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A comparison of reintroduction and natural recolonisation by *Sphagnum* on degraded blanket mire

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Introduction

Blanket bog is classed as a priority habitat under the EU Habitats Directive and there are c.25,000km^2 in Britain. Indeed, Tallis (1998) noted that 95% of blanket bog within the UK is designated as a Site of Special Scientific Interest (SSSI) or Special Area of Conservation (SAC). These mires are extremely diverse habitats and provide numerous ecosystem services such as water filtration and carbon sequestration, with peatlands globally storing 30% of all land-based carbon (Maddock, 2008). The *Sphagnum* mosses are keystone species central to the ecological functioning of bog habitats. They sequester more carbon in temperate and northern ecosystems than any other vegetation and *Sphagnum* mosses can hold up to 20 times their weight in water. They decompose slowly under anoxic conditions to form peat (Carroll *et al*., 2009).

However, only 4,000km^2 of Britain's blanket bogs are still in a state approaching a natural condition; with 74% being degraded and classed as in either unfavourable health or unfavourable recovering health (Anderson, 2016). The Dark Peak has a particularly long history of ecological damage, with modification to blanket bog areas occurring since the 1300s with an estimated 80 million cubic metres of peat being removed for fuel use (Ardron, 1999).

Intensive degradation has also resulted from widespread drainage of areas of moorland for livestock grazing. This has caused a transition of vegetation to dry heathland, as wet bogs are unsuitable for livestock grazing and can result in the animals developing foot rot (in the case of sheep) or becoming mired. This also makes the areas more suitable for Red Grouse *Lagopus lagopus scotica* shooting as Heather *Calluna vulgaris* becomes increasingly dominant and there may be associated managed burning. In areas such as the South Pennines there is also the adverse impact of gaseous and particulate air pollution from nearby industrial and urban centres. During the 1970s and 1980s there was a tenfold increase in anthropogenic SO_2 emissions that fell as acid rain on the neighbouring countryside (Mylona, 1996). Core samples analysed from Bleaklow (SK0925495938) and Kinder Scout (SK0851787520) showed a correlation between the increase of soot contaminants in the upper 10cm of the surface peat deposits and the dramatic decrease of *Sphagnum* around this time (Tallis, 1988). Increased concentrations of sulphuric acid within the peat have led to displacement of calcium, magnesium and potassium ions, resulting in increased leaching and nutrient loss and reduced pH. Between 1880 and 1991 6,400kg/ha of wind-blown sulphur from centres of industrial activity was deposited on the Southern Pennines compared to 1,580kg/ha deposited in the Northern Pennines (Carroll *et al.*, *loc. cit*).

With leaves being only one cell thick and easily damaged, *Sphagnum* mosses are extremely vulnerable to the impacts of air pollution (Thompson & Bottrell, 1998). The effects of this pollution led to the Peak District and South Pennines being described as an ecological desert for *Sphagