

Figure 1. Location map showing Abergwesyn Common. Source: the National Trust

As with most upland sites Abergwesyn is important for archaeology including Bronze Age ritual sites and many early medieval features such as deserted villages plus some modern features. There are 866 archaeological features recorded, many of which are Scheduled Ancient Monuments (SAMs).

Abergwesyn Commons

Figure 2 shows Drygyrn Fawr, on Abergwesyn Hill, the highest point at around 640 metres and the focus of this presentation. The picture illustrates the *Molinia*-dominated habitat frequent across this common. Below Drygarn Fawr is the Gwesyn Valley which is quiet and remote and which gives this common its name.

Figure 2. Aerial view of Abergwesyn Common

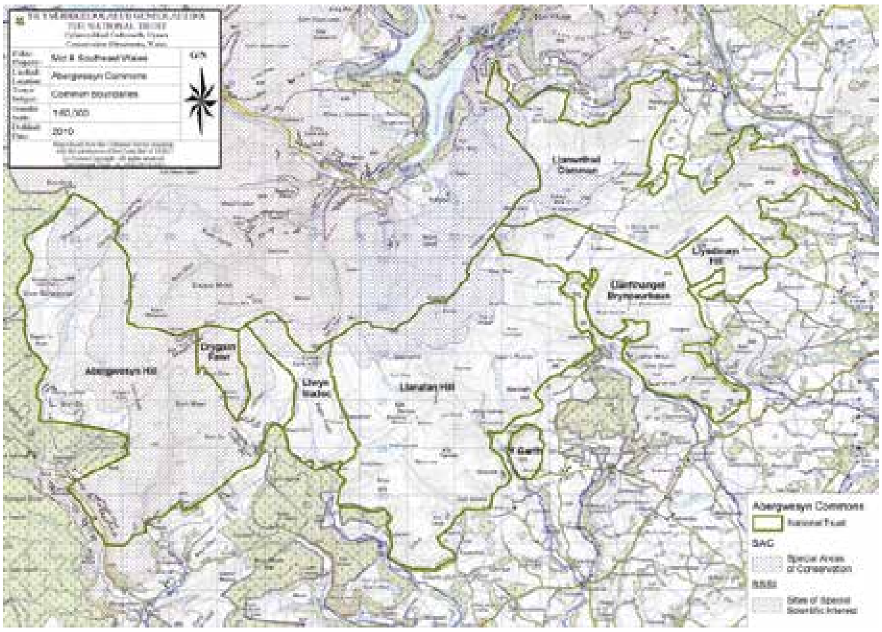


Figure 3. Map showing the boundaries of Abergwesyn Commons

Overall this property comprises a group of eight contiguous blocks of common land (Figure 3). There are historic rights to graze livestock (sheep, cattle, ponies), to collect bracken, peat and sometimes firewood. Abergwesyn has high nature conservation value, with bogs, flushes and birds. In the west much of the commons fall within the Elenydd/Mallaen Site of Special Scientific Interest (SSSI) and most of this includes the Special Protection Area (SPA) for upland birds including breeding Golden Plover *Pluvialis apricaria*. In the centre a small area falls within the Special Area of Conservation (SAC), designated for its blanket bog.

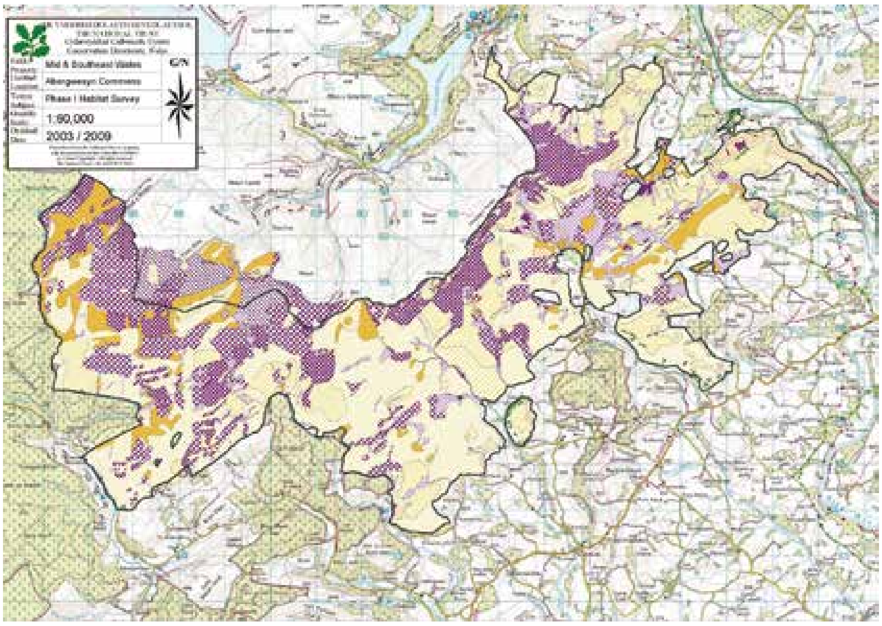


Figure 4. Phase 1 habitats on the Abergwesyn Commons. The map shows the key habitat types. The purple areas broadly cover wet to dry modified blanket bog in the centre and west where Molinia dominant. The total area of peat based soil is around 2000 ha. However, it's not all Molinia-dominated blanket bog, there are valley mires consisting around 1000 ha; acid grassland approx. 2100 ha; dry heathland approx. 1000 ha and many wet flushes.

There are approximately 248 graziers/commoners with access to the whole area with rights to graze up to 8000 Welsh mountain ewes, some cattle and ponies. When the National Trust bought the site in the 1980s there were about 130 active graziers. Now there are only 30 to 40 active graziers across the whole group. Figure 4 shows the key habitat types.

Recent activity

The Abergwesyn Project ran from 2009 to 2012 and was a local partnership project under the umbrella of a wider NT and Biffa-funded[1] project, "Peatlands for the Future", which included four NT sites, Abergwesyn being the only one in Wales at that time. Funding was used to carry out various land management trials. A Project Officer was employed to help deliver the key tasks and build better relationships with commoners. In summary the project:

- implemented a cattle grazing trial;
- supported biological monitoring and survey of peat areas;
- supported *Molinia* cutting and working with RSPB to provide habitat for Golden Plover;
- provided protection for the bare peat.

A cattle grazing trial was established to start the restoration of blanket bog by opening up dense vegetation and reducing the dominance of *Molinia*. Poaching is known to open up the soil and allow seed germination. A number of graziers were approached and one came forward on Abergwesyn Hill, who was keen to participate. The Biffa Funding was used to buy six cattle, for which the grazier then became the registered owner and keeper; he bought three more at the end of May 2010. They were put out onto the *Molinia* by the end of June until October-November. The herd increased to twelve plus a bull in second season (2011). Although the initial plan was to create a breeding herd, it only continued for two seasons (2010-2011) after which the grazier decided it was too difficult to manage the stock over winter.

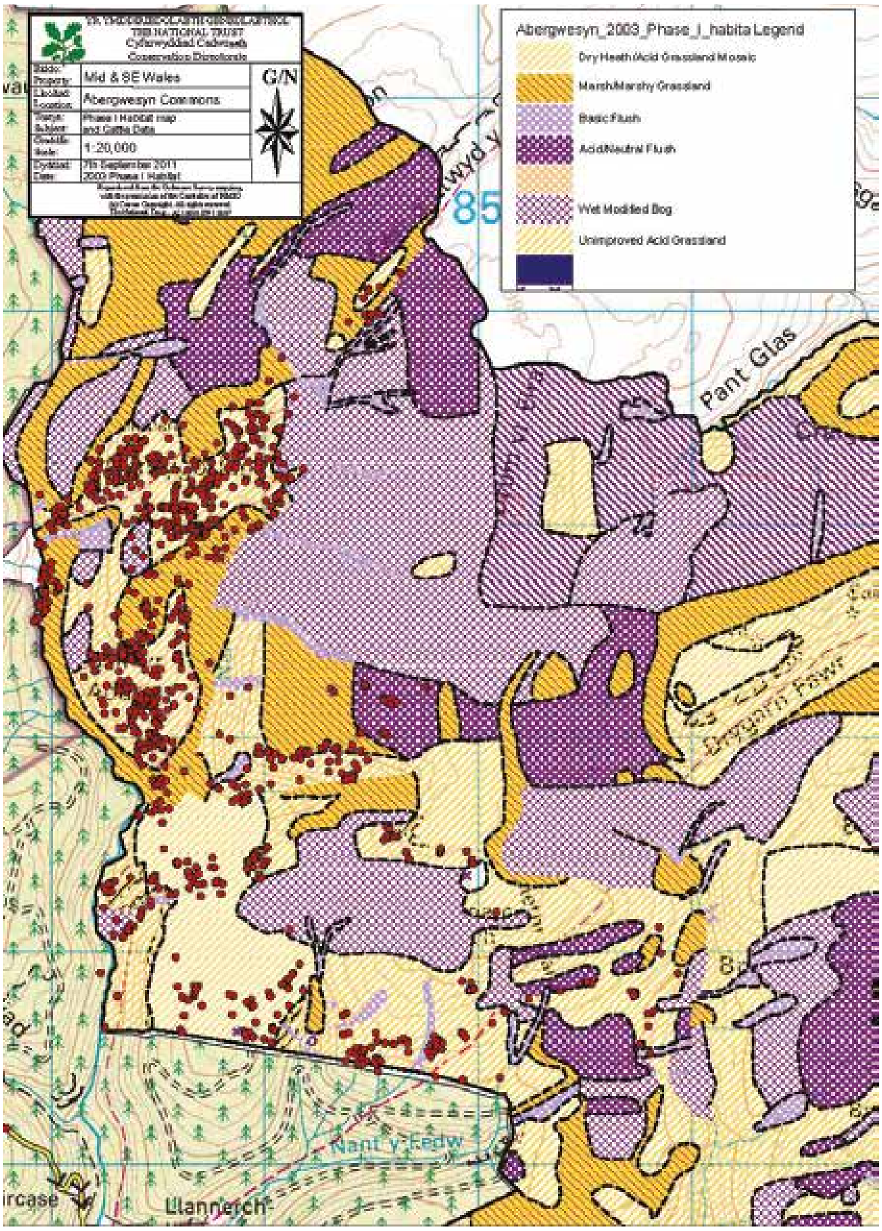


Figure 5. Point data (red circles) to show where cattle were tracked in the Biffa-Award grazing trials on Abergwesyn Commons over the summer grazing period of 2011.

GPS collars were fitted to 5 of the 12 cows in the second season. This gave point data of cattle locations over the summer grazing period in 2011 (Figure 5). The project demonstrated that it is possible to turn cattle out on to large tracts of unfenced land. They did not die or just wander off as a number of local farmers had feared. However, the cattle did tend to graze the drier acid grassland in the sheltered areas, and some of this was *Molinia*- dominated. Ideally, ways to encourage the herd onto the wetter blanket bog areas should have been explored, but the trial was not long enough to measure any benefit for bog restoration. It was noted that it would be expensive if using this approach over a bigger area. In this trial, taking into account cattle purchase, winter B&B costs, feed, haulage, mineral supplements, vet and medicinal costs and shepherding the average cost per cow was £660 per annum. The stock husbandry climate has become even more complex since the trial, with TB controls for example, and the economics of keeping cattle do not improve for the farmer.

Cutting *Molinia*

Amongst other reasons, this is done to control wildfires. Abergwesyn had been prone to large grass fires particularly in the period 2000-2008. They usually occurred in the late spring which was the worst possible timing for ground nesting birds. Some fires have allegedly been started by graziers though they are by no means the only potential instigators. Cutting fire breaks was adopted as a way to control the spread and minimise the impact of wildfire. Figure 6 shows the extent of the fire in spring 2010, when it is last known to have occurred.

Figure 6. Effect of unplanned fires on Abergwesyn Commons. This most recent fire took place in Spring 2010.

Cutting firebreaks to control wildfires has not been successful. In the spring 2010 following the first cutting there was a large fire and although the cutting helped reduce impact of fire it did not create an effective barrier.

Many practitioners will be familiar with using heather brash and mulching as a way to protect bare peat. Cut *Molinia* is a readily available material for mulching bare peat areas and some successful bare peat protection using *Molinia* mulch has been carried out on the NT tenanted holding, Y Gyrn, Blaenglyn Farm, in around 2007. This mulch was spread at a depth of around 5-10 cm. Bare peat erosion on Abergwesyn Commons is not extensive but confined to specific areas but is sufficiently serious in those areas to warrant remediation. Trials would ideally have taken place on around 5-10 ha on the largest area of erosion at Cnapiau'r Ferlen about 5-10 hectares (Figure 7) but it was beyond the available budget at the time. Consequently the work took place on one area on the watershed between NT-owned and Elan Valley Estate land at Cerrig Llwyd y Rhestr on Abergwesyn Hill Common, which was around one hectare in size and fitted in with other trials involving the cutting the vegetation. The material was air-lifted from the source to the trial site, and spread up to 15cm deep. Figures 8a & 8b show the bare peat before and after mulching with cut *Molinia*.

Figure 7. Heavily-eroded but untreated erosion at Cnapiau'r Ferlen.

Figure 8. Molinia mulching on the watershed between NT-owned and Elan Valley Estate land at Cerrig Llwyd y Rhestr on Abergwesyn Hill Common. a) Bare peat before application of mulch; b) Mulch spread at a depth of around 5-10 cm.

Improving habitat for Golder Plover

Although the *Molinia*-cutting was initially undertaken to create fire breaks that had little impact on restricting the spread of fires, using the cut *Molinia* for mulching bare peat was successful. It provided a physical protective layer against wind and water erosion and peat oxidation, providing a favourable layer for vegetation establishment. This has lead over time to a cover of moss, grass, rush and other heathland species. The adjoining bare peat areas are still largely devoid of vegetation. Fortuitously, the cutting trials were identified by the Royal Society for the Protection of Birds (RSPB) as having a role in their work to improve upland habitat for birds, including Golden Plover. Initially carried out to assist in the revegetation of degraded blanket mire, improvement of habitat for Golden Plover provided an additional reason for cutting. The focus for further work was shifted to the core population area for Golden Plover on Abergwesyn Hill Common.

To establish the impact of cutting (an activity that would hopefully modify the blanket bog vegetation structure) transects were set up to record Golden Plover breeding behaviour. The RSPB carried out the monitoring and survey work in 2011 and 2012. Latterly the survey has been completed by a freelance ornithologist funded by NT and the Elan Valley Trust. At the same as work was being carried out on NT land on Abergwesyn Hill Common, the Elan Valley Trust were using funding from the then Countryside Council for Wales (CCW) to carry out similar trials on a site at Trumau, on their own holding, another core breeding area for Golden Plover. The results for all sites are provided in Table 1.

Table 1a. Breeding success of Golden Plover on Molinia-cutting sites at a) Abergwesyn and b) Trumau

Site	Visit no.	Date	Golden Plover record	Grid Ref.	On or adjacent to managed area? Y/N
Abergwesyn	1	20/04/2011	1 pair	SN849598	Y
Abergwesyn	2	02/06/2011	1 pair	SN850598	Y
Abergwesyn	2	02/06/2011	1 pair	SN857598	N
Abergwesyn	1	08/05/2012	1 pair	SN850588	Y
Abergwesyn	1	08/05/2012	1 pair	SN856610	N
Abergwesyn	2	31/05/2012	1 pair	SN850598	Y
Abergwesyn	2	20/06/2012	1 territorial individual	SN850591	Y
Abergwesyn	2	20/06/2012	5 individuals	SN850590	Y
Abergwesyn	1	21/05/2014	Nil	-	-
Abergwesyn	2	19/06/2014	1 male	SN850598	Y
Abergwesyn	1	04/05/2015	Pair	SN849593	Y
Abergwesyn	2	27/05/2015	1 male	SN850592	Y
Abergwesyn	3	18/06/2015	Nil	-	-

Table 1b.

Site	Visit no.	Date	Golden Plover record	Grid Ref.	On or adjacent to managed area? Y/N
Trumau	1	19/04/2011	1 pair	SN866673	Y
Trumau	1	19/04/2011	1 individual	SN871675	N
Trumau	2	03/06/2011	1 pair	SN865672	Y
Trumau	2	03/06/2011	1 pair	SN863671	Y
Trumau	2	03/06/2011	1 pair	SN876656	N
Trumau	1	24/04/2012	1 pair	SN873655	N
Trumau	2	30/05/2012	1 pair	SN862669	Y
Trumau	2	30/05/2012	1 pair	SN860679	N
Trumau	1	26/05/2014	1 pair, prob nest	SN881660	N
	1	26/05/2014	1 pair, + chicks	SN873656	N
Trumau	2	23/06/2014	1 (prob) pair	SN860668	Y

The results from the Abergwesyn survey show that not only do Golden Plovers use the managed areas, but the management appears to have influenced territory selection and have the potential to positively influence breeding success. Indications from the Trumau figures are less clear and it cannot be concluded that cutting management has influenced breeding success of the Golden Plover. Overall, the results suggest that cutting alone is not enough to create suitable habitat conditions for Golden Plover.

Monitoring changes to vegetation following cutting

A rapid vegetation assessment was developed to fit the time available for monitoring, looking at the attributes shown in Table 2. The aim was to assess the effectiveness of cutting *Molinia* to improve blanket mire vegetation and its suitability for Golden Plover at Abergwesyn Hill in July and October 2014. The assessment was taken to show that:

- Cutting on areas of deep level peat has created a vegetation structure attractive to Golden Plover and may help provide a short term fix to halt the decline of this species.
- Cutting has encouraged some positive indicators on the areas of deep peat such as *Sphagnum* mosses, dwarf-shrubs, Cotton-grasses, sundew and sedges. The *Sphagnum* and dwarf-shrubs have a low cover and their expansion in the blanket bog remains vulnerable to dominance by *Molinia*.
- Cutting has reduced the dominance of *Molinia* on some of the areas of deep peat such as Nant yr Rhestir and, overall, cutting has reduced its tussocky structure.

Table 2. Rapid condition assessment method and its attributes.

Sampling unit	Common Standards Monitoring 2x2 m circles
Sample locations	Locations recorded using GPS with 5 to 10 sample circles taken per area depending on the size of the cut area
Vegetation attributes	Visual estimate of % cover of Molinia, Sphagnum, dwarf-shrubs, graminoids (Cotton-grasses, rushes, deer grass and fine leaved grasses), cranberry, bog asphodel, white beaked sedge and sundew. All can be converted to presence absence for comparison with previous monitoring
Vegetation density/height	Average density/height of the vegetation above the peat surface
Physical factors	Peat depth (probing), Slope, Bare ground, Presence of flushes or other
Grazing	Evidence of grazing pressure

Given the costs of using machinery in the remote and difficult terrain of the Cambrian Mountains, cutting cannot be afforded on such a large scale and by itself may not be the long term solution to the problem of *Molinia*-dominated vegetation on blanket mire. However, the outcomes of the experiments at Abergwesyn suggest that it does have a role to play in the targeted conservation of Golden Plover, though it remains to be seen whether this is a long-term improvement. Ideally, cutting should be combined with aftermath grazing, such as by shepherding, and this would better maintain the required structure. There do appear to be short term benefits for blanket mire restoration, though it also remains to be seen how the cut surface develops over time. Further monitoring is essential.

Notes

[1] Biffa Award is a significant part of the Landfill Communities Fund, supporting positive change across the UK. Biffa Award projects make up an eclectic community across the country; with projects ranging in size and scale from a £500 to £1.6 million. (From website, Ed.)

Changes in the grazing regimes on Elenydd Site of Special Scientific Interest and the experimental management of *Molinia caerulea*

Ken Perry, Cyfoeth Naturiol Cymru/Natural Resources Wales

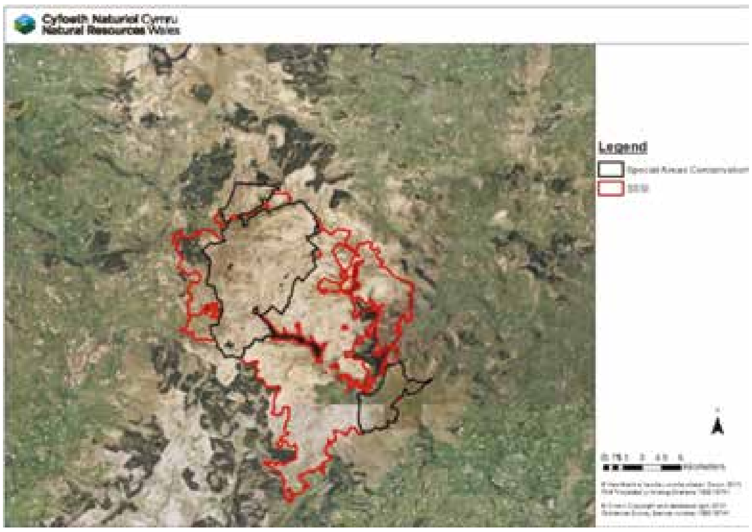
Introduction

This paper describes work carried out on the Elenydd Site of Special Scientific Interest (SSSI) in mid-Wales, United Kingdom. Large areas of blanket bog that should bear plant communities with a mix of sedge, grass, dwarf-shrub and *Sphagnum* moss species, have a cover of dominant tussocky Purple Moor-grass *Molinia caerulea* with few associated plant species. This type of vegetation is not ideal for important moorland birds, such as Golden Plover *Pluvialis apricaria* which, together with the need for a more diverse vegetation type, provides the stimulus for developing management techniques to replace the *Molinia*. Several cutting and grazing trials, and the types of machinery used, are described as well as possible economic uses for *Molinia* litter harvested from the moors.

The Site

The Elenydd SSSI extends to 22,672 ha and the majority of it has an altitudinal range of 300m to 641m and an average rainfall of 1830 mm a year. The boundary of the Elenydd SSSI and the Elenydd Special Area of Conservation (SAC, part) is shown on Figure 1. Good quality blanket bog habitat National Vegetation Classification (NVC) plant communities M18 and M19 is concentrated in the SAC, and most is on the western (wetter) parts of the site. There are extensive areas of *Molinia*-dominated blanket bog, particularly outside of the SAC, including acid grassland on shallower peat, and on thinner peat soils. Very little of it is dominated by either Mat-grass *Nardus stricta* or Moor-rush *Juncus squarrosus*. The abundance of *Molinia* is illustrated by the light colour areas on this aerial image except in the SE where it does not show up as white because this part of the image was acquired during the summer.

Figure 1. Boundary of Elenydd SAC and SSSI



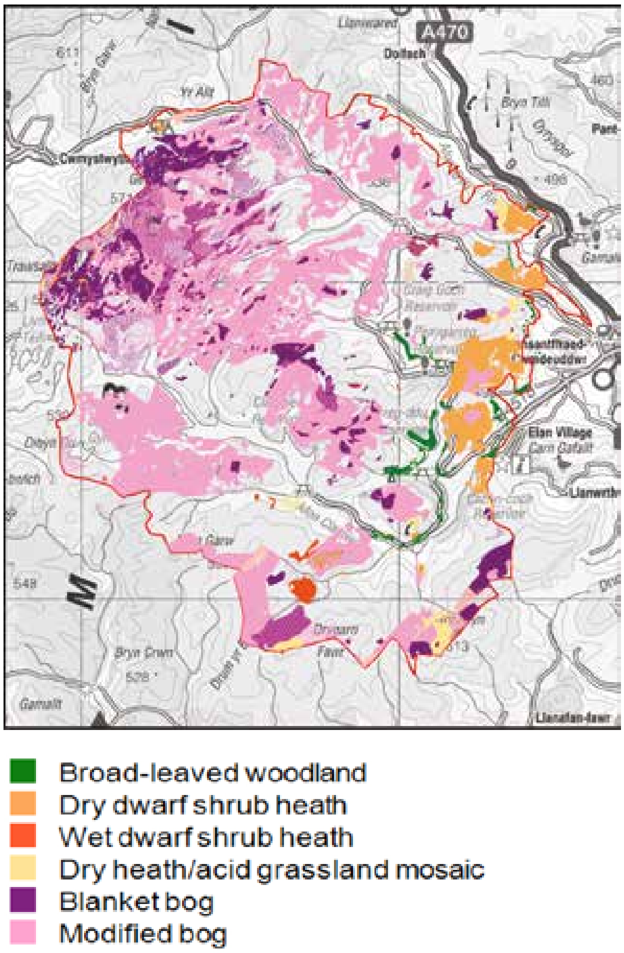


Figure 2. Distribution blanket bog and modified bog on Elenydd

A more detailed map of the Phase 1 habitats from upland and other habitat surveys between 1979 and 1997 is shown in Figure 2, covering land within the catchment of the Elan Valley Reservoirs and managed by the Elan Valley Trust; it includes some land outside the SSSI. The total area of blanket bog habitat within the displayed area is 7957 ha, and the majority of this is modified bog dominated by *Molinia*, and, from another data source, there is an additional 4662 ha of habitat on shallower peat that matches the marshy grassland Phase 1 category (not shown in Figure 2).

Historically, the passing of the Birmingham Corporation Water Act 1892 led to the compulsory purchase of the land within the River Elan and Claerwen Valleys and the construction of five reservoirs. This resulted in the loss of much of the in-bye land that would have provided winter pasturage for the livestock grazed on the moorland in the summer months. The reservoirs are now managed by Dwr Cymru (Welsh Water), although the farmland has been leased to the Elan Valley Trust on a 999 year lease. There is minimal treatment of the water at source, and although there is treatment at the 'end of pipe' the use of herbicides to control bracken, for example, is prohibited and the grazing of cattle within the valley is not actively encouraged. Both of these constraints exclude some of the restoration techniques used elsewhere in the UK to diversify *Molinia*-dominated habitat.

The land is either tenanted or common land and there are no fences between tenancies and the commons because these are prohibited by the 1892 Act, to provide access and presumably to safeguard the water supply. The holdings vary in size, ranging from single parcels of a few hundred hectares and are rented to nearby valley farms, with entire farms extending to over 2700 ha; about 70% of this, the largest farm, is dominated by *Molinia*.

A number of projects have researched the problems associated with *Molinia*-dominated blanket bog (abbreviated to MDB) on Elenydd SSSI and two are of particular importance. One undertook an assessment of peat stratigraphy and concluded that the dominance of *Molinia* was a recent phenomenon (Chambers *et al.* 2001). Another looked at techniques for the restoration of MDB to blanket bog dominated by a mix of species (Anderson *et al.* 2006).

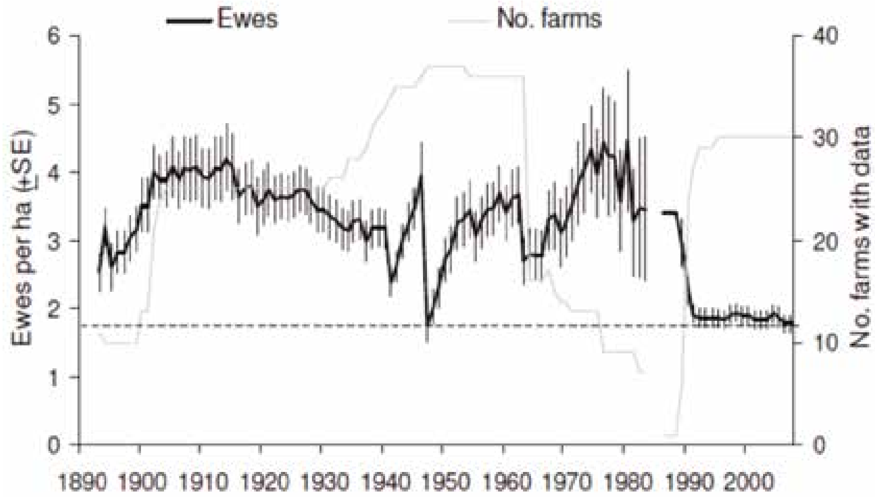
These reports have been followed by various small scale projects in which the National Trust and the Elan Valley Trust look into ways of getting active management of MDB through grant-aid support and applications to various funding streams. NRW has also looked into developing a LIFE[1] project bid to encompass *Molinia*-dominated peatlands across the uplands of Wales and has involved some initial scoping of locations and site conditions and a lot of walking through the *Molinia*-dominated landscape of Elenydd.

It was clear that whilst there may be potential for restoration there were large areas that appear to have been hydrologically damaged by past management and concomitant peat erosion. This erosion is not visible as extensive areas of bare peat, as seen in the Peak District, but large areas are dominated by *Molinia*, at least in part due to the regular burning and higher grazing levels that used to take place. In many areas the erosion has shown that the recovery to wetter peat forming conditions is some way off without additional intervention. However, the reorganisation of Countryside Council Wales (CCW) into Natural Resources Wales in recent times has meant that funding for further experimentation was not immediately available.

Changes in grazing and burning patterns over time

Local records show that in the mid-20th Century significant numbers of cattle were driven to the uplands for the summer, but this has not happened for many decades since well before the SSSI was first re-notified under the Wildlife and Countryside Act 1981 (as amended) in 1986. Whilst there are small number of hill ponies the majority of the grazing has been with Welsh Mountain Ewes, but even before the change from headage to area payment schemes there have been fluctuations on flock numbers, as is shown in Figure 3. This shows marked declines in numbers of ewes, dropping to around or below 2 ewes per hectare since 1990 (<0.05 Livestock Units (LSU) ha^{-1}). These changes have been encouraged by a series of agri-environment schemes, starting with Cambrian Mountains Environmentally Sensitive Area (ESA) agreements from 1986, Tir Gofal (TG) from 2003 and now Glastir since 2014. Some of the earlier ESA agreements were supplemented by agreements with the Nature Conservancy Council and then CCW under SSSI management agreements to pay for additional stock reductions and off-wintering payments.

Figure 3. Site-level variation in sheep density on the Elenydd over 114 years. The sample size for each year is shown on the second y-axis. The dashed line indicates the minimum sheep density for the whole period. Data include parts of holdings that fall outside the common survey area.



Some farms still have a few cattle, but because of water catchment restrictions, poor financial returns on suckler herds, testing for tuberculosis and the need to provide winter housing, few have been willing to contemplate reintroducing them. One or two farms have added small numbers of cattle in the last 10 years and those who have done this within fenced land are pleased with the results; a few more are now showing interest. These developments have been important for helping to provide and maintain suitable breeding habitat for Curlew *Numenius arquata*, which is one of the other important bird species.

Many of the farms have little or no in-bye land to hold stock in the valley when wishing to keep them off the moorland. For many, this would have been lost when the reservoirs were flooded. This means that once stock are on the moorland just before lambing in April or May, they stay there until they are removed in the autumn. Some have solved the problem of winter husbandry by buying lowland farms, but others still rely on paying for winter grazing as far away as Cornwall. There are still some ewes kept on the moorland over the winter in Powys but in reality much of the moorland provides very little quality grazing over winter and early spring and animals kept there require very costly supplementary feed.

There is a history of burning every few years for many parts of the Elenydd SSSI, to produce a fresh flush of spring grass from those areas dominated by *Molinia*. This practice has been effectively stopped since 1992/93 when the SSSI was amended because this is considered damaging to the blanket bog, though there are occasional unconsented fires on some parts of the site. It is possible that the cessation of burning may have contributed to the decline in the breeding population of Golden Plover (*Pluvialis apricaria*). This is because the burning would have removed any taller dead *Molinia* in the more open bog habitat and attracted grazing livestock which would have kept the vegetation shorter and more attractive to the species for breeding and foraging.

Most farms have transferred to Glastir agreements since TG ended in 2013. New prescriptions under Glastir set the maximum (and sometimes minimum) daily grazing rates, whereas previously the stocking rates were set as averages. Farmers have to be far more careful to keep to the terms of the agreement, recording stocking changes in a log book. They are responsible for the records of all stock on their land, which is difficult given that there are no fences on the moorland and some are inclined to stray.

Increased cattle grazing has been recognised elsewhere as a useful tool in *Molinia* control, but there are significant disincentives for the farmer. In addition to the risk of tuberculosis, winter housing, manure and water quality concerns, 30% of the livestock units (LSU) in a parcel need to be cattle to get an extra £12 ha^{-1} payment under Glastir. Given that most open hill land parcels are hundreds of hectares and a large amount of fencing may be needed, it is rarely practical, and the incentive has only been used on one farm on enclosed land with MDB. There are small numbers of mountain ponies, but these are kept for sentimental and cultural rather than economic reasons. The problem is that with no fences farmers are nervous because stock are able move between holdings and some have already received financial penalties for having ponies on their hills that were not in their stock movement records.

Some of the principles determining the shape of the Glastir cattle options as they currently stand are set out below. This is an important factor in the management of the Welsh uplands, which includes the issue of diversifying the dominant *Molinia*, because it is the practical link between hypotheses developed from research and the ability to actually implement the perceived solutions. It is similarly important for farmers because it sets the framework within they can both take up the solution and make it pay, or reject it because they see it as a potential financial loss.

Stocking rates under Glastir

Farmers must have formal consent from NRW to enter into a Glastir contract because it involves so-called Notifiable Operations within the SSSI legislation. Two different approaches underpin the requirements. Most of the good quality blanket bog is located in the west but it contains significant areas of MDB. For this, NRW prescribes a standard stocking rate for all applicants: a maximum of 0.1 LSU ha^{-1} from 1 April to 30 September followed by total stock removal in winter. Higher stocking rates could have been permitted in summer if farmers had been willing to introduce more cattle but there were no financial incentives to do this and the disincentives described above meant that no-one wanted to take it up. These lower rates were designed to encourage recovery of the ericaceous shrub cover in dry heath and blanket bog habitat (SAC/SSSI interest features). This is based the presumption that higher levels of sheep grazing on MDB would prevent this recovery because they would preferentially graze off any shrubs when *Molinia* provides no grazing in winter. This takes into account observations of what has happened on some areas of upland on two other nearby SSSI where there has been no sheep grazing or no winter grazing (K. Heppingstall, pers. comm.).

Table 1. Examples of changes in stocking levels in LSU/ha or number of sheep on Elenydd SSSI to show variation in stocking patterns between different land parcels.

Farm	Parcel type	1990	ESA		Tir Gofal (Average)		Glastir*		% summer change since 1990
		Summer	Summer	Winter	Summer	Winter	Summer	Winter	
A	Enclosed	-	-	-	0.26	0.26	0.4	0.2	+53%
C	Open Hill	-	0.37	0.37	0.37	0.22	0.19	0.19	-48%
D	Open Hill	0.47	0.26	0.2	0.2	0.1	0.15	0.06 permitted (0.01 actual)	-68%
D (Sheep numbers)	Open Hill	3784	2149	1627	1627	804	1176	500	-68%
E	Open Hill	-	-	-	0.21	0	0.1 (0.18)	0	-52%
F	Open Hill	-	-	-	0.15	0.15	0.1	0.05	-33%
G (permitted)	Open Hill	0.5	-	-	0.35	0.35	0.34	0.18	-32%
G (actual) (Sheep numbers)	Open Hill	1179					400		-66%

* Glastir uses daily maximum

In Powys, where there is far less high quality blanket bog outside of the SAC, there was a broader approach to calculating stocking rates to cope with the considerable areas of MDB on deep peat that would benefit from restoration activity. Knowledge of each farm was used to determine whether the generic stocking rates should be moderated to achieve the overall increase or decrease in stocking believed to deliver management for habitat maintenance or improvements. The overall complexity includes having to accommodate differences in grazing potential of different habitat types occurring as a mosaic, the overall distribution of habitats, the terrain, available shelter and the proximity of in-bye land. Exceptions occur, such as for one farm where NRW allowed winter grazing levels all year round to this to see if it encouraged dwarf-shrub growth on the small areas of blanket bog that were already there. The farmer required this because he could not see a future for farming with costs of winter feed/grazing continuing to rise.

A balance also had to be struck between the habitat requirements for some of the upland bird species and the desire to see an improvement in the prominence of ericaceous shrubs on the areas of deep peat and degraded heathland habitats as is required by the SAC, Special Protection Area (SPA) and SSSI designations. Outside of the SAC more weight has been given to maintaining the grazing levels required for Golden Plover. In the example quoted above, a compromise was agreed in which some livestock were kept on the areas used by Golden Plover at an intensity that was also consistent with maintenance of the SAC features.

Table 1 illustrates some of stocking rates applied under Glastir and includes a comparison with past practices. As mentioned already it is important to note that stocking rates under Glastir have changed to a daily maximum (and minimum), but the farmer can stock between these two values and every movement of stock onto and off the parcels has to be recorded to demonstrate compliance with the terms of their Glastir contracts. As a whole the Elan Valley Trust flock has been reduced by 41% since 1989 and at least one farm in the SAC has been asked to reduce its summer grazing levels by 70% since 2013.

Figure 4. Example of options for maximum stock levels for a Glastir advanced grazing plan on Elenydd in a calendar year based on current practice and the previous regime under Tir Gofal.

The example used in Figure 4 is for an area of blanket bog that is important for breeding Golden Plover and is not typical of what is represented in Table 1. Grazing levels agreed here (GA3) range from 0.07 LSU ha^{-1} in January, through to 0.1, 0.2 and then just below 0.28 LSU ha^{-1} for the last 3 months of the year. As this area is exceptional, scenarios for GA1 and GA2 as the more usual regime are included for comparison. This area was visited in November to assess grazing impacts on the ericaceous shrubs and it was then decided to carry on with *status quo* and higher grazing levels up to the end of December, even though these exceptionally high late summer and early winter grazing levels run the risk of suppressing the growth of ericaceous shrubs.

From an agricultural perspective, farmers are responding to incentives and the requirements of agri-environment schemes to provide goods and services such as heather restoration at a time when the direct economic returns from livestock rearing in the uplands is challenging. This may be seen as good for the environment and people, but some of the farmers feel that the continuing downward trend in stock numbers are bad for the hills and that in the future the public purse will be paying for them to put more stock on the land. Whilst reduced grazing will permit existing shrubs to increase in height and cover it is less certain whether those such as Heather *Calluna vulgaris* and Bilberry *Vaccinium myrtillus* can colonise new areas, especially if the existing vegetation is overwhelmingly dominated by *Molinia*. There are studies conducted by ADAS (ADAS 2001) showing heather will expand from existing plants but that it does not appear to recolonise areas where it has been lost when grazing pressure has been reduced in the short term.

Upland bird requirements

The assemblage of breeding upland birds is one of the special features of the SSSI. CCW commissioned the Royal Society for the Protection of Birds (RSPB) to identify the habitat requirements for birds on Elenydd (Lamacraft *et al.* 2012), with emphasis on five focal species. The report describes the specific habitat conditions to maintain or restore the population levels of these, which should also benefit other species in the assemblage. Management areas for the five focal species, which include Golden Plover (*Pluvialis apricaria*), are shown in Figure 5.

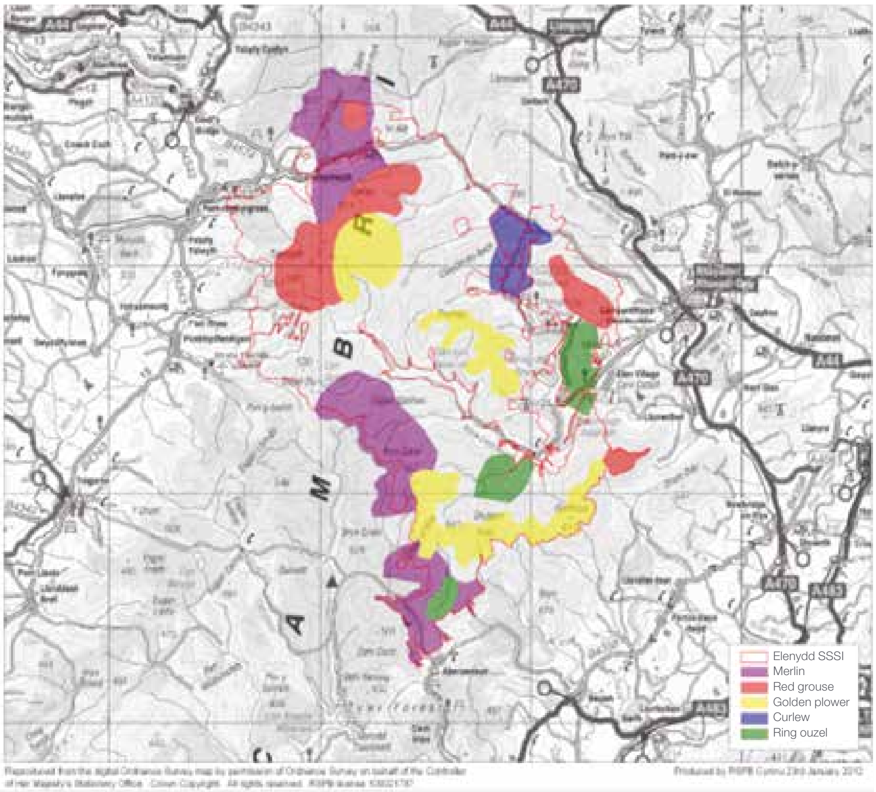


Figure 5. Areas for the five most important breeding bird species on the Elenydd SSSI that are a focus for management to benefit all species in the breeding bird assemblage.

Golden Plover has seen dramatic declines from an estimated 112 breeding pairs in the 1982 to 11 pairs in 2007 (Johnstone *et. al.* 2008). Whilst there is likely to have been several reasons for this decline, the cessation of regular burning, and large reductions in grazing animals have probably contributed (Johnstone & Dyda 2010). A recent PhD study at Aberystwyth University found *Molinia* had increased in density rather than extent (M. Green *pers. comm.*) where decreasing Golden Plover populations were being studied.

This Elenydd bird report has been used to justify and support a number of projects to try and prevent further loss of breeding habitat for Golden Plover. Given the downward trends in livestock numbers it was important to find other ways of managing the vegetation. Diversifying species composition in *Molinia*-dominated areas should also benefit Red Grouse *Lagopus lagopus scoticus* and Merlin *Falco columbaris*; there is evidence of Red Grouse in very small remaining pockets of short vegetation in these areas.

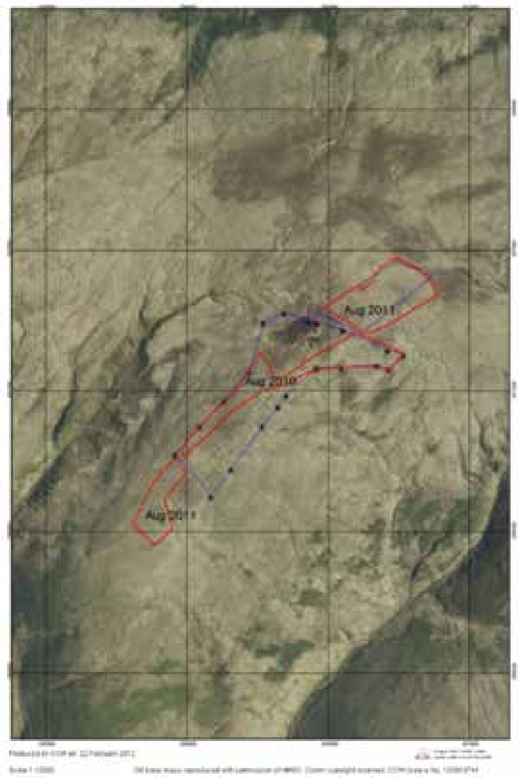
Habitat improvements for breeding birds: Trumau, Elenydd

Cutting Molinia on Trumau

In this project *Molinia* was cut back and followed up with intensive grazing; its aim was to encourage more open vegetation and the spread of heather around a known Golden Plover breeding area. The areas covered by this project are shown in Figure 6.

Plants species composition and cover were first recorded using one metre quadrats on a grid system, the position of each being fixed with a Trimble GPS accurate to around one metre. The vegetation was then cut in late August 2010; an additional area was cut in 2011, to include blanket bog that had good bog moss cover but where RSPB

Figure 6. Trumau, Elenydd where temporary electric fencing, mowing and focussed grazing were trialled to benefit Golden Plover. The red line shows the areas cut and the blue line is the locations of the fencing.



had suggested that *Molinia* may be making the vegetation structure less attractive to plover. The darker vegetation (Figure 6) shows where Golden Plover breeding has been recorded in recent years. The machine used was able to remove all vegetation, including *Molinia* tussocks at ground level, leaving them less than one centimetre high.

With some exceptions, *Molinia* was cut by a machine that cut and collected arisings which were piled up at the edge of the cut areas. Golden Plover were seen to feed on ground that had only been cut a day or so before. Their numbers were monitored in the spring of 2011 and 2012, and birds used some of these piles as observation points.

Figure 7. Pony grazing on Trumau, Elenydd on the cut area in September 2010

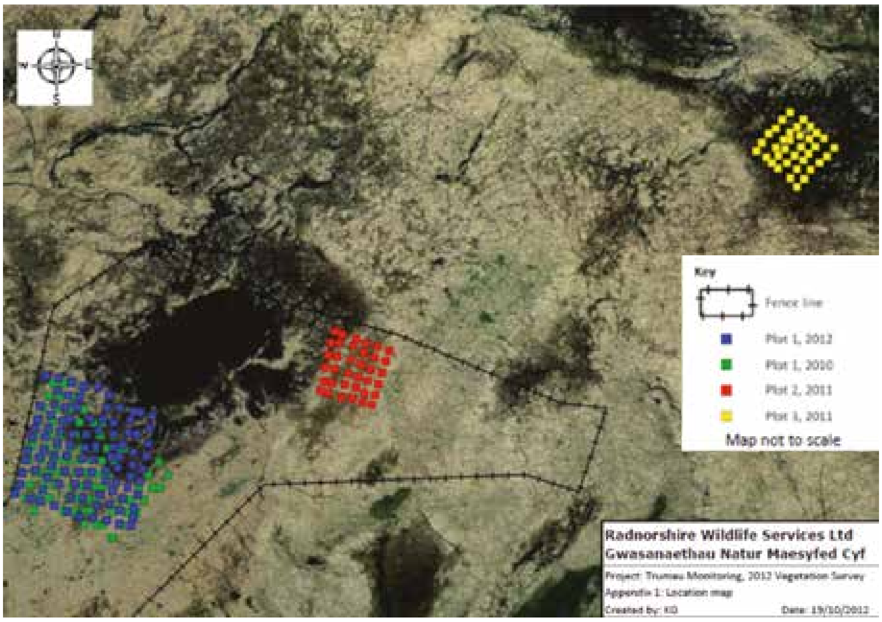


Figure 8. The location of vegetation monitoring plots and the first electric fence erected in 2010 on Trumau, Elenydd

Temporary solar powered electric fencing was used to keep animals on the cut area. The fence also stopped other stock from grazing the area during the winter as a means of minimising grazing damage to any pioneer ericaceous shrubs. Ponies were used immediately after the cut in autumn 2010 (Figure 7). In subsequent years stock were grazed from late June until the autumn, or removed before then if they were losing condition. It was clear that ponies did not enjoy the confinement on an exposed ridge so they were removed after a few weeks so only sheep were used from late summer 2011. The fencing was removed in 2014.

The monitoring plot locations are shown on Figure 8. The dark areas include the wetter more open vegetation, although it may still contain some *Molinia* and the dense black between plots 1and 2 is a bowl of eroded peat. The sample points for Plot 1 shows that the 2010 area was repeated in the vegetation recording of 2012, but Plot 2 has not been repeated. Plot 2 was left uncut, as was the darker area in Plot 1; both of these areas had a strong growth of heather and other blanket bog species included *Sphagnum*. Plot 3 covered a more open area with more or less continuous *Sphagnum* cover and some *Molinia* which was cut in 2011 to see if plover could be encouraged into this area, which appeared much wetter than other areas.

Golden Plover set up territories around the cuts but no successful breeding took place within the cut area and repeats of bird monitoring show that this continues to be the case.

Some of the data interpretation from the vegetation monitoring in Plot 1 is shown in Figures 9 and 10. Figure 9 shows changes in the cover of *Molinia* after cutting, and Figure 10 shows vegetation height. There was a marked decrease in *Molinia* cover in Plot 1 as shown by the red squares in the 2012 records. There was an even more marked reduction in vegetation height, but this is only to be expected, given that tussocks were cut off to ground level and would take a few years to regenerate their vigour. After three years there were still areas

Figure 9. Changes in Molinia cover 2010-2012 in Plot 1 on Trumau

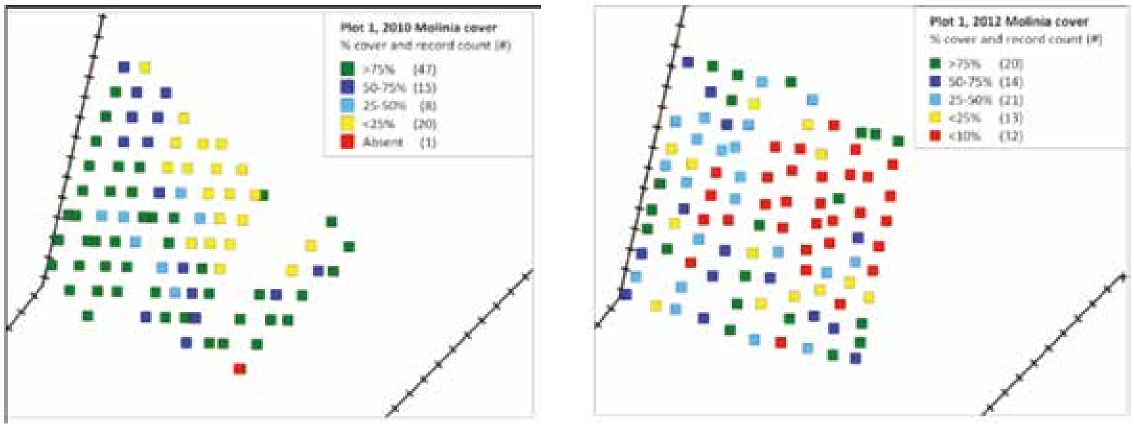
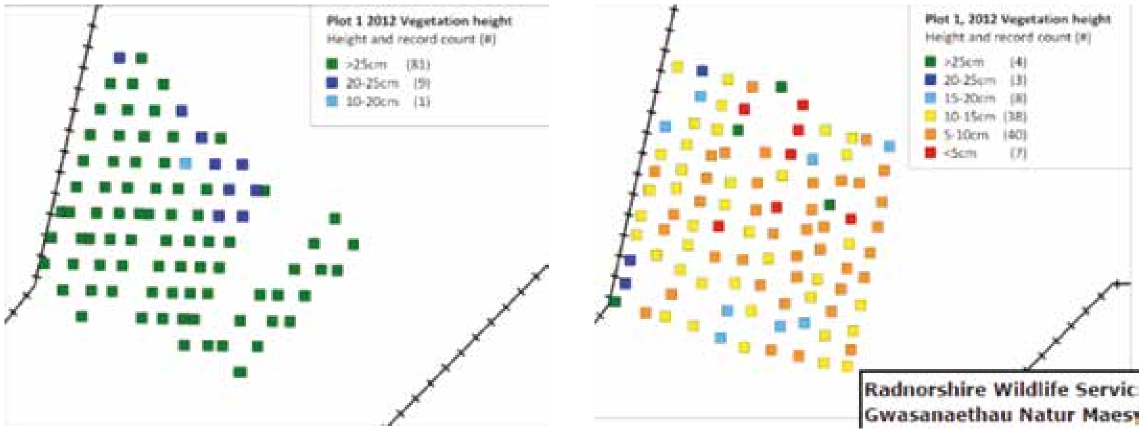


Figure 10. Changes in vegetation height 2010-2012 in Plot 1 on Trumau



of short sward on drier ground in the southern edges of the 2010 enclosure, but elsewhere *Molinia* has returned to visual dominance although the tussocky structure has not yet returned. There was little evidence of a change in the frequency or cover of other species in the samples, but this is unsurprising as two years is too short a time for the vegetation to recover from being severed at ground level.

The work has not yet produced the more open conditions required as foraging and breeding habitat for Golden Plover. A more detailed knowledge of peat depth and the distribution of vegetation with ericaceous shrubs and *Sphagnum* moss would have helped to focus the experiment on blanket bog. Supplementing the cutting with seed from heather brash or seed may also have produced more beneficial change than was experienced.

It seems clear from this and the work on Abergwesyn described by Joe Daggett (this volume) that attempting to improve the breeding success of Golden Plover by expensive cutting is perhaps only part of the solution. Similarly, reducing the grazing by itself will not produce the required outcome. Other sites have been more successful, for example at Mynydd Hiraethog in North Wales, where cutting on tall blanket bog led to Golden Plovers attempting to breed on land that had no records for the previous 20 years (RSPB *pers. comm.*).

Cutting *Molinia* in the Elan Valley: the Purple Moor-grass Project, 2015

Following on from the Trumau project the Nature Fund of the Welsh Government supported more work on *Molinia* management (Elan Valley Trust, 2015). The objective was to achieve real improvement in biodiversity in the Cambrian Mountains, with 'long term resilience for agriculture and the wider economy' through innovation in farm management for biodiversity and diversification into new markets 'to realise the potential of our upland areas'.

The areas used are shown in Figure 11 and these avoid any that were already being funded through Glastir agreements. In these locations cutting could benefit the breeding bird species including those which were considered to be particularly important (Lamacraft *et. al.* 2012) and/or had some potential for benefit to farmers. Experience from the Trumau project had shown there was no need to remove the cut material. A variety of machines were trialled in January 2015 to judge what might be the most effective.

Figure 11. Areas identified for cutting Molinia to benefit birds or habitat in the Nature Fund Project

a. b.

Figure 12. The Teagle Flail used in the January 2015 trials

a. b.

Figure 13. The Johnson Rotary Slasher used in the January 2015 trials

Two machines were judged the most effective for the required purpose based on end results and cost. The first was a Teagle flail (Figures 12a & 12b) which had a six foot cutting width and costs about £5k. This was one of the most impressive machines on display and clearly had the power to deal with "virgin" *Molinia*. Although the topper itself did not have any height adjustment some manipulation could be achieved using the tractor hydraulics. This was quite a compact machine on a medium powered tractor (100 HP) and there is clearly potential for this to be used on "first cut" *Molinia* in relatively sensitive areas with minimum compaction.

The other piece of kit considered adequate was a Johnson Rotary Slasher (Figures 13a and 13b). There is already local experience of using it to cut *Molinia*, heather, bracken and gorse. It operates using a single 8-foot rotor with 3 blades when cutting *Molinia* but can be readily adapted to have flail chains fitted. The cutting height can be adjusted and it can be operated in reverse. It has the capacity to comfortably deal with the *Molinia* tussocks and at approximately £4k represented good value for a very effective machine.

The green lines shown on Figure 14 represents a series of single track cuts. These were designed to encourage livestock to graze across the whole area by following the cut lines. It also allowed the experienced operator to avoid cutting vegetation that has heather or patches of bog vegetation. In the future it is expected to develop as a habitat mosaic of benefit to birds.

Figure 14. One of the cut areas on the Troedrhiwdraen Farm, Elenydd

Table 2. The perceived advantages and disadvantages of cutting Molinia

Positive Advantages/benefits	Disadvantages/Negative effects
Avoids flush of regrowth (perhaps reduces competitive advantage)	Expensive and time consuming
may damage peat surface but this creates creates new plant niches	May damage habitat and farm machinery
Grazing impacts probably similar (ie short sward see images)	Peat compaction? (especially if collecting material)
Less damaging to *Sphagnum*, but this would depend how much was present and whether a fire burnt into the peat	Is leaving cut material in situ harmful to habitat and species diversification. (Evidence from the trials is that this should not be a concern.)
Controlled and directed at target areas	
Peat compaction	

Some of the perceived advantages and disadvantages of cutting when compared with burning are listed in Table 2, but the results of the cutting trials in January to March 2015 and site visits to two of the sites used in September and October 2015 suggest that at least some of the listed concerns for habitat recovery may not be warranted.

Figure 15 was taken of an area that had been cut with the Teagle flail in March and what it looked like in September, with the uncut sward on the left of the image. Given the likely volume of material evident in the uncut area the cutting would have left a thick mulch of finely chopped *Molinia* in rows (as shown in Figure 12b). This visit showed that there was little evidence of any mulch smothering the ground so it seems likely that the material is chopped so finely that it desiccates and decomposes rapidly, even when it represents years of accumulated litter, and is unlikely to smother the ground and prevent other species growing. The wetness of the ground is demonstrated by the presence of Bog Asphodel *Narthecium ossifragum*.

Livestock were seen to graze the large patch of cut vegetation and the more open structure, as shown in Figure 16, provides a more suitable breeding habitat for Skylark *Alauda arvensis* and other small birds, which in turn provide prey for breeding Merlin *Falco columbarius*, an interest feature of the SPA; it should also prove suitable for breeding Curlew. These areas were still being grazed in October, although Figure 16 shows that the height of the *Molinia* is variable.

Figure 15. *Area partially cut with the Teagle Flail in March 2015 and its appearance in September 2015*

Figure 16. Close-up picture of vegetation shown in Figure 15 (September 2015) in which the cut material has largely decayed or disappeared.

Table 3. Comparative costs of removing Molinia biomass

Payment levels	Costs
Glastir (only set to be a contribution to costs)	£68.50/ha
Nature Fund	£120/day arisings left – cheaper & quicker (less impact)
Contract worker	£250/day arisings left
Specialist contractor /machine to cut, collect and stockpile material on site, as on Trumau	£350 + VAT (2010 prices)
Box of Swan Vesta matches	33p

Factors to assess when planning to cut the vegetation include the accessibility of the site, height of tussocks, ground wetness and the available machinery. A comparison of some of the costs is given in Table 3. Costs for collecting the cut material for use elsewhere on the farm is likely to be somewhere between nature fund and contract worker price, but the amount that can be cut in a day will depend on conditions and may only be one to two hectares in extreme cases. When an area has been cut once, the temporary absence of tussocks means that subsequent cutting can be quicker, but a second cut is only necessary where grazing is not achieving the target condition as described for Trumau.

Figure 17. Illustrating the products from the different cutting machinery; the darker area on the right was cut by the Teagle flail and by the Johnson Rotary Slasher on the left.

Many of the trial plots are to be harvested in the future and the ground is now suitable for this or for baling using conventional farm machinery where ground conditions allow. The area used for the machine tests shown in Figure 17 was revisited in early October 2015 and, as expected from previous work, there was very little of the thick thatch of dead vegetation present in the previous January.

Potential uses for *Molinia* litter at Henfron Farm

One of the farmers in the Nature Fund project has been cutting *Molinia* since 2006 on accessible ground and has used the bales on his farm for fodder and bedding. His experience has shown that it takes about six years for it to recover with sufficient biomass to warrant another cut.

This farm has also investigated the use of cut and baled *Molinia* for a number of potential uses. In addition to the more historical practices of using it as fodder ('rhos hay') and a bedding alternative to reduce straw costs, it has carried out trials with biofuel briquettes of compressed material which work well in log burners, but has not proved cost-effective when all the time required to produce them is included. The nature fund provided funds for the purchase of a machine for a small-scale biochar trials (Figures 18a and 18b). The farmer is now looking into producing compost using the biochar and incorporating sheep manure and sheep's wool.

a.

b.

Figure 18. Biochar production at Henfron in Nature Fund trials

The vegetation of *Molinia*-dominated plots cut at Henfron

This farm was one of the areas within the Nature Fund project where differences in the composition of the vegetation from cut areas were compared. It recorded variation in species and also vegetation density, using a standard weighted sward stick[3]. Each area had been cut at a different time so the recording was looking at the vegetation since last cut with no historical data for prior to cutting (Figure 19). The areas cut in 2015 were small in comparison to previous cuts because it was done with a powered mower attached to the rear of a quad bike. This quad mower may prove really useful in wetter areas for Golden Plover habitat improvement.

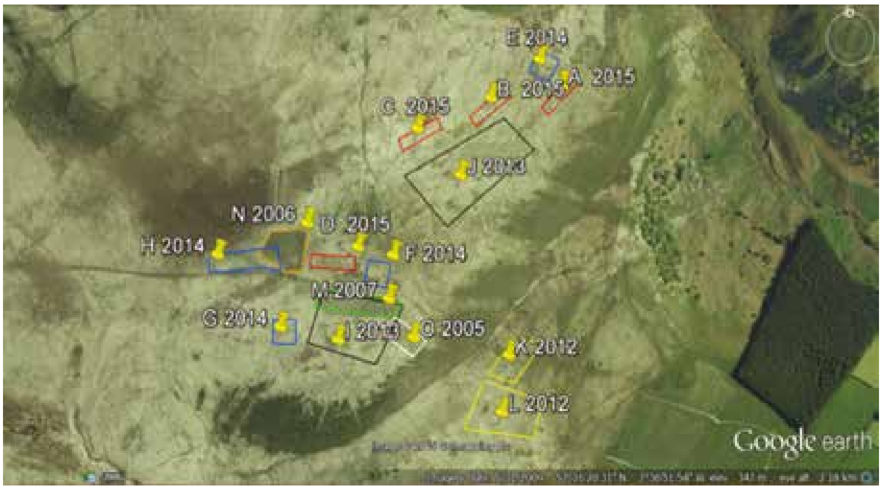


Figure 19. Distribution and date of last Molinia cuts, Henfron farm

Ten 1m x 1m quadrats were recorded along a transect across the centre of each cut area. Two examples from this project are described to show the variation in structure and species composition. Note that in most instances 'Moss Cover' combined the cover of acrocarpous, pleurocarpous and bog mosses.

Plot N was cut in 2006 and is located close to an area of blanket bog so is likely to be on at least shallow peat. The June 2015 records are summarised in Figure 20, where the presence of Cranberry *Vaccinium oxycoccos* is indicative of an affinity of the vegetation with blanket bog. The average sward density was 13.1 cm^2 (measured with the Borman's disc) and the average maximum height of Bilberry was 16.1 cm. The likelihood is that vegetation density is determined by the time since the last cut. By contrast, Plot L is likely to be on mineral soil and the lower proportion of *Molinia* (Figure 21) suggests that this may be more likely to be acid grassland, such as a Common Bent-Sheep's Fescue type, that happens to also have a lot of *Molinia*. Reference to bedstraw may well be *Galium saxatile*, and this, together with *Agrostis capillaris* and *Festuca ovina,* would fit the description of the NVC U4 grassland community. It was also noted that there were more sheep grazing in this area, and this would help to prevent *Molinia* dominance, which is perhaps why Bilberry average height (8.5 cm) was almost half that measured in Plot N.

Figure 20. Proportion of each species in 2015 as a percentage of the total cover in Plot N Henfron, cut in 2006

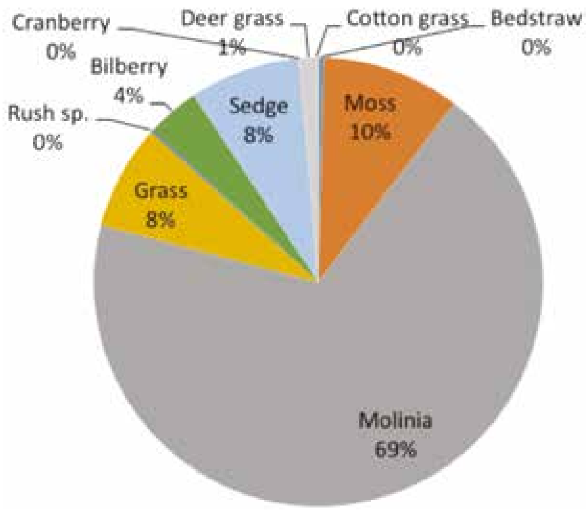
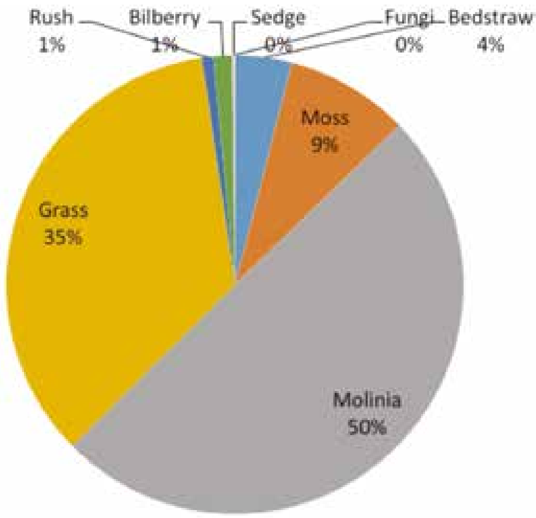
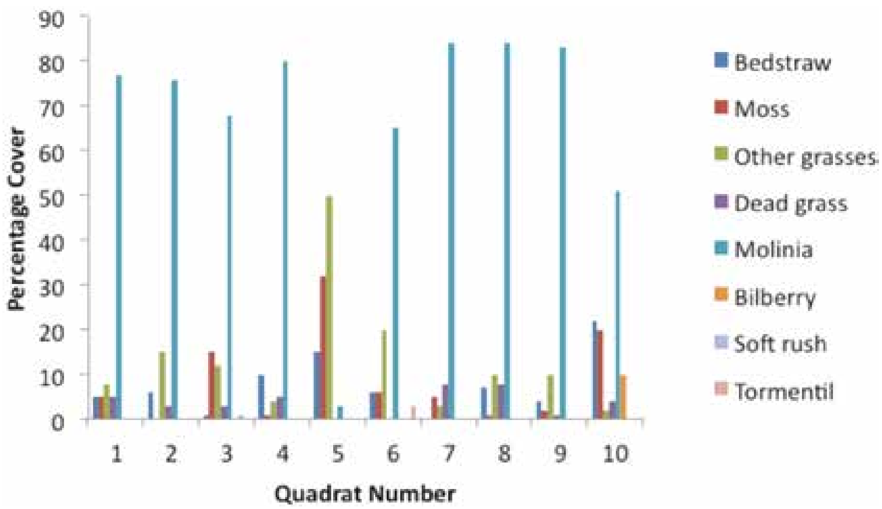


Figure 21. Proportion of each species in 2015 as a percentage of the total cover in Plot L Henfron, cut in 2012



In many of the samples most of the cover was provided by *Molinia*, but the percentage cover of other species across individual quadrats varied. An example of this is shown in Figure 22 for an area cut late 2014 so species had only had a couple of months of regrowth before being recorded in June.

Figure 22. Cover of each species in Plot F Henfron, 2014 cut



Moving forward – A Natural Resource Management Approach

Conservation bodies would like to see *Molinia*-dominated blanket bogs on Elenydd change to something more varied and consistent with, for example, the description of Natura 2000[4] blanket bog.

As mentioned earlier for Glastir, stocking rates on parts of Elenydd are designed for conditions where very low grazing levels in summer combined with its cessation from the 1st October are the best way of achieving recovery of natural habitats. It is practical in an environment where the direct economic returns to the farmers from more intensive livestock management are unavailable. Evidence from other sites in central Wales suggests that, in the absence of grazing, or under this light grazing regime, there have been noticeable improvements in the quality of *Molinia*-dominated blanket bogs. It has been suggested that this should now become the norm on sites that are designated as SSSI and SAC. The same prescription has also encouraged the development of heathland habitat. However, such low grazing levels may also result in the loss of important structural elements of bog and grassland habitats that are important for other species, like the golden plover.

It has been suggested that blanket bogs do not need any grazing at all because the shrubs can outcompete *Molinia,* but this is an unsubstantiated generalisation that ignores site-specific circumstances like nitrogen deposition or adverse hydrology. However, there are many parts of Elenydd where it is not all blanket bog and there is no or very little evidence of ericaceous shrubs within a *Molinia* dominated sward, apart from perhaps small amounts of Bilberry. There have to be shrubs to start with if the 'hands off' approach is to be successful.

There are other parts of the Elenydd SSSI where higher grazing levels have been permitted to maintain specific structural attributes of the vegetation, such as a mosaic of *MDB* and shorter vegetation closer to typical blanket bog. Scattered plants of ungrazed heather have also been seen in MDB in some of these areas.

While MDB is particularly susceptible to wild fires that cannot be controlled, the same would apply to tall ungrazed heather. At low grazing levels the heather would recover and in the meantime provide the structure important to other species, though whether this is more valuable would need to be evaluated. It is also acknowledged that tall heather would expand ground nesting opportunities for Merlin. Only time will tell what grazing intensity is the most appropriate, but this may vary and Elenydd is a sufficiently large site so the different approaches to grazing prescriptions are justifiable where it is possible to manage for conservation and farming.

Some broader aspects

Upland areas like Elenydd provide multiple benefits to society including nature conservation, agriculture, water management, carbon capture, cultural values and the local agriculture-led economy. Such things are now referred to as Ecosystem Services. Uplands are important for everyone's wellbeing as a place to visit and enjoy, and it is interesting to note that some visitors have commented that they find it harder to move around Elenydd now that there are fewer sheep and the paths they create. This is just one example of the unintended consequences that need to be considered when making decisions about managing upland areas.

The projects described in this paper and other work planned for Elenydd and the Elan Valley suggest that tackling *Molinia*-dominated blanket bog and delivering what some bird species need to recover their populations require flexible approaches and that compromises need to be made. Site management should take account of all stakeholders' needs and those of other habitats with different biodiversity requirements. For example, restoring acid grassland that has become infested by *Molinia*, as on Henfron Farm, will draw grazing pressure away from the bog whilst maintaining a more species-rich sward in the acid grassland that is more beneficial to the farm.

We could simply leave these areas to become wilderness. We would see new opportunities and the different landscape would be appreciated and welcomed by many. The author of this paper believes that High Nature Value Farming is a way forward and considers that there is a need to work with the farmers and other stakeholders in areas like Elenydd. Given the poor economic prospects for farming in extreme upland environments this could deliver more benefits to society. It would make the most of the current trend for many farmers to be more interested in working together to deliver those benefits.

Any views set out or expressed in this paper are the views of the author and should not be taken as representing the views of Natural Resources Wales.

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Notes

[1] LIFE is the EU's financial instrument supporting environmental, nature conservation and climate action projects throughout the EU. Since 1992, LIFE has co-financed some 4 171 projects, contributing approximately €3.4 billion euros to the protection of the environment and climate.

[2] Note that this figure is lower than many of the stocking rates permitted under agri-environment schemes in operation since 2000.

[3] This was measured using a Borman's disc, which was a plastic disc of standard weight and diameter which is left to fall freely down a metal pole marked at 1cm intervals. The height at which the disc settles is a measure of vegetation density.

[4] Natura 2000 is a list of habitat types contributing to the European Union's suite of Special Areas of Conservation, protected under the Habitats Directive.

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Molinia diversification trials on Pennine moorland near Huddersfield, West Yorkshire, UK.

Mike Pilkington, Moors for the Future Partnership, Edale, S33 7ZA, UK

Source of information

This paper is based on the main text of a report written for the organisations supporting the project: Natural England, Yorkshire Water plc, and the National Trust. Annexes containing detailed analyses are not included in these Proceedings.

Introduction and Background

An increasing dominance of Purple Moor-grass *Molinia caerulea* on the moorlands of the South Pennines and other upland habitats is widely attributed to decades of inappropriate regimes of burning and grazing (Anderson *et al,* 2006). The resulting degradation of dwarf shrub canopy together with the development of bare peat patches allows for the proliferation of faster growing graminoids[1].

Molinia-dominated moorlands are not without ecological benefit. They are known to provide feeding grounds for Curlew *Numenius arquata* and Twite *Carduelis flavirostris* and also provide suitable breeding habitat for Merlin *Falco columbarius* and Short-eared owl *Asio flammeus* with the latter feeding on voles living within the *Molinia* swards (Anderson *et al.*, 2001). Nevertheless, the long-term objective for many degraded upland SSSIs of the South Pennines is for their restoration specifically towards either blanket bog or dwarf shrub habitats that are rich in *Sphagnum* and dwarf shrubs but poor in graminoids (Anderson, 2003). This objective has recently gained impetus from 'Biodiversity 2020', a UK government strategy that aims to increase the proportion of SSSIs that are in favourable condition to at least 50% by 2020 (Natural England, 2012).

The control of *Molinia* traditionally involves repeated actions of destructive mechanical and chemical disturbance, including: burning; mowing (the latter involving cutting or flailing); removal of mulch; windrowing of mulch (spreading mulch in lines of about 1-2 m in width and 4-5 m apart); poisoning with herbicide (usually glyphosate). These actions may be used in different combinations and over different time periods and may be followed by reseeding with desired moorland species. For example, in a trial to compare various ways of controlling *Molinia* carried out in the Dark Peak (Derbyshire), the most effective treatment involved removal of stock grazing, burning and then poisoning any regrowth with glyphosate in August of the same year. This was followed by a repeat of these treatments the following year, in addition to flailing to break up the tussocks of *Molinia* where suitable access allowed. Finally, seeds of Heather *Calluna vulgaris* and Cross-leaved Heath *Erica tetralix* were applied, the latter particularly in wetter areas (Anderson *et al.* 2001).

These methods clearly involve intense and sustained management; they are also expensive, resource-heavy and potentially damaging to the habitat itself as well as to riparian habitats downstream of the swards. Indeed, the impact of these repeated and highly disturbing treatments on peatland function generally was acknowledged by Natural England, as was the use of one-off burning and alternative treatments to reduce graminoid dominance (Natural England, 2013).

Therefore a means of controlling *Molinia* that involved low management and fewer resources, while being less polluting to the habitat itself and those around it, would be highly desirable, while still being commensurate with Natural England's favourable condition targets for these habitats.

One of the few studies in this area was initiated by Manchester Metropolitan University (MMU) with the collaboration of Moors for the Future (MFF) in August 2010. This experiment investigated the effect of using different species of *Sphagnum* propagules in the form of 'beads' on flailed *Molinia* swards on Butterley Moor. *Sphagnum* beads consist of a synthetic sheath around fragments of *Sphagnum* to provide a protective and nutritive environment for the developing *Sphagnum* plant. (See Methods section for more information on *Sphagnum* beads). To some extent this study was therefore an investigation into the efficacy of such propagules in developing *Sphagnum* colonies in addition to the role of *Sphagnum* in the diversification of *Molinia.*

The MMU experimental plots were re-surveyed in September 2013 after 3 years of development, and the results showed that:

(a) In Molinia that had been flailed and into which Sphagnum beads had been immediately sown, S. papillosum had the most consistently high cover throughout all the replicates although S. cuspidatum showed the highest cover in a single replicate and the highest mean cover of all replicates. In contrast, S. fallax and S. palustre had poor cover;

(b) In Molinia plots that had been flailed immediately after sowing beads of S. fallax, the cover of S. fallax was significantly greater than in identical Molinia plots that been left unflailed (although there may have been visibility issues);

(c) In Molinia plots on sloping ground that had been flailed 2-3 weeks before sowing beads of S. fallax, the cover of S. fallax was zero, and this was attributed either to the drier conditions on this sloping ground or the effects of relatively intense grazing disturbance;

(d) In Molinia plots at the base of a hill that had been flailed 2-3 weeks before sowing beads of S. fallax, the cover of S. fallax was 'extensive', although this was attributed to the pre-existence of high background cover of Sphagnum, with additional benefit likely to have come from the light grazing regime which facilitated the creation of colonisable hoof prints and the dispersal of fragments of Sphagnum from the existing colonies during the flailing process (Rosenburgh and Caporn, 2013). The most recent communication from these trials suggested that beads initially developed well in the wet areas of cut Molinia where they had made contact with peat between the Molinia plants and also had the protection of the surrounding Molinia plants. However, the subsequent growing-over of the thick Molinia sward had prevented further establishment of the Sphagnum (Caporn, pers. comms., Sept. 2015).

Experimental Aims

The aim of this present trial is to show whether a simple 'one-off' flailing intervention, accompanied by the application of *Sphagnum* propagules, will lead to significant increases in the cover and numbers of different *Sphagnum* species and is accompanied by reductions in the cover of *Molinia caerulea* and other graminoids. Subsidiary aims include the effect of: windrowing the post-flailing mulch, or leaving it lying on the surface; the propagule and species type providing the most effective colonies; the topography of the terrain that is most suitable for propagule development; and the relationship of this development with water table depth.

Methods

Locations

The three sites were located within a few kilometres of each other and clustered around the M62 motorway, west of Huddersfield (Figure 1). The sites at Green Withens and Linsgreave Clough, both owned by Yorkshire Water, are located on Rishworth Moor and Moss Moor, respectively. The site at Burne Moss, owned by the National Trust, is located to the north west of Marsden, between March Haigh and Slaithwaite Moor. All the sites were *Molinia*-dominated blanket bog (McBB), with the critical feature of having at least 0.5 m depth of peat. Other criteria for choosing the sites included accessibility and also the juxtaposition of relatively flat, homogeneous *Molinia*-dominated vegetation alongside more gullied topography, to incorporate both the main "dry" treatment areas as well as the gullied "wet" treatment areas. More information on the three sites is given in the full report.

Figure 1. The three sites chosen for the Sphagnum-in-Molinia trial in the South Pennines

Experimental Design

A randomised block design was chosen, in which the basic block was a set of six treatment areas, four main areas of which were always 20 m x 20 m squares arranged in a grid and separated by a 5 m buffer strip (Figures 2a & 2b). These four main treatments were applied randomly in the block, consisting of: control ('C', no treatment); control with *Sphagnum* propagules 'CB'); flailed with *Sphagnum* propagules ('FB'); and flailed + windrowed with *Sphagnum* propagules ('FwB'). These four treatment areas were always aligned with slope – to lower the risk of tractors overturning. In the event, all of the sites had gentle slopes and there was no such risk.

Two further treatment areas were chosen to complete the block - these were located in gullied, inaccessible areas of the *Molinia*-dominated swards (Figure 1). They consisted of: wet control ('WC'), no treatment); wet with *Sphagnum* propagules ('WB'). In one of the sites (Green Withens), which had a sufficiently wide boggy region, these treatment areas were in the form of two adjacent 20 m x 20 m squares. In the other two sites, these treatment areas were extended along 100 m stretches of two similarly sized and adjacent gullies, with a width of 2 m either side of the central water course.

The block was replicated over the three different sites: Green Withens, Linsgreave Clough and Burne Moss.

a.

b.

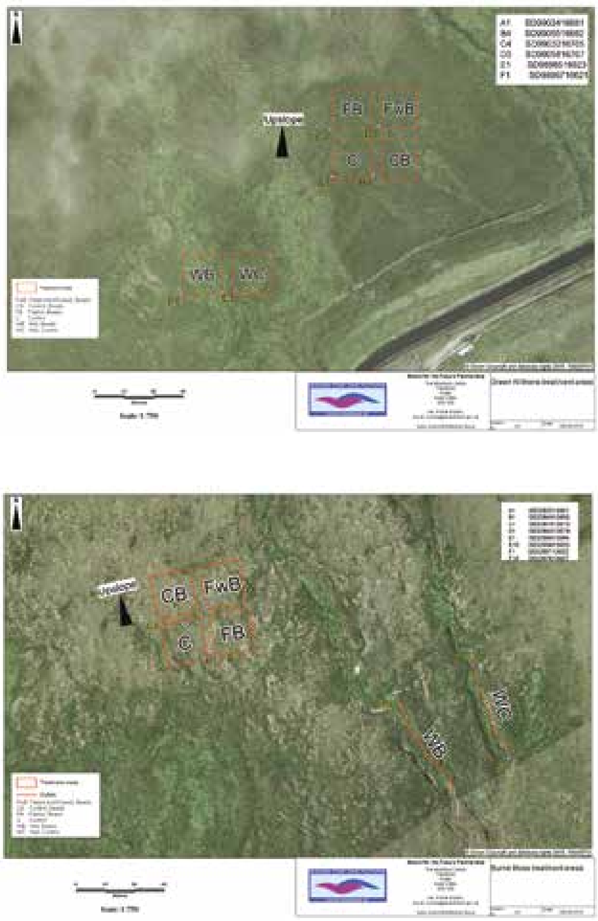


Figure 2a and 2b. The two forms of experimental design

The diagrams show the four 20 m x 20 m treatment areas arranged in a grid square separated by a 5 m buffer zone. The two gullied "inaccessible" treatment areas were arranged in one of two forms, either as two adjacent 20 m x 20 m squares (2a, Green Withens) or approximately 100 m long and 4 m wide (2 m on either side of the water course) along the course of two parallel gullies (2b, e.g. Burne Moss (but also found at Linsgreave Clough).

Ten randomly-placed, 2 m x 2 m quadrats were marked with two stakes within each of the 20 m x 20 m treatment areas, except where the gullied treatment areas followed the line of gullies (Burne Moss and Linsgreave Clough), in which case the quadrats were arranged in a line approximately 10 metres apart. In all cases the quadrats were placed square with magnetic north such that the two stakes were positioned in the north-eastern and south-western corners (Figure 3).

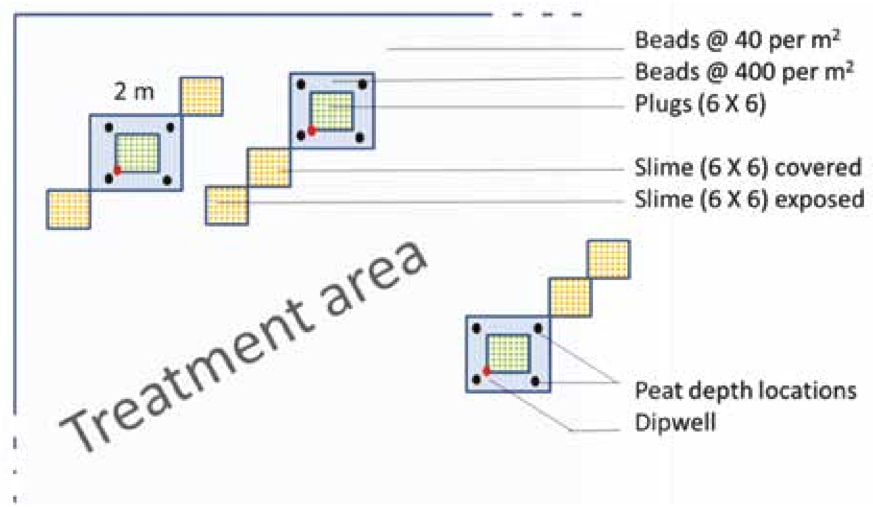


Figure 3. Diagram showing the layout of the propagule treatments and the locations of dipwells and peat depth spot measurements

Details, including exact location of the sites and treatment areas as well the relative positions of individual quadrats, are provided in Annex 1 of the full report.

Sequence of events

Six treatment areas, each with the ten fixed quadrats, were marked and staked out in each of the three sites in January 2014 (Table 1). Two separate baseline surveys, one for vascular vegetation and one for the presence of naturally occurring *Sphagnum* colonies were carried out in early spring and summer of 2014. The flailing treatment, installation of dipwells and inoculation of *Sphagnum* beads inoculated all occurred in October 2014. Following a settling-in period of two months, monthly dipwell surveying began in January 2015. A second wave of *Sphagnum* propagules ('plugs' and 'slime') were inoculated in July 2015, followed by the first annual survey of vegetation in August and September 2015.

Table 1.

2014		2015	
Jan	Staking treatment areas and quadrats	Jan	Monthly dipwell surveys starts
Feb	*Sphagnum* survey	Feb	
Mar		Mar	
Apr		Apr	
May		May	
Jun		Jun	*Sphagnum* plugs and slime
Jul	Vascular survey	Jul	Plugs and slime subsample survey
Aug		Aug	Sphagnum and Vascular survey
Sep	Flailing & windrowing	Sep	
Oct	Installing dipwells	Oct	
Nov	*Sphagnum* beads	Nov	
Dec		Dec	

Red = setting up Green = treatment Blue = survey

Flailing interventions

A single flailing intervention was chosen, but applied in two different ways; either with mulch left lying or with mulch 'windrowed' (raked into parallel rows 1-2 m wide and approx. 5m apart). For these relatively small treatment areas, windrowing was carried out manually with hay rakes; for larger areas mechanical windrowing devices would be used. Flailing was carried out by DTMS Ltd. (external contractors). Quadrat stakes had to be removed immediately ahead of the tractor flail and replaced immediately after it had passed. In this way, the precise location of the quadrat was re-instated, and the integrity of the baseline survey data preserved. Bright yellow metal and plastic "Feno Markers" (M&P Survey Equipment Ltd., Meridian House, Chester, CH2 4HX) were sunk just below the ground surface to assist with finding the precise location. Photos of flailing and windrowing are shown in Annex 2 of the full report.

Sphagnum propagules

Sphagnum 'beads' were the primary *Sphagnum* propagules used in these trials and were developed to include a protective and nutritive sheath around fragments of *Sphagnum* plants. The protective gel also facilitates inoculation by hand spreading. Beads can be spread at almost any time of year – the protective sheath can survive an autumn application, although it is best to avoid spreading in icy conditions.

Sphagnum 'plugs' were designed to provide a relatively quick establishment of *Sphagnum* colonies. Plugs consist of a pre-grown *Sphagnum* colony (approx. 3 cm diameter) originating from propagated fragments of *Sphagnum* plants collected in the PDNP. Due to their pre-grown status, *Sphagnum* plugs require longer production times and require greater effort to 'plant'. Also, due to the potential for freezing temperatures and frost heave in winter, they are not suitable for planting in late autumn. Rather it is recommended that plugs should be planted in late spring when temperatures are on the rise.

Sphagnum 'slime' is composed of two phases that are mixed on site; a protective matrix that is less viscous than that used for beads and fragments of *Sphagnum* which are larger than that used for beads. Propagules of slime are applied as 'blobs' from an adapted backpack sprayer furnished with a peristaltic pump and a wide nozzle.

All *Sphagnum* propagules originate from fragments of twelve species of *Sphagnum* which were collected within the boundary of the Peak District National Park (PDNP) and then propagated up to provide bulk. These were present in different proportions, but dominated by *S. fallax* and *S. palustre* (Table 2).

Table 2. Proportion of Sphagnum species in the implants and other preparations.

Species	Proportion in the mix
S. fallax	30-50%
S. palustre	20-40%
S. papillosum	~10%
S. capillifolium	~10%
S. cuspidatum	~10%
S. fimbriatum	~10%
S. subnitens	5-10%
S. denticulatum	~1%
S. squarrosum	~1%
S. russowi	<1%
S. tenellum	<1%
S. magellanicum	<1%

These predicted proportions of species in fragmented (beads and slime) or semi-grown (plugs) propagules will be more accurate depending on the size of the propagule in question and the number of propagules in a sample. Nonetheless, to date there is no information available to show the proportions of species in mature colonies arising from these propagules and it is likely that different conditions will promote the growth of different species.

Sphagnum propagule treatments

The *Sphagnum* bead treatment was applied by hand-spreading in the four relevant treatment areas (CB, FB, FwB and WB (see Figure 1)) immediately after the October 2014 flailing treatment. Beads were spread at a rate of approximately 40 beads m^{-2} throughout the 20 m x 20 m treatment areas, or, for the gullied treatment areas, throughout an area approximately 2 m either side of the central line of the water course and for 100 m of its length. Inside the 2 m x 2 m quadrats of these areas, beads were spread at a rate of approximately 400 beads per square metre. Uniquely in the Flailed and Propagules (FB) treatment area, beads were first spread over the lying mulch and then mixed up with the mulch, using rakes and garden forks.

Sphagnum plugs were planted as a 6 x 6 grid formation into each of the 2 m x 2 m quadrats of the four relevant treatment areas (Figures 2a & 2b). The plugs were confined to a central square metre of each of the 2 m x 2 m quadrats and planted using a long-handled dibber with a foot lever. Due to operational reasons the plugs were planted at a later date than the beads, in the summer of 2015. The plugs came in the form of pre-shaped discrete units of *Sphagnum* with no attached peat, some 50 of which were rolled up in cellophane.

Sphagnum slime was inoculated into separate 1 m x 1 m quadrats (joining on to the 2 m x 2 m quadrats, Figure 3) as follows: 20 quadrats in the FwB (Flailed, Windrowed, with Propagules) treatment area, with 10 covered with mulch and 10 left uncovered; 10 quadrats in the CB (Control, with Propagules) treatment area; 10 quadrats in the WB (Gully Propagule) treatment area. The blobs were arranged in a 6 x 6 grid formation, but became invisible soon after inoculation.

The propagules were developed in conjunction with the Moors for the Future Partnership by Micro Propagation Services Ltd., (Kirk Ley Rd, East Leake, Loughborough, Leicestershire LE12 6PE). Photos of propagules and inoculation are shown in the full report.

Depth of peat and Water table

Peat depth was measured at a minimum of four locations within each of the quadrats in all of the treatment areas (Figures 2a & 2b). Water table depth was measured using a single dipwell positioned inside each of the quadrats in all of the treatment areas (Figure 3). The dipwell was constructed from 1.2 m of 40 mm (internal diameter) plastic plumbing pipe, sealed off at one end with duct tape, drilled with holes on four vertical planes at right angles and at a separation of about 15 cm, such that the top hole was about 30 cm from the top open end and inserted so that about 20 cm remained above ground level. Water table was measured monthly in the dipwells of the three sites and on the same morning. Caps were fitted to prevent small rodents from becoming trapped. A photo of a dipwell is provided in the full report.

Baseline monitoring within the treatment areas

Surveying for *Sphagnum* colonies and vascular vegetation was carried out within the randomly located plots using simple searching strategies. *Sphagnum* surveys were completed by trained National Trust volunteers and MFF staff in January and February 2015. Vascular vegetation surveys were completed in Green Withens and Linsgreave Clough in July and August 2015 and at Burne Moss in August 2015. The following is a brief method for the surveys:

The quadrat boundary was delimited using either a folding quadrat or a tape measure and canes, to facilitate monitoring. Representative digital photographs of each quadrat were taken (one overview and one looking into the quadrat) and their reference numbers noted.

The species composition of each quadrat was recorded, and percentage cover of each species was estimated to the nearest 1% where cover was less than 15%, and to the nearest 5% above this level. In the *Sphagnum* survey the cover of individual *Sphagnum* species was estimated and patch size was additionally recorded as both the longest and the shortest axes. In the vascular plant survey the overall cover of *Sphagnum* (if present) was again estimated (but not at species level and only as percentage cover) and similarly for pleurocarpous bryophytes, *Polytrichum* species, other acrocarpous bryophytes, liverwort species and *Cladonia* lichens. The presence and approximate % cover of dead plant material, bare peat, and open water were also recorded.

The approximate height of the following vegetation groups (where present) was recorded close to the corners of each quadrat, and compiled to give an average height for each quadrat: dwarf shrubs; moorland herbs and ferns); grasses, sedges & rushes; bryophytes & lichens; and dead plant material. The presence of signs of grazing and animal droppings was also noted.

Ongoing monitoring

Ongoing surveys for *Sphagnum* should take place at least initially on an annual basis to assess the success of *Sphagnum* bead and plug development. Both the *Sphagnum* survey and the vascular plant survey should in future take place simultaneously – it was found that the dense cover of *Molinia* in summer did not hinder surveying for *Sphagnum* species any more than in winter. Surveying for water table depth in the dipwells should take place monthly at all sites and at the same approximate time although it may be necessary to miss out one or two months during winter snow fall.

Results of Baseline surveying

Full results of statistical testing are given in the full report.

Vegetative cover: *Molinia* and both indicator (Table 3) and non-indicator species of blanket bog

Indicator species
Andromeda polifolia
Arctostaphylos spp
Betula nana
Carex bigelowii
Calluna vulgaris
Cornus suecica
Drosera spp.
Erica spp.
Empetrum nigrum
Eriophorum angustifolium
Eriophorum vaginatum
Menyanthes trifoliata
Myrica gale
Narthecium ossifragum
Non-crustose lichens
Pleurocarpous mosses
Racomitrium lanuginosum
Rubus chamaemorus
Rhynchospora alba
Sphagnum spp.
Trichophorum cespitosum
Vaccinium spp.

Table 3. Positive indicator species for blanket bog (JNCC, 2009).

Although *Molinia* was the dominant vegetation, percentage cover differed significantly between all three sites, occupying 97%, 78% and 64% at Green Withens (GW), Burne Moss (BM) and Linsgreave Clough (LC), respectively (Figure 4, left).

Molinia cover also varied amongst the different treatment areas, before the treatments had been applied. However the significantly higher cover in the quadrats of the gullied treatment areas (97% - 100%) than in the control or any of the other treatment areas is likely to be a function of this particular environment (Figure 4, right).

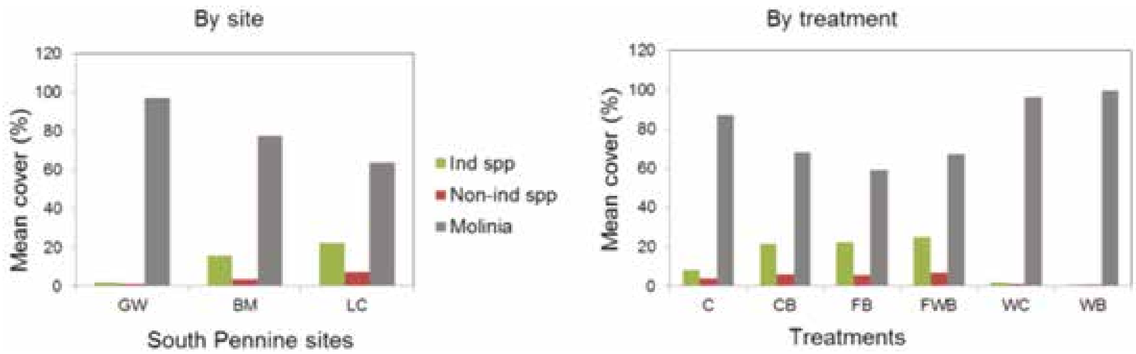


Figure 4. Cover of Molinia, indicator species and non-indicator species in the sites (left) and treatment areas (right)

GW = Green Withens, BM = Burne Moss and LC = Linsgreave Clough, n = 60

C = dry control, CB = Sphagnum propagules, FB = flailed and Sphagnum propagules, FWB = flailed, windrowed and Sphagnum propagules, WC = wet control, WB = wet and Sphagnum propagules), n = 30

The cover of blanket bog indicator species was significantly different between all of the sites with the lowest cover at GW (2%) followed by BM and LC (16% and 23%, respectively). Similarly, the cover of non-indicator species was also significantly different between all of the sites with lowest cover at GW (2%) followed by BM and LC (4% and 7%, respectively).

The cover of indicator species in the quadrats of the six treatment areas (before the treatments had been applied) was approximately 20%, although cover in the control area (8%) was significantly lower than in the other 'dry' treatment areas and significantly higher than in the wet control area (2%) and wet bead area (1%). A full list of blanket bog indicator species is given at the end of this report.

Blanket bog indicator species were mainly represented by *E. vaginatum* which occupied 1%, 2% and 14% of cover in the quadrats at GW, BM and LC, respectively (Figure 5, left). *E. angustifolium* also occupied a relatively high cover, at 0.5%, 4 % and 5%, at GW, BM and LC respectively. There also was a relatively high cover (and frequency, not shown) of *C. vulgaris* in Burne Moss (9%) and a relatively low cover of *Sphagnum* species throughout. In the six treatment areas, three of the blanket bog indicator species were present at relatively lower cover in the control area (before treatments had been applied) and at substantially lower cover, approaching zero or completely absent, in the two gullied treatment areas (Figure 5, right).

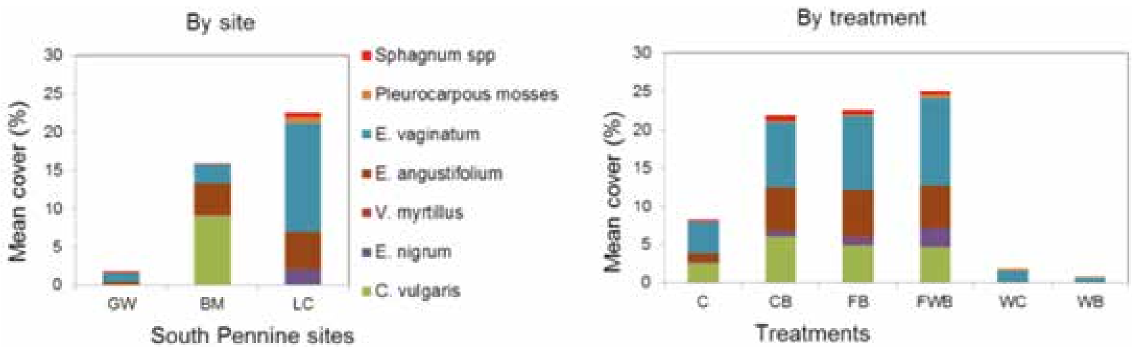


Figure 5. Cover of individual indicator species in the sites (left) and treatment areas (right). See Figure 4 for key to abbreviated site and treatment names.

Non-indicator species (of blanket bogs) were mainly represented by mosses and liverworts. Mosses of the *Polytrichum* genus, together with other acrocarpous mosses and also liverworts collectively occupied 1%, 3% and 6% of the quadrats in GW, BM and LC, respectively, and there was also varying, and relatively low cover of *Deschampsia flexuosa* (Figure 6, left). Compared to the other treatment areas (before treatments had been applied), non-indicator species cover in the two gullied areas was relatively low, although there was a higher proportion of *Deschampsia flexuosa* cover (Figure 6, right).

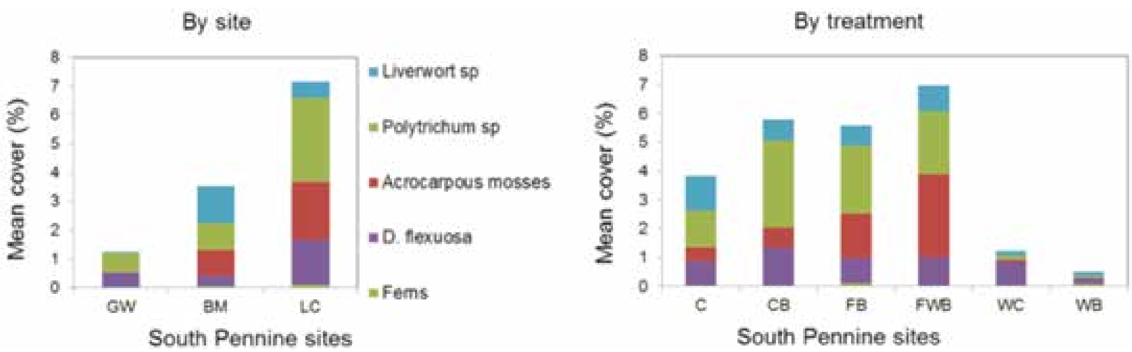


Figure 6. Cover of individual non-indicator species in the sites (left) and treatment areas (right). See Figure 4 for key to abbreviated site and treatment names.

Linsgreave Clough had the lowest cover of *Molinia* and the highest covers of *E. vaginatum, E. angustifolium, Empetrum nigrum, Deschampsia flexuosa,* and both *Polytrichum* mosses and other mosses. A strong inverse correlation was found in the full dataset from all the sites, between the cover of *Molinia* and that of (i) cotton-grasses *(E. vaginatum, E. angustifolium)*, and (ii) blanket bog indicator species (Figure 7).

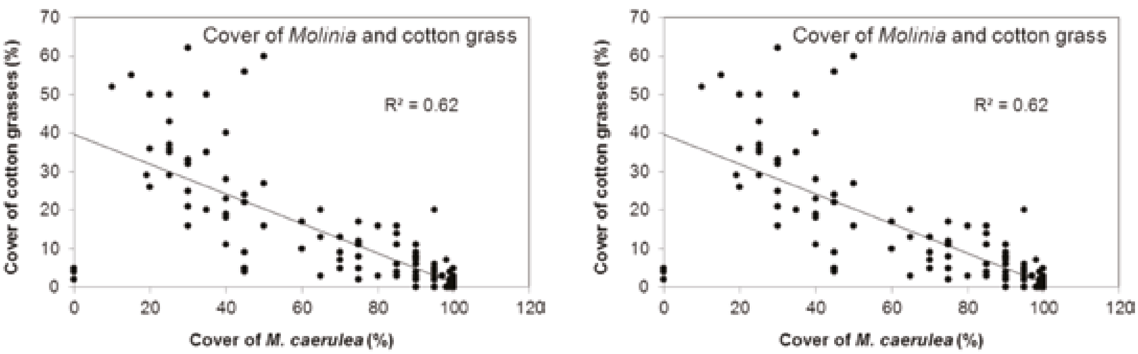
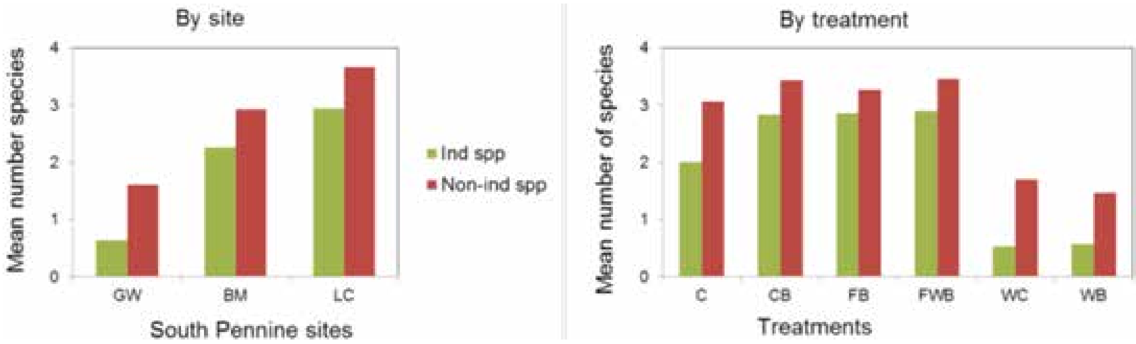


Figure 7. Relationship between the cover of M. caerulea and the cover of (left) both E. vaginatum and E. angustifolium and (right) collective indicator species in all of the sites. Lines fitted by linear regression (R2 = regression coefficient), n = 180

Numbers of species

The number of blanket bog indicator species per quadrat was approximately 1, 2 and 3 at GW, BM and LC respectively (Figure 8, left) and was significantly different between all three sites. This is well below the target number of six indicator species for blanket bog habitats as suggested by Common Standards Monitoring (JNCC, 2009). The number of indicator species per quadrat in the two gullied treatment areas was significantly lower than in any of the dry treatment areas (Figure 8, right).

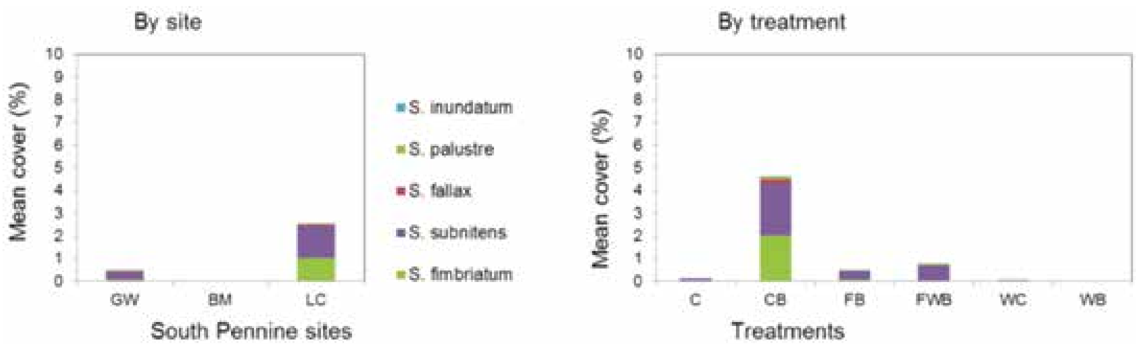
Figure 8. Number of species in the sites (left) and treatment areas (right). See Figure 4 for key to abbreviated site and treatment names.



Sphagnum species

Sphagnum was present with a mean cover of 0.5%, 0% and 2.5% in the quadrats at GW, BM and LC respectively (Figure 9, left). The cover at LC was significantly higher than at GW or BM. *Sphagnum* was mainly represented by *S. subnitens* which had 0.3%, 0% and 1.4% cover in GW, BM and LC, respectively. The second species with relatively high cover over all the sites was *S. fimbriatum* at 0.1%, 0% and 1% cover in GW, BM and LC, respectively. *S. fallax* and *S. palustre* were both found with cover of 0.03% over all the sites. The species of *Sphagnum* with the lowest overall cover over all the sites was *S. inundatum* (less than 0.01%).

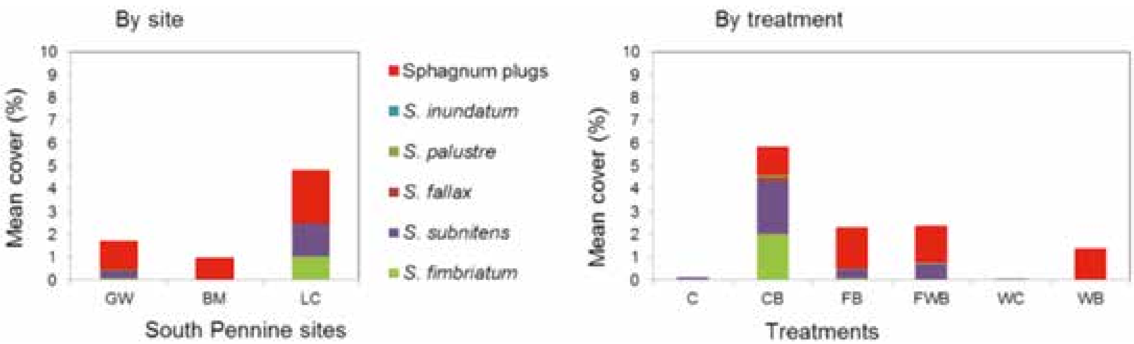
Figure 9. Sphagnum species in the sites (left) and treatment areas (right). See Figure 4 for key to abbreviated site and treatment names.



There appeared to be considerably higher cover of *Sphagnum* in the Control-with-propagules treatment area (CB) (4.6 %) than in any of the other areas. However, the higher cover in this treatment area, due mainly to *S. subnitens* (2.3%) and *S. fimbriatum* (2.0%) was found in isolated patches (Figure 9, right). The cover of *Sphagnum* in the gullied treatment areas was significantly lower than that found in the other areas.

The addition of the *Sphagnum* plug propagules raised the average percentage cover of *Sphagnum* over all sites from an average of 1% to 2.5% (Figure 10).

Figure 10. Sphagnum species and Sphagnum plugs in the sites (left) and treatment areas (right). See Figure 4 for key to abbreviated site and treatment names.

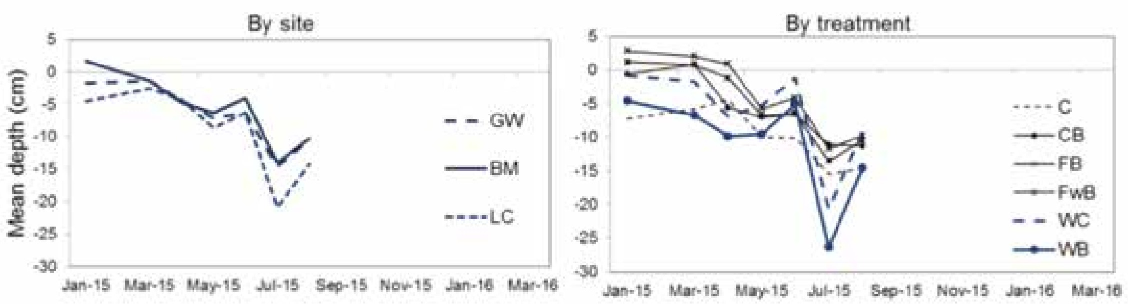


Water table depths

Water table depths receded from the surface in the summer months, reaching its lowest level in July at all three sites (Figure 11, left). Lowest levels of water table were found at Linsgreave Clough (21 cm) with Green Withens and Burne Moss recording lowest depths of 15 and 14 cm. respectively.

There was less variation in lowest water table depth amongst the different treatment areas (Figure 11, right), although both of the gullied treatment areas had noticeably lower water table depths than those of the main treatment areas. Highest water table levels were recorded in winter becoming closest to the surface at Burne Moss and in the flailed treatment areas.

Figure 11. Water table depth in the sites (left) and treatment areas (right). See Figure 4 for key to abbreviated site and treatment names.



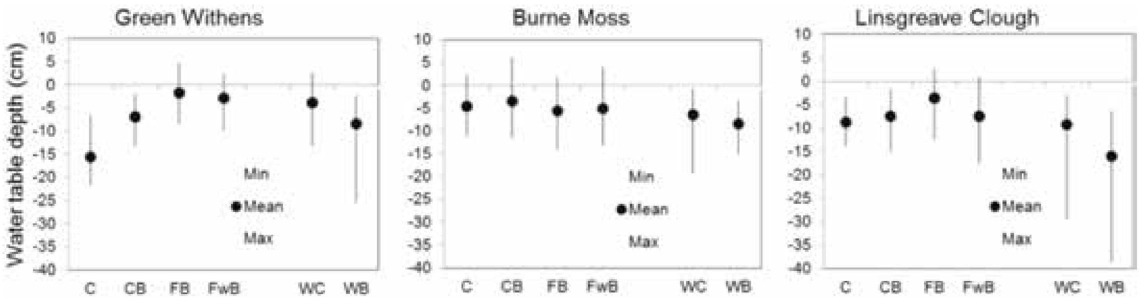


Figure 12. Water table depth in the different sites and treatment areas. See Figure 4 for key to abbreviated site and treatment names.

The statistical effects of site and treatment on mean water table depth (Analysis of Variance) were not consistent or clear (Figure 12). An interactive effect suggested that water tables were raised in both the flailed areas (FB, FwB) and one of the gullied areas (WC), but only at Green Withens.

To further explore these interactions, water table depths in both of the gullied treatment areas and in both of the flailing treatment areas were combined to show a single effect of 'flailing' and 'gullying' on mean water table depth. This suggested that there was a general effect of flailing (statistical probability $P< 0.01$) in raising the level of mean water table.

While the effect of *Molinia* as a replacement for *Sphagnum* cover has been shown to increase the rate of evapotranspiration during dry periods in lysimeter studies (Schouwenaars, 1990), it is tempting here to suggest that the higher water table levels found in the flailed treatment areas of these trials was a result of reduced evapotranspiration from the flailed *Molinia* plants. However it is also possible that changes to the nature of the plant cover following flailing and subsequent changes to the resistance to surface water flow paths may also have played a part in some of these patterns (e.g. Schouwenaars, 1995).

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Notes

[1]Grass-like plants such as grasses and sedges.

Views and perceptions: feedback groups via questions and break-out

Questions and Comments

Discussion Day 1 – 14 September 2015 Recorded by Ros Tratt

What are the causes of the pre-dominance of *Molinia* in particular habitats, regionally?

The variety of papers presented highlighted that *Molinia* is present in a wide range of plant communities and habitats in Britain (Roger Meade, David Glaves). Although *Molinia* occurs throughout Britain, it has a mainly western distribution and occurs on mineral soil and on shallow and deep peat. Areas with particularly high cover of *Molinia* on blanket bogs are Exmoor, Dartmoor and the South Pennines (David Glaves, Naomi Oakley). There is palaeo-environmental evidence that *Molinia* has become increasingly dominant in some areas, particularly since the 1960s, and in many upland areas this rise to dominance has been associated with burning and increased deposition of pollutants (Julia Mc Carroll). Treatments aimed at reducing dominance of *Molinia* on moorlands (herbicide, flailing, grazing) seem to have a limited impact in the long-term, with *Molinia* cover returning to pre-treatment values when treatments stop (Rob Marrs). In degraded raised bog situations, re-wetting treatment has been successful in reducing *Molinia* dominance (Paul Thomas).

In the South Pennine Moors, burning is thought to have triggered the dominance of *Molinia*. Many moorland areas, including areas dominated by *Molinia* are near roads, so have been subjected to arson, other areas have been accidentally burned by moorland managers (Emma Coombs). *Molinia* areas tend to be most vulnerable to arson in the spring when the tussocks have dried out; heather areas are most vulnerable in the late summer. Some *Molinia*-dominated areas have been managed to provide upland grazing with burning of large areas to encourage an early bite of grass re-growth in the spring. This type of burning every 1-2 years is believed to have led to the dominance of *Molinia* in areas of the Peak District. (Penny Anderson). This is similar to the practice of swaling in Wales and SW England. Burning for game is a different practice and even though fires very occasionally get out of control and spread into other areas, generally gamekeepers carry out small, managed burns which are carefully controlled (Simon Thorpe).

Where *Molinia* occurs on deep peat deposits, burning *Molinia* may not damage the peat, because grass burns tend to be rapid and just take of the top layers of dry grass, so *Molinia* could be regarded as being protective of peat deposits, in a way that dwarf-shrub dominated vegetation is not! (Not sure to whom this was attributable).

What are the likely effects of climate change on *Molinia*?

A decrease in precipitation, with no change in drainage may lead to an increase in *Molinia* in wetland habitats (bogs and fens) (Joan Daniels).

Carbon dioxide (CO_2) is increasing – now about 400ppm in the atmosphere, having increased from 333ppm. Temperatures are increasing too. Dutch work on *Molinia* has shown that there are combined effects of adding CO_2 and nitrogen (N) to *Molinia* in mixed dwarf-shrub, *Molinia* vegetation. *Molinia* is an efficient competitor for nutrients in low nutrient environments and responds more to CO_2 and N than ericaceous species (Simon Caporn).

Molinia caerulea may also be a 'conduit' for methane, releasing it from deep peat (Jack Rielly).

Even though it is often regarded as a problem, and a threat to 'heather moorland', *Molinia* areas can have multiple benefits for the local environment and economy. For example, *Molinia* is an important food source for livestock in the uplands, particularly in the spring and can be successfully managed with the right type of stock and grazing regime. We need to take an ecosystems approach to assess the role of *Molinia*-dominated habitats in different areas and attempt to balance the requirements of farmers, water companies, shooting etc. as well as wildlife (Mark Phillips).

Discussion Day 2 – 15 September 2015 Recorded by Roger Meade

Presentation: Cutting *Molinia* to improve habitat for Golden Plover, Abergwesyn Common; Joe Daggett.

Q1. Where did the cattle go? The sheep and cattle fed on the acid grassland (including *Molinia*) as well as the blanket mire. They follow flailed tracks.

Q2. Do ponies have a unique role? They are second-best; there are issues with identification chips and registration and there is no financial incentive. As grazers they are as selective as sheep.

Q3. Are there benefits if the Molinia is cut more than once? The aim is to cut in autumn to avoid disturbance to birds. No benefits have been recorded from repeated cutting but removals of tussocks is worthwhile.

Presentation: Molinia management and birds; Dave O'Hara

Q1 (comment, Avril Gough). Graziers are of key importance in controlling *Molinia*; take care of them and the land will be managed appropriately.

Q2 (comment, unattributed). Cold burns are required in August-September to stop *Molinia* spreading.

Q3 (comment, Marjorie Davey). There were many cuckoos in the uplands this year, using low areas of invading Sitka Spruce on the edge of the blanket mire. It is difficult to know how to get scrub into the grazed landscape as sheep eat *Salix* seedlings.

Presentation: The importance of controlling water and other management techniques; Penny Anderson

Q1 (unattributed). Is the past the right guide for the future? Is what we grow up with taken to be natural? Peter Jepson commented that some flushes in the west Pennines have lost plant species such as *Linum catharticum* and *Lotus uliginosus*, associated with calcareous shale bands, and this shows a fundamental change in the plants' environment. Simon Caporn suggested there might be limits in the attempts to replace dominant *Molinia* with a more diverse plant cover because of excess concentrations of nitrogen and ozone in the atmosphere.

Presentation: Replacing Molinia with Sphagnum; Michael Pilkington & Emma Fawcett

Q1 (unattributed). Was there any work done with Geoff Eyre to bring in *Sphagnum* moss propagules? No.

Q2 (unattributed). Which *Sphagnum* moss species are included in the plugs used in the experiment? Cannot be sure about each bundle but *S. papillosum* is included.

Q3 (comment, MP). There is grazing on all the experimental sites.

Presentation: Molinia and an SSSI in Waiting; Peter Jepson

Q1 (comment, Ken Perry). *Molinia* stays wet until about 11:00hr each day, thus providing a relatively humid environment of benefit to *Sphagnum* moss.

Q2 (unattributed comment). Common standards monitoring can be very arbitrary.

Q3 (unattributed comment). Only active blanket bog is listed as an Annex 1 habitat under the EU Habitats Directive. John Barret commented that there is an increase in active bog northwards, but about 90-95% of England's upland bogs are net emitters of carbon.

Q4 (unattributed). What has increased *Molinia*-dominance in the west Pennines? As far as the speaker is concerned, it always was, but there are hidden drains, some are of stone construction and may be very old.

Presentation: Principles for conservation objectives for Molinia on upland SSSI; Dave Stone

Q1 Joan Daniels. Is there an aspirational vision for controlling air quality and limiting its effects on bogs? Natural England feels able to provide leadership. Defra is producing an environmental plan and Natural England's conservation strategy will be part of it. There will be a broader review of the SSSI series, including the range of interest features and the outcomes will be integrated into chapters of the SSSI selection guidelines.

General questions and comments from Day 2

In answer to the question 'what do we want' there were comments that a better balance of habitats is required. There is a difference in language and terminology between conservationists and other land users and this hinders joint working and progress. There was reference (E Marriage) to the mixed farming that started 8000 years ago leading to a balance between plants and animals. There are dangers in using NVC plant communities as the prescription for the future. Nature needs people to be farming the hills and there is a shared interest. Monocultures such as dominant *Molinia* are the product of land-use and without knowing how it was arrived at it is equally difficult to prescribe change.

Key points from the breakout sessions

Delegates gathered in five groups to discuss topics that had been built up from the main issues of concern provided by them on Post-It notes the previous day.

Subjects for group discussion

a) Compare the requirements of nature conservation and agriculture on blanket mire: identify areas of discussion that might yield a win:win outcome on Molinia-dominated sites.

b) Balancing nature conservation interest features on blanket mire. How closely linked or opposed are those of species (birds, invertebrates) with those of habitat and provision of ecosystem services on *Molinia*-dominated sites?

c) Explore the strengths and weaknesses of considering *Molinia*-dominated blanket mire to be either:
- Natural and requiring SSSI representation, or
- An aberration that must be replaced at all costs.
- List the implications for current SSSI selection criteria.

d) What is an achievable and sustainable outcome from the management of *Molinia*-dominated blanket mire consistent with SSSI, SAC and SPA designations?

e) Burning *Molinia*: ecological and agricultural consequences. Explore the available permutations of season and frequency, evaluating outcomes for agriculture and nature conservation and recommend what is best. In the event, there were too few signed up for this topic to proceed.

f) Prioritise management techniques such as restoring hydrology, controlling burning and grazing, and using herbicides on *Molinia*-dominated blanket mire. What is the ideal sustainable prescription in delivering nature conservation outcomes and the required ecosystem services?

While each group reported back to the conference individually, common strands have been picked out as headings to form the following analysis of the delegates' opinions. Each is followed by a comment from the Proceeding's editor to show that the opinions have been taken into account.

Principal objectives of moorland management and contextual considerations

1. Grouse shooting, livestock farming, water supply, wildlife and flood alleviation are the principal objectives of moorland management.
2. Need to establish achievable aims for each site.
3. Some delegates believe that forming peat is a sufficient objective in itself.
4. Returning vegetation and its functionality – hydrology to its natural state.
5. The site needs to be more resilient, more diverse, and more “active”. (Avoid the word “restore”.)
6. The nature of the moorland in question must be within the range of likely outcomes when categorised. If soligenous, in that it receives water from rain and slope run-off, a blanket mire is unlikely to develop. But Blanket Mire is a mix of bog and fen so some *Molinia* is OK.
7. Conservation objectives must be practical – so we might accept a higher % cover of *Molinia* than accepted in Common Standards for Monitoring (CSM), produced by the JNCC to inform the writing of conservation objectives for habitats.
8. Reduction of *Molinia* and increase in *Sphagnum* should be sought.
9. The eventual outcome should be an improvement in ecosystem services, carbon storage and biodiversity, agriculture, sport, access, enjoyment.

The main thread is that the moorland has to provide a number of services beside nature conservation. Emphasis on the stabilisation and growth of peat, and the use of agricultural practices to provide a vegetation structure encompassing the range of birds, invertebrates and plants is central to the decision-tree that advocates a ‘horses for courses’ approach, differentiating between the two ends of the target habitat spectrum as blanket mire or dwarf-shrub heath. The editor is very supportive of using the term ‘blanket mire’ in place of ‘blanket bog’ as this enfranchises a wider range of NVC plant communities as indicative of favourable condition, bringing in those of wet heath as well as of raised bog.

The view was expressed more than once in the conference that the well-being of wildlife would follow if agriculture became the prime driver for management in the uplands, as well as elsewhere. This view is at odds with the fundamentals of nature conservation in the UK and Europe more widely and it is beyond the scope of the conference to bottom out and explore common strands in the thinking behind the principle.

Site characteristics and history

1. Need to understand the site history: consideration needs to be given to what status the moorland had before intervention and before deciding what we are trying to achieve.
2. Need to confirm that it is blanket mire in the first place.
3. Then follow this with thorough site investigation.
4. Consider diversity and how to manage areas outside blanket mire.
5. Some delegates are not convinced mires could support themselves, and that the best that could be achieved is to restore the hydrological functions and recognise that incidental changes occurred from other activities.

It is not clear what incidental activities lie behind point (5), but the decision-tree recognises the difficulties, for example, of reducing the amount of assimilable nitrogen precipitated from the atmosphere, and that restoration of blanket mire is likely to fail where it is significantly above the critical load. The rationale within the decision-tree strongly endorses the need to validate an area as potential blanket mire by looking at the stratigraphy and the plant species currently growing alongside the *Molinia*. It clearly advocates dividing the land to be managed into that with potential for mire and the remainder as potential for dwarf-shrub heath.

How to achieve the site objectives

1. Need step-wise management goals; it is best to decide what is the next state, then move on to set milestones (although these may change).
2. Avoid generic strait-jackets.
3. Hydrology is the key; get this correct and other objectives will follow.
4. Increasing the wetting has more risk to agriculture.
5. Managing the waterflow and maintaining accessibility are considered to be the chief priorities for sustainability. Much depends on land ownership as to what is feasible. Other aspects are site specific so it is not possible to generalise.
6. One should not define a target state too much.
7. Knowledge transfer – environmental experts & public.
8. Active communication is important.
9. Conservation and agriculture need each other – maybe each is rather unidirectional.
10. Grazing: evidence gap – cattle movements within large sites. Sheep have many grazing patterns.

Clarity of purpose and need for clearly definable goals are supported here and in the decision-tree, and that hydrology is key to achieving the restoration of blanket mire. The list recognises that each situation is different and that judgements have to be made rather than deciding by rote. Although the importance of networking, learning from others and sharing experience are brought out in the Observations and Critique, they are not part of the decision-tree. It is clear from at least three of the papers that grazing is extremely important in maintaining diverse blanket mire and dwarf-shrub heath, but that its use is rarely appraised objectively so that lessons are not easily teased out of the experience in a way that can be used by others. The need to find a workable model for conservation and agriculture is also highlighted, though it is beyond the scope of the conference to resolve.

Molinia dominance

1. *Molinia* is part of many habitats.
2. It responds to management – and enrichment from the atmosphere.
3. It is not always obvious what causes *Molinia* dominance.

The decision-tree includes an appraisal of air quality data for the area within which a particular site lies and stresses the need to repair the hydrology in a way that can weaken the *Molinia*.

Benefits of *Molinia* dominance

1. *Molinia* is better than bare peat.
2. It can improve water quality and is better for this than *Calluna*-dominated land.
3. There are spin-offs e.g. biofuel – *Molinia* has a high energy value.
4. It can be used for bedding or rough fodder.

While these statements may be true, none are likely to have a sufficiently high priority over the nature conservation imperative to return blanket mire and dwarf-shrub heath to their expected floral and avifaunal diversity. The water quality observation (2) remains equivocal.

Principal considerations on *Molinia*-dominated blanket mire

It is important:

1. To establish what is an achievable & sustainable outcome from the management of *Molinia*-dominated blanket mire consistent with SSSI, SAC, and SPA designations.
2. To prioritise management techniques such as restoring hydrology, controlling burning and grazing, and using herbicides.
3. To work out what is the ideal sustainable prescription in delivering nature conservation outcomes and the required ecosystem services.
4. To balance nature conservation and agriculture.
5. To understand what happened on a site – history.
6. To agree what is next state, then to move on to set milestones (although these may change).

Some of these points, such as the importance of hydrology (2) and the need to consider the stratigraphy and past land-management (5), are included in the decision-tree. The remainder are covered in the Observations and Critique.

Overview, Discussion and Working Towards a Decision-Tree

Written by Roger Meade

An overview is *inter alia* to give the reader a rounded view of the information emerging from the conference. It is important because it brings together all the strands to provide a rounded opinion and this can only be a good thing in helping each of us to make wise judgements. As in so many decisions about land management, the unique nature of each situation means there are rarely any off-the-shelf solutions and the way forward must draw on the full breadth of available knowledge and then weigh up the balance of probabilities surrounding the possible outcomes.

The programme was carefully crafted to cover all the subjects the steering committee thought should feed into a wider discussion about the status and management of *Molinia caerulea* as a dominant plant on upland peat. Some speakers addressed the record of past vegetation as seen in the peat profile, others the changes in land management practice and the role of atmospheric deposition in determining the dominant plants. Some explained the process for deciding what uplands currently occupied by *Molinia* should be like and the types of change that can follow their interventions.

In essence, it is unlikely that *Molinia* has been widely dominant on upland peat in England or Wales before the industrial revolution was well underway (Chambers & Mc Carroll). Although *Molinia* thrives when irrigated with oxygen-rich water, it is inhibited by stagnation, but this inhibition of growth associated with anoxia in the rooting environment is reduced when there is a copious supply of nitrogen from the atmosphere (Anderson). Although the atmospheric deposition of oxides of both nitrogen and sulphur have decreased in recent years, they are still above the recognised 'critical loads' and *Molinia* can benefit from continued nitrogen precipitation and from what has accumulated over time. By contrast, there is a nitrogen deposition threshold above which *Sphagnum* mosses do not prosper, and their growth may still be further inhibited by the precipitation of certain sulphur compounds (Caporn *et al.*).

This review draws on the written presentations to:

- Set out the extent and nature of dominant *Molinia*;
- Explore the setting of the parameters for defining favourable condition;
- Advise on the ecological *bona fides* of dominant *Molinia* now found on the erstwhile territory of blanket mire and dwarf-shrub heath;
- Review factors responsible for sustaining dominant *Molinia* or its alternatives and their importance in remediation;
- Suggest what restoration aims are reasonable and the efficacy of the tried techniques in achieving them;
- Provide a decision-tree for would-be interventionists.

The resource

The UK uplands contain a lot of *Molinia*-dominated habitat. "Based on these proportions and the extent of the habitats, it is estimated that up to *c*.44,000 ha may have 50% or greater *Molinia* cover representing 6% of English moorland (and *c*.27,000 ha with 75% or greater cover). The number of blanket bog indicator species and their combined cover declined with increasing *Molinia* cover, especially above *c*.80% cover." (Glaves). These percentages for *Molinia* are equivalent to the Domin cover values recorded for dominant *Molinia* (8-10) and represent a type of blanket mire vegetation falling outside of the range of cover values cited for NVC communities M18 and M19, though it is within the range for some sub-communities of M17; as Glaves points out, such a high cover of *Molinia* leaves little space for a diversity of other species, and species diversity is an important attribute of quality in blanket mire.

Although 6% may seem a high figure for English moorland being covered by dominant *Molinia*, it leaves a lot in which it occurs at lower cover or not at all. The figures are not designed to reveal how much habitat is actually improving and how much is getting worse. The West Pennine blanket mire is presently a stronghold for *Molinia* and yet Jepson reports that sites observed over decades have an increasing cover and diversity of *Sphagnum* mosses; Caporn *et al.* and Anderson similarly comment on such an increase in the Peak District as well. No acceptable standard of evidence has been presented to confirm that the vegetation is approaching the desired NVC communities, though Jepson, based on his professional judgement, believes it to be the case. This observed trend should be factored into decisions about whether intervention is really necessary for each individual site.

It may be worth observing that M18 is also the desired community on degraded but recovering lowland raised bogs, but analysis of communities in which *Sphagnum* has increased over decades, such as at Danes Moss, Macclesfield (Meade, in press) shows the predominant NVC communities to be M2 and M21, even though an analysis using MATCH lists M18 for a few quadrats, albeit with a lower coefficient than for M21. The *Narthecium ossifragum-Sphagnum papillosum* valley mire is a widespread and common community and is populated with similar *Sphagnum* species to those found in M18 and M19. It is important to make sure the tests for favourable condition are sufficiently broad in NVC terms to accommodate these early products of restoration and recovery.

The observed increase in *Sphagnum* in the South Pennines (Caporn *et al*) and on parts of the West Pennine moors (Jepson) contrasts with the very small amount of *Sphagnum* moss recorded in tussocky *Molinia* on Greaves Moss on the Marsden Moor Estate (Underdown & Meade); the name 'Moss' and the reported depth of peat suggest that the management aim on Greaves Moss should be the restoration of blanket mire with communities M18 and/or M19 as the ultimate aim, but that currently there is little evidence of any progress towards that end.

Some presentations focus on blanket mire (Anderson) while others are less specific and broaden the scope to various types of upland heath, especially those in which dwarf-shrubs are well-represented (Perry, Daggett, O'Hara, Wood). *Sphagnum* moss is an important component for some presenters (Pilkington), though it is clear from the NVC accounts in Rodwell (Ed; 1991-2000) that a) *Molinia* is a major component in some heaths (also Meade), and b) *Sphagnum* mosses are well-represented in wet heath communities (M15, M16) as well as the blanket mire types such as M17, M18 and M19.

It is important to be clear about our aims when setting out to control *Molinia*. Several presentations are specific about their management aims, and in several cases it is to reinstate dwarf-shrub heath. This is particularly important in providing the necessary habitat for birds such as Golden Plover (Perry, Daggett, O'Hara, Wood), though the restoration aims described by Daggett for Abergwesyn are primarily for blanket mire. The distinction may not have been so clear throughout the conference, in some cases the implicit assumption being that the aim is to reinstate species-rich blanket mire with copious *Sphagnum* (Glaves), in others that the aim is dwarf-shrub heath, but even then that restoring some blanket mire as well would be a bonus. The historically previous habitat, as deduced from stratigraphy or anecdotal evidence, should act as a guide to its current potential and thus become the aim of restoration.

The desired state – setting the benchmarks – the definition of 'good'

Background

Over the decades there has been a steady pressure for statutory nature conservation bodies to become more accountable. Government sets the agenda, provides the money, and requires evidence of it being spent effectively. As a consequence, for site selection and for assessing condition, our multifaceted biological resource has become more and more compartmentalised. All special sites are evaluated and chosen on their 'attributes' and generic methods have been developed to detect whether or not the condition of each example is 'good' (Stone). As might be expected, the process has its strengths and weaknesses.

Operating the process requires compromises. It pre-supposes that the natural world of habitats can be subdivided into neat boxes and that there is a definable space between one category and another. In practice, the transition between the more obvious types is continuous and the examples on some sites may be poor fits in any particular pre-determined box.

For example, many mires (bogs and fens) are easily identifiable as such, while others merge into wet heath, wet grassland and even wet woodland. Generically, a raised bog in the lowlands is structurally very similar to a raised bog in the uplands[1], though the condition assessment method for a lowland raised bog has evolved differently from the one used in the uplands, being the products of different author groups. When both are applied to the same site they can lead to different conclusion about its condition. For example, there is little doubt that Tarn Moss, Malham, is a raised bog though it occurs at a much higher altitude than most and it would be stretch credulity to describe it as 'lowland'. Applying both the upland blanket mire and valley bog (designed *inter alia* for large expanses of upland 'blanket' peat) and lowland raised bog condition assessments (designed for smaller, discrete peatland sites) it emerges as 'favourable' using the first, but 'unfavourable' using the second (Meade, 2007). It really matters into which box (upland blanket mire or lowland raised bog) you place your site, because it's the only means of knowing whether Tarn Moss is 'good' or 'not so good', *sensu* Stone.

Despite the flaws, such categorisation is essential if statutory bodies are to be able to operate and be accountable for their actions. It places a heavy responsibility on those bodies to make sure their intellectual constructs are based on sound science. These benchmarks cannot be revised at a whim, the risk of doing so being that the whole process and its associated structures, such as SSSI notification and condition assessment, could need to be revised. It is understood (Defra website[2]) that the next few months may be a rare opportunity to review *inter alia* the status of dominant *Molinia* in upland habitats.

At this conference we are concerned with blanket mire and other upland habitats, such as dwarf-shrub heath, because this is where *Molinia* has become dominant. While diversification of the *Molinia* to restore dwarf-shrubs and a more open sward is important for the bird attributes, it is perhaps at the easier end of the spectrum to achieve. By contrast, blanket mire has a more exacting hydrology and is associated with additional ecosystem services such as carbon capture and moderating the speed of release of precipitation water to the lower reaches of the catchment.

Molinia and floristic variation in blanket mire

The structure and flora of blanket mire is far from uniform across the UK. While in the South Pennines we think of blanket mire as occurring on the uplands above a certain altitude, further north and west in the UK it occurs at increasingly lower levels where it becomes more endowed with pools and surface patterning, with more widespread *Sphagnum* moss and other typical bog species; towards the south and east there is a greater tendency for there to be widespread peat erosion and dominance by Hare's-tail Cotton-grass *Eriophorum vaginatum*.

Despite this geographical diversity, condition standards have to be set and applied to individual sites across the country. Although dominant *Molinia* occurs on blanket mire and is assigned to NVC community M25, it is not prominent in the accounts of geographical variation and it is deemed to represent a degraded state, not least, because it is a recent phenomenon (Chambers & Mc Carroll).

This lengthy introduction is provided to illustrate just how difficult it can be to develop a 'watertight' process. Dave Stone sets out the current protocol in his paper, though it may still remain less than totally clear how one moves from the theoretical to say what 'good' looks like on an individual site and whether dominant *Molinia* should have any part in it, say, in the South Pennines, where blanket mire is close to its south-easterly climatic limit.

Two conceptual approaches are cited by Stone for assessing the ecological status of *Molinia*. One is a coincidence with the described composition of NVC plant communities. If the vegetation is M18 or M19, as is expected on 'good' quality blanket mire, the maximum quoted Domin cover (Rodwell (Ed), 1991-2000) for *Molinia* is 4 and 7 respectively. This range excludes the 8 to 10 that would represent its cover when dominant, though a cover of 9 is quoted for NVC wet heath community M15 that may also occur on deep peat. Based on this test and following the logic to its conclusion, dominant *Molinia* can never be acceptable on blanket mire. The strength of the conclusion rests with the acceptability of the initial hypothesis that 'good' blanket mire bears NVC communities M18 or M19, an exclusive decision-path along which blanket mire with dominant *Molinia* is bound to fail. We must be vigilant in making sure that the enormously valuable NVC does not become an intellectual straight-jacket and be used in ways that were never intended by its authors; the tail must not be allowed to wag the dog.

Coincidence with published NVC communities is a rather similar measure to deciding that blanket mire should contain a chosen degree of species diversity (Glaves), and the second is likely to be informed by the first. The key lies in deciding whether dominant *Molinia* on blanket peat can, under any circumstances, be natural or typical; if the answer is affirmative, the next question is 'where and under what circumstances'. Currently, we take the view that it is neither natural nor typical, so 'where and when' is irrelevant.

Molinia and ecosystem functionality

The other approach to establishing an authenticity judgement for dominant *Molinia* is the failure of ecosystem functionality; "*Molinia* dominance is symptomatic of a break-down in ecosystem processes" (Stone). Based on a quick internet search, such processes are variously described as:

- "The physical, chemical and biological actions or events that link organisms and their environment." (*GreenFacts*);
- "The four fundamental ecological processes of ecosystems are the water cycle, biogeochemical (or nutrient) cycling, energy flow and community dynamics, i.e. how the composition and structure of an ecosystem changes following a disturbance (succession)." (Mexican Biodiversity);
- "Water cycle, energy cycle, mineral cycle and community dynamics" (ManagingWholes.com).

Examples of ways in which *Molinia* dominance may be indicative of a breakdown could include:

- decreased ability to capture atmospheric carbon in new peat;
- oxygenation by root penetration and oxidation of peat leading to carbon dioxide and/or methane release;
- release of DOCs[3] and particulates;
- tussocky *Molinia* denying the characteristic avifauna its essential habitat.

On the positive side, no evidence of it leading to an increase in the release of DOCs (Walker)[4] was presented at the conference and it forms a strong root layer able to resist peat erosion.

Although one (bullet 3) is equivocal, it is reasonable to conclude that dominant *Molinia* causes failure in at least four ecosystem processes, though the first three are consequences of the same process. In developing remediation, action is needed to reverse the cause of the *Molinia* dominance, rather than the presence of *Molinia per se*, as it is a consequence of other factors having changed. This is a fundamentally important perspective and, if accepted, helps prioritise what needs to be done. The processes with the highest priority for action are the hydrology (Anderson) and deposition of atmospheric nitrogen, or removing what has already been deposited and stored in superficial peat and plant tissue (Caporn *et al.*).

It is important to be aware that the '*Molinia* problem' is not the only one on these high peat moors in the South Pennines. Much intensive and expensive work has been done over the last two years to re-establish vegetation on bare peat, usually occurring at a slightly higher altitude than the tussocky *Molinia*. It involves adding plant macronutrients (N, P), lime and seeds of a 'nurse' grass crop to stabilise the surface before desired species can become established. It is perhaps ironic that enhanced nitrogen availability downslope of these applications is one of the factors associated with the dominance of *Molinia* (Caporn *et al.*).

Factors responsible for sustaining dominant *Molinia* or its desirable alternatives

Parallel but separate working on closely related habitats is not confined to the development and application of condition assessment protocols. Dominant *Molinia* on drained and cutover lowland raised bog is a similar problem to that in the uplands. The succession on dry abandoned peat cuttings from dense *Molinia* to birch woodland that occurs without intervention is documented by Eigner & Schmatzler (1991) in their handbook for raised bog restoration and underpins the Lower Saxony mire restoration programme dating from the 1970s; a similar concern in the Netherlands is evident, for example, in the studies of the damaging effect of dense *Molinia* on the hydrology of cutover raised bogs by Schouwenaars (1990), also quoted by Pilkington.

All lines of advice and management experience over several decades show that a high and stable water table is necessary to weaken or kill off the *Molinia* and for replacement species such as Cotton-grasses and *Sphagnum* mosses to flourish. The outcomes of such management on parts of the Manchester Mosslands is described in this volume by Thomas; the development of these species to replace dominant *Molinia* on two sites that were similarly managed is described by Meade (1992; 2003; also 'in press').

There are obvious environmental differences between dominant *Molinia* on these lowland bogs and on blanket mire in the uplands. For example, the climate is less harsh in the lowlands, with lower precipitation (depending on its geographical location in the UK), and the land is usually much flatter. It is relatively easy to re-instate existing bunds or build new ones, to impound surface water to keep the peat waterlogged; series of contour bunds may be created on steeper slopes (paddy field analogues), and this is much closer to what could be done on upland blanket mire. Needless to say, such works on lowland bogs are complemented by fastidiously blocking up any drainage constructed for the benefit of peat extraction or agriculture, though weirs with V-notches or overflow pipes have to be installed to manage the water levels within precise limits and to avoid erosion.

Anderson emphasises the importance of hydrology in developing a more diverse blanket mire flora from dominant *Molinia* and this leads on to the need to identify areas in which the hydrology can be repaired. Semantically, repair can only be applied to recognised damage and this in turn requires identification of the damaging features such as drainage, over-steepening and erosion. One way to do this would be to adopt the same approach as Evans *et al.* (2005) in which LiDAR[5] was used to provide a representation of the topography that could be used to identify and prioritise the most easily-restored locations. While commissioning LiDAR is expensive, most of the cost is in getting the aircraft off the ground, and the unit cost diminishes as the in-flight area covered increases. There is often existing cover, and this can be acquired from the Environment Agency at lower cost.

The output can be used to develop a digital terrain model, from which the need for ditch blocking and bund creation can be estimated. It can be used to differentiate between land on which blanket mire has been and could be again, and drier areas where the aim of management should be dwarf-shrub heath.

One element in common between the restoration aims for blanket mire and for dwarf-shrub heath lies in the removal of the dominant *Molinia*. Water-level monitoring on plots in the South Pennines, set up to monitor the success of implanted *Sphagnum* moss (Pilkington), has tentatively shown that the water level in the peat falls less in summer where the *Molinia* has been cleared. It is consistent with the findings of Schouwenaars (1990) on lowland bogs where the water loss by evapo-transpiration is high from tussocky *Molinia*. Its roots penetrate the peat to many tens of centimetres gaining access to water that needs to be retained for the survival of *Sphagnum* mosses and shallower rooting ericaceous species and Cotton-grasses.

Managing the water table to keep it within a few centimetres of the surface is not just to weaken or kill off the *Molinia*. It is also necessary for the survival, establishment and growth of *Sphagnum* mosses; this is one of the most important structural components of 'good' blanket mire, and present in a range of acceptable NVC plant communities, including wet heath, e.g. NVC communities M2, M17, M18, M19 and M21.

Molinia is able to respond by growing more robustly than its rivals in response to exogenous macronutrients such as nitrogen (Caporn *et al.*; Walker). Historically, there has been very high atmospheric deposition of nitrogen and sulphur compounds from the burning of fossil fuels and even now they are above the critical loads[6] for blanket mire (Caporn *et al.*). Once assimilated by the grass, the nutrient is either retained in the tussock by reabsorption or recycled by decomposition of the leaves that die in the autumn (Walker). While reducing atmospheric deposition is dependent on the implementation of emission controls and beyond the means of most land managers, practical steps to remove the accumulated nitrogen are more possible. It is currently the practice to leave severed *Molinia* tussocks in windrows but this does have the disadvantage that stored nutrients will be released by decomposition and become available to recruited seedlings. It would be better to remove cut material, or at least store it where the products of decomposition are lost from the ecosystem.

Grazing is clearly a very important determinant of vegetation in the uplands. It is widely believed, for example, that overgrazing by sheep is responsible for a transition in acid grassland to dominant Mat-grass *Nardus stricta*; excessive grazing, such as occurred in the past when agricultural incentives encouraged overstocking, can lead to complete denudation of the peat, resulting in severe peat erosion. Accounts from managed upland peat areas (Wood, Perry, Daggett) all emphasise the importance of introducing the 'right' grazing regime, with cattle reported as preferred in the Upland Evidence review (Glaves), and the need to allow dwarf-shrubs to become established before it is introduced. While grazing of tussocky *Molinia* may break open the sward and allow other plants to develop, the process can be speeded up using herbicides (Marrs *et al.*).

Much of the discussion at the conference involved the role of agriculture in achieving the conservation aims. Clear differences emerged quite strongly at times, showing that the perception of each side by the other is still somewhat stereotyped and not always positive. While these Proceedings can flag it up and point out the importance of agricultural practice in producing the types of habitats required by nature conservation, no easy solutions were suggested. The accounts of how important the choice of grazing animals can be have been highlighted by Daggett, Perry and Wood, with some insights into the difficult economics that need to be right for the farmer. Taking the view that 'it was forever thus' is not an acceptable way forward and we really do need to generate a culture of shared values and trust in order to make progress. We also need the right financial incentives and this is a matter for government and its advisers.

Restoration aims

- The Proceedings includes four papers centred on restoring dominant *Molinia* to something else. For easy reference, these are:
- *Molinia* reversion on Derwent & Howden Moor: Looking at the techniques and results of restoring *Molinia* dominated blanket bog and dry heath. C. Wood.
- Cutting *Molinia* to improve habitat for Golden Plover, Abergwesyn Common. Sharing experience: An account of management techniques used and a critique of their usefulness. J. Daggett.
- Changes in the grazing regimes on Elenydd Site of Special Scientific Interest and the experimental management of *Molinia caerulea*. K. Perry.
- *Molinia* diversification trials on Pennine moorland near Huddersfield, West Yorkshire, UK. M. Pilkington.

One bullet acknowledges there are two different habitats to aim for, one is to improve the habitat for birds and two are less specific in what the target habitat should be. Between them it is possible to generalise that there are at least two different habitats to aim for, that birds will benefit and that almost anything would be preferable to a *Molinia* monoculture.

The first three projects concentrate on combinations of cutting and grazing, and useful detail is supplied for those wishing to do similar work. The paper by Marrs *et al.* also comes in here, because it describes the use of herbicides, partly as a surrogate for cutting, but also in combination with follow-up grazing. All stress how different is each site and that bespoke prescriptions have to be put together for every example. One interesting approach was to use the available effort to cut trackways into the dense *Molinia* so that grazing animals would follow the easy route and then access the uncut grass next to it.

The last (Pilkington) concentrates on changing the balance between *Molinia* and *Sphagnum* cover by cutting and/or grazing the grass and at the same time adding moss propagules as various preparations in nutritive gel or as implants of *Sphagnum* 'posies'. So far there is insufficient information to judge how well the various *Sphagnum* inocula have performed, but potential users may also wish to keep an eye on the Cumbria BogLIFE project in which a number of techniques, including gel-coated propagules, are being explored to achieve much the same thing on sites such as Bolton Fell Moss, an 'intermediate' mire having many similarities with blanket mire. One innovative technique used elsewhere and also in BogLIFE is the harvesting of 'pleurocarpous' mosses such as *Hypnum cupressiforme*, a plentiful species on heathland, to protect young *Sphagnum* in much the same way that Canadian bog restorers (Rochefort *et al.*, many papers) use straw – which, at least in Cumbria, is inclined to blow away.

Amongst the many lessons to be learned from these papers is the need to:

- Be clear about your management aim – blanket mire (including bog) or dwarf-shrub heath;
- Assess the atmospheric nutrient loading and judge if it is just too high for blanket mire;
- For blanket mire make sure you can provide sustainably high waterlogged conditions;
- Carry out trials with various types of *Sphagnum* implant before committing to expensive sources;
- Do not wildly scatter expensive propagules based on a wing and a prayer unless you have endless resources;
- Be prepared to carry out follow-up management for an unknown period when cutting or using herbicide;
- Talk to others managing similar habitats – there is a strong need for networking;
- Extend the networking into the lowland 'parallel universe';
- Above all, monitor your success and make sure the rest of the world has access to your expertise!
- Reciprocally, make sure you are aware of what the rest of the world, particularly Europe, is doing.

Decision-tree for habitats to replace dominant *Molinia*

As has already been discussed, dense *Molinia* has developed in wet peaty environments in the uplands spanning a range of soils from deep to shallow peat and has occupied former habitats ranging from blanket mire to dwarf-shrub heath. Land managers are faced with a range of factors affecting the outcome of various interventions, and their decisions need to be tempered by the relative nature conservation benefits envisaged by statutory nature conservation bodies for each of the possible outcomes.

The following collation of these factors and possible outcomes is affected by a number of things. There are no certainties. The outcome will be influenced by the determination of the manager and the amount of resources available to 'drive' the change in the required direction. Some things are fixed, such as the landform, past accumulation of peat and the changes the vegetation has gone through in the past. Rather, the likely outcome from a particular set of circumstances is expressed as 'presumption in favour of' and 'presumption against', based on an intuitive computation of probabilities.

Each factor is considered in isolation and the land manager will need to look at all of them and make judgements based on the which habitat outcome is presumed to be the more likely in most, also taking account of the strength with which each ‘presumption’ is given.

Critical loads of nitrogen deposition are given for a range of habitats by the Air Pollution Information System (APIS). As kg per hectare per year, this is currently set at 5-10 for raised and blanket bog and 10-15 for wet heath, the nearest analogue to dwarf-shrub heath for which a figure is quoted. It means that blanket mire is more sensitive to nitrogen deposition than dwarf-shrub heath. It is likely that deposition figures for a particular location can be found in publications such as NEGTAP (2001) though these figures are obviously dated.

Presumption for target habitat
N deposition close to or below 5 – 10 kg ha^{-1} yr^{-1}. **blanket mire**
N deposition above 5 – 10 kg ha^{-1} yr^{-1} but around or below 10 – 15 kg ha^{-1} yr^{-1}. **dwarf-shrub heath**
N deposition above 10 – 15 kg ha^{-1} yr^{-1}. **management likely to be unsuccessful**

Topography

While it would be possible to set thresholds based on degree of slope, this would vary geographically and is more universally applicable if described as any land, flat or sloping, on which *Molinia* is currently dominant. It is likely to be correlated with peat thickness, in that it accumulates at a higher rate and to a greater depth on watersheds and in or over sumps where the land is flat.

Blanket mire is often described in terms of its macrotope, or widest possible hydrological entity in which a particular site-based example is found. In practice, an original macrotope has become dissected by land ownerships and types of use or management into what are now recognised as sites[7]. Habitat restoration is often to be applied to a site, which then has to be interpreted in eco-hydrological terms for it to make sense. A pragmatic approach is to divide a site into flattish land with deeper peat (say, >30cm) and sloping land that may have <30cm of peat, more akin to the ‘B’ horizon of a podsol. While the resulting piece of land is considered in isolation, in reality its viability needs to be assessed in relation to adjoining land that may not be available for management.

Presumption for target habitat
Land flat or of gentle slope; peat >30cm deep. **blanket mire**
Land sloping, peat <30cm deep. **dwarf-shrub heath**

Evidence from peat stratigraphy

Any vertical cutting shows that peat is made up of layers that have different appearances. Some may be black and without obvious bits of dead plant, others may be lighter, orange, and contain recognisable plant fragments such as rhizomes of *Eriophorum vaginatum* and intact strands of *Sphagnum* moss species. These are all clues to the conditions prevailing within the landform before *Molinia* became dominant and so can show whether the necessary conditions have the potential to be re-created. It provides more evidence for whether a particular site, or part of a site, has the potential for mire, wet heath or dry heath.

A black, putty-like peat with no recognisable plant fragments is typical of a relatively dry environment, such as may be found in wet or damp heath; it is often the only type of peat where the total deposit is thin. By contrast, although a blanket mire may contain similar strata, it is likely to be interspersed with other types in which the plants mentioned above are evident. Although the hydrology may have been changed since these indicative peats were laid down, its presence shows that the basic unmodified landform has the potential to support blanket mire.

Presumption for target habitat
Peat thick (>30cm), stratum colour variable, identifiable plant remains in some. **blanket mire**
Peat thin (<30cm) entirely black and putty-like. **dwarf-shrub heath**

Natural hydrology

This may be expressed in various ways to demonstrate its suitability for peat formation, as in active blanket bog. One is the precipitation:evaporation ratio, an excess of precipitation over evaporation being necessary to keep conditions sufficiently wet for peat formation. Another is that the saturated zone within the peat should not fall more than about 15cm below the surface for a significant period of time. A third is defined by the Irish-Dutch LIFE project peat bog study (Schouten (Ed.), 2002) as acrotelm capacity. In this, the flow pattern and length of flow path of the atmospherically-sourced water are strongly correlated with the development of the bog acrotelm, the free-draining surface layer made up of living and recently dead plant material; in quality bog, the acrotelm has a high proportion of *Sphagnum* mosses contributing to its biomass.

To some extent, the simple dipwell, in which the water level in the inserted tube represents the top of the saturated zone within the peat, provides a proxy measurement of these contributory hydrological factors. There is often no indication as to whether a high water level in the dipwell does represent the upper limit of the bog catotelm, or if it is periodically replenished by surface flow. Whichever, it provides a relatively simple way of deciding whether the site or sub-site is suitable for management as blanket mire.

It is important to distinguish historical and potential hydrology from that which might currently be in place because of drainage or other water management. The second is considered separately. If there is no evidence of artificial drainage and the water table is already low, then the only available remediation may be that of removing the established *Molinia* tussocks and the enhanced evapo-transpiration associated with them. There is little evidence on which to base a threshold, but it is suggested that this might provisionally be set at 40cm below ground level (BGL); this should not be seen as absolute and recorded experience is needed to define a more accurate figure. Meanwhile, a recorded water table of lower than 40cm BGL should not in itself be taken as a reason for abandoning attempts to recreate characteristic blanket mire in appropriate locations.

Presumption for target habitat
Groundwater minimum <25cm BGL as it stands. **blanket mire**
Groundwater minimum >25cm BGL with prospects for raising by water management. **blanket mire**
Groundwater minimum <40cm BGL, no prospects for management. **dwarf-shrub heath**
Groundwater minimum >40cm BGL, probably **dwarf-shrub heath** with or without management, but see caveats explained above.

Drainage

The category includes works for which this was the primary aim and others from which it has become a consequence. For example, parallel moor-grips deliberately lower standing water, enabling grasses and dwarf-shrub heaths to out-compete Cotton-grasses; over time, their effect through the confining of flowing water in channels may be to cut deeply into the peat, exacerbating the extent and degree of drainage. Capture of surface water into canal-feeding reservoirs via leats may also interrupt the natural flow of surface water that could otherwise sustain mire.

The aim of water management for mire is to slow down the loss of atmospherically-sourced surface water by blocking ditches to the degree that flow once more occurs in wide water tracks, contributing to the acrotelm capacity. Given the difficulties often experienced with gulley blocking in deep peat, and the tendency for sub-peat 'pipes' to form and then cave in, a judgement has to be made as to whether any particular eroded drain is reparable.

A judgement also has to be made as to whether the development of blanket mire vegetation on a gentle slope, particularly where some is already present, could be assisted by the creation of low contour bunds to slow down the loss of water and consequently increase its residence time for the growth of *Sphagnum* mosses.

Presumption for target habitat
Drains cut for agricultural improvement easily blocked **blanket mire**
Surface-water interceptive drains decommissioned **blanket mire**
Potential for contour bunding **blanket mire**
No reasonable prospect of reversing the drainage **dwarf-shrub heath**

Encouraging plants already present and introducing others

It is noted on the Marsden Moor Estate that scattered hummocks of a range of *Sphagnum* moss species already occur under tussocky *Molinia*, though their stressed appearance suggests that their spread is likely to be very slow. Although a similar range also occurs in wet heath and so does not unequivocally show a presumption for mire restoration, it is more so than if they were absent. A concept of 'critical mass' is supported by some bog restorers (e.g. Zandstra, Meerstalblok Reserve, the Netherlands, 1990s, pers. comm.) by which *Sphagnum* appears to gain control of the environment to a degree that it can suddenly expand massively in extent.

There is also a strong desire to reduce the waiting time by scattering viable fragments of *Sphagnum* moss, though it is arguable whether there is a strong likelihood of success from these if some have not already established naturally, unless accompanied by a change in the hydrology for the better.

While *Sphagnum* is taken as a potent symbol of healthy blanket mire, perhaps because of its strong association with peat deposits, stratigraphy shows that other species, such as *Eriophorum vaginatum* and *E. angustifolium* are also strongly associated with peat formation, sometimes almost to the exclusion of *Sphagnum*.

It follows that the presence of plants associated with peat formation, or evidence that they can be established, provides a presumption in favour of blanket mire restoration. In their absence, dwarf-shrub heath might be a more achievable aim.

Presumption for target habitat
Presence of plants associated with peat formation. **blanket mire**
Evidence that plants associated with peat formation can be established. **blanket mire**
No such evidence. **dwarf-shrub heath**

Availability of management tools

It is clear from the presentations that the tools required to convert dominant *Molinia* into either blanket mire or dwarf-shrub heath may not always be available. If there are not the means to clear the tussocks then the only option is to hope *Molinia* can be weakened by managing the hydrology towards wetter and waterlogged conditions. No such option is available to create conditions for dwarf-shrub heath. It may be that the use of herbicide is cheaper than mechanical clearance, but its use may be contrary to the policy of some conservation bodies.

Presumption for target habitat
Insufficient resources to clear tussocks away **options reduced**
Insufficient resources to clear tussocks away but ability to raise water table cheaply **blanket mire**
Insufficient resources to clear tussocks away, site remains dry no change **tussocky *Molinia***

The 'presumptions' are summarised in Table 1.

*Table 1. Synopsis of the decision-tree**

Factor	Criterion	Presumption for
Air and water quality	N deposition close to or below 5 – 10 $kg^{-1}/ha^{-1}/yr^{-1}$	blanket mire
	N deposition above 5 – 10 $kg-1/ha^{-1}/yr^{-1}$ but around or below 10 – 15 $kg^{-1}/ha^{-1}/yr^{-1}$	dwarf-shrub heath
	N deposition above 10 – 15 $kg^{-1}/ha^{-1}/yr^{-1}$	no change
Topography	Land flat or of gentle slope; peat >30cm deep	blanket mire
	Land sloping, peat <30cm deep	dwarf-shrub heath
Evidence from peat stratigraphy	Peat thick (>30cm), stratum colour variable, identifiable plant remains in some	blanket mire
	Peat thin (<30cm) entirely black and putty-like	dwarf-shrub heath
Natural hydrology	Groundwater minimum <25cm BGL as it stands	blanket mire
	Groundwater minimum <40cm BGL with prospects for raising by water management	blanket mire
	Groundwater minimum lower than BGL, no prospects for management	dwarf-shrub heath
	Groundwater minimum lower than BGL**	dwarf-shrub heath
Un-natural hydrology (drainage)	Drains cut for agricultural improvement easily blocked	blanket mire
	Surface-water interceptive drains decommissioned	blanket mire
	Potential for contour bunding	blanket mire
	No reasonable prospect of reversing the drainage	dwarf-shrub heath
Encouraging plants already present and introducing others	Presence of plants associated with peat formation	blanket mire
	Evidence that plants associated with peat formation can be established	blanket mire
	No such evidence	dwarf-shrub heath
Availability of management tools	Insufficient resources to clear tussocks away	options reduced
	Insufficient resources to clear tussocks away but ability to raise water table cheaply	blanket mire
	Insufficient resources to clear tussocks away or graze heavily, site remains dry	stuck with *Molinia*

*Presumptions arising from consideration of the factors need to be taken 'in the round'. They need to be applied to a homogeneous sub-site defined by a combination of desk exercises and field checking. This table must not be applied without first reading and understanding the accompanying text. **See caveats in the text about use of the provisional 40cm BGL threshold

Notes

[1]A raised bog is a product of acid peat accumulation to form a slow-growing, gently domed structure, irrigated by atmospheric water, draining towards a fen-like lagg around its edge.

[2]It is understood from the Defra website that some Common Standards Monitoring Guidance is under review.

[3]Dissolved organic carbon making potable water a yellow-brown colour.

[4]Though a specialist in United Utilities has expressed the contrary view that DOC release from dominant *Molinia* is higher than from more botanically diverse blanket mire vegetation arising from restoration works (K Perry, pers. comm.)

[5]Lidar (also written LIDAR, LiDAR or LADAR) is a surveying technology that measures distance by illuminating a target with a laser light. Although thought by some to be an acronym of Light Detection And Ranging, the term lidar was actually created as a portmanteau of "light" and "radar". Lidar is popularly used as a technology to make high-resolution maps, with applications in geodesy, geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, atmospheric physics, airborne laser swath mapping (ALSM) and laser altimetry. What is known as Lidar is sometimes simply referred to as laser scanning or 3D scanning, with terrestrial, airborne and mobile applications. (*Source: Wikipedia*).

[6]In the study of air pollution, a **critical load** is defined as *"A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge"*. (Nilsson and Grennfelt 1988). (*Source: Wikipedia*).

[7]A site is unit of land, usually with a defined boundary, arising from the way land has been split up for various uses. It does not necessarily coincide with an ecological entity, such as a hydrological unit or blanket mire macrotope.

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Annex 1: ‘Managing *Molinia*’: Conference Evaluation Report

Background

The ‘Managing *Molinia*’ Conference was organised by the Marsden Moor National Trust team and received financial support from Natural England and International Peat Society. Conference sessions were held at Huddersfield Town Hall on 14 September 2015 (day and evening) and 15 September (day). A field trip was held on 16 September 2015. Approx 90 delegates registered and attended the conference; some delegates registered and attended only on specific days. Just under half the delegates attended the evening session and about half registered and attended for the field trip.

The Conference Planning Group comprised Roger Meade (Chair, NT volunteer), Craig Best and Bob Henry (Marsden NT staff team), Nick Pollett, Alan Stopher and Andrew Underdown (NT volunteers). This report includes findings/comments from an online survey which delegates were invited to complete after the conference. The report also draws on the comments and observations of planning group members.

The Online Survey

The online survey was made available on the SurveyMonkey platform at no cost. Fifty-seven delegates responded; this is a good response rate (approx 63%) for a survey of this kind.

Delegate views of the conference (in terms of quality and relevance)

Figure 1. Overall view of quality and relevance

Table 1. Ratings of usefulness/relevance of each session

	Not useful/ relevant	A little useful/ relevant	Quite useful/ relevant	Very useful/ relevant	Did not attend	Total responses
Day 1: Daytime sessions	3.63% 2	0.00% 0	21.82% 12	74.55 % 41	2	57
Day 1: Evening session	6.67% 2	3.33% 1	40.00% 12	50.00 % 15	25	55
Day 2: Daytime session	2.00% 1	2.00% 1	18.00% 9	78.00 % 39	4	54
Day 3: Field trip	0.00% 0	2.86% 1	22.86% 8	74.29 % 26	18	53

Table 2. Ratings of usefulness as a networking event

Not useful/relevant	A little useful/relevant	Quite useful/relevant	Very useful/relevant	Total
3.51% 2	1.75% 1	31.58% 18	63.16% 36	57

Commentary

- 95% of delegates rated the overall event as good or excellent (Figure 1).
- Around three quarters of delegates described the main sessions of conference and the field trip as 'very useful and relevant'. (Table 1)
- 95% of delegates said that the event was very useful or quite useful as a networking event. (Table 2)

Here are some delegate comments which reflect this overall positive view of a very relevant and useful event:

'Broadly the standard of most presentations was good to very good and covered a good range of related and relevant topics around the theme of Molinia'

'Good well balanced programme overall especially the mixture of academic research and case studies from around the country'.

'Really good event - very useful to get so many partners and organisations together in one room to discuss and share ideas on key management issues'

'I thought all the sessions were relevant, the whole conference was well structured and the content was excellent throughout'.

'I can't fault the course at all. This is the best and most useful training course I've been on in well over a decade. It was incredibly good value for money'.

Views and comments on the programme

When asked what they found most useful, most delegates (about three quarters) wrote about a range of elements in the programme, rather than singling out only a specific session (based on 46 responses). This confirms their views expressed in the ratings – that all or most of the components of the conference were useful to most people. Here are examples of the positive comments about various elements of the programme:

'The wide mix of papers covering different aspects of the issue, workshop/discussion and field visit.'

'Presentations by experienced ecologists'

'Listening to a range of views from research and best practice across the talkers'

'Great mixture of people and opinions'

'I enjoyed the field excursion particularly as the sites were ones that I deal with within my day to day work'

'Being able to network and hear about the work that has been carried out.'

The planning group had opted to develop topics and membership of break out groups 'live' during the conference in order to be responsive to issues being raised. This was hard to arrange seamlessly in the time/space available and there were a few comments about this. A few responses came from delegates who had a general (pre-existing) view that workshop/discussion time at conferences is less valuable. The planning group was aware that delegates would vary in their preferred learning style and felt it important to include an opportunity for small group discussion for those who find this valuable for their learning.

Perspectives by background/ area of interest

Table 3. Delegates' areas of professional interest

Answer Choices	Responses	
Conservation management	61.40%	35
Academic/ scientific	14.04%	8
Farming/ gamekeeping	8.77%	5
General management	5.26%	3
Other	10.53%	6

Delegates who described their area of professional interest as Conservation Management formed a majority of conference delegates. (Table 3) This key group had high satisfaction ratings. Over half described the event as excellent; 34 out of 35 described the conference as good or excellent.

‘Farmer/Gamekeeper’ was a smaller group in the conference (6 delegates, 5 responses). These delegates did not rate the event quite as highly as the majority ‘Conservation management’ group – nevertheless, 3 out of 4 delegates gave ‘Very useful’ ratings to parts of the programme. Some comments expressed the view that these perspectives should have been more fully represented in conference inputs:

‘Having a speaker talking of the users perspective and the importance of the Molinia, blanket bog, moorland to them, whether it is a gamekeeper rearing grouse or a farmer that depends upon the grazing to make his farm unit viable’.

Conference arrangements

Table 4. delegates views on the conference arrangements

	Poor	Satisfactory	Good	Total
Pre conference information and registration	1.79% 1	26.79% 15	71.43% 40	56
Venue and food	1.79% 1	39.29% 22	58.93% 33	56
Transport	0.00% 0	20.41% 10	79.59% 39	49

There were a few comments about the limitations of the conference room:

Most delegates considered the venue to be good (Table 4).

Might be worth booking a bigger room – it was a bit small, and the chairs too close together for comfort.

However, overall ratings are quite satisfactory and there were also positive views expressed about the facilities:

Fantastic venue - beautiful building and very helpful staff. Good to have long coffee and lunch breaks to network

A follow-up event?

Table 5. Delegates’ views on a possible follow-up event

Yes	91.07% 51
No	8.93% 5
Total	56

A high proportion of respondents would be interested in any available follow-up (Table 5). A couple mentioned that a follow-up should be shorter (two days or one day). Suggestions for a follow-up were varied; some could be covered in a single event, others could not. One theme was a continuing interest in learning about research and trials:

‘An opportunity to discuss specific research and management in parts of the UK’

‘More case studies and any recent research on control techniques and hydrological characteristics associated with good and poor molinia stands.’

‘More scientific or factual findings based on Molinia trials’

‘Some poster sessions of other work’

A few respondents were interested in further field visits:

'Field visits to a wider range of sites with active Molinia management/restoration.'

'Useful to have a trip to look at good quality mires elsewhere to help inform the vision for Molinia- dominated peatlands'

'An extended variety of treatment options on the field trip... being able to compare herbicide treatments with cut treatments.'

Some were looking for opportunities to consider other perspectives:

'A presentation to cover wildfire and its effect on the environment, livelihoods and future of the moors.'

'Presentation from farmers actually under taking the Molinia and land management'

'Engagement with both the farming and sporting communities.'

'Would be good to have more practitioners (esp farmers) speak!'

'Livestock grazing and sustainable marketing'

Others wanted further chances to discuss implementation issues:

'Time to discuss ... about implementation of techniques...'

'A day specifically to look at options and choices would be good. We often fall into the trap of doing some for the sake of it and not thinking about not doing anything as an option.'

Some comments referred to the issue of geographical range:

'Lowland element would be useful'

'It would be good to be clear about any geographical limitations to the discussion – i.e. whether focussed on South Pennines in particular, or Molinia in general.'

Several comments referred to other vegetation management issues which could benefit from an event along the same lines:

'Wider moorland vegetation restoration – managing heather dominance, perhaps in collaboration with NT Peak District Estate?'

'It would be good to see other habitats or management issues covered in the same depth as this.'

'Any specific management issue is worth targeting in an event like this ... Maybe the Natural England evidence reviews can be used to target other themes – where info is poorly evidenced in published papers/books but practitioner info maybe available.'

Conclusion

The evaluation evidences that delegates found the event to be very relevant and expressed high levels of satisfaction. Delegates made some useful comments/suggestions which would be relevant to planning any follow-up or event of a similar kind.

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Compiled on behalf of Molinia Conference Planning Group December 2015

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Clumps of mixed Sphagnum species planted during *Molinia* diversification trials on Burne Moss near Huddersfield (paper by Mike Pilkington refers). Photograph by Alan Stopher.

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NE part funded the conference through the upland network and had speakers and presenters at the event and field visit.

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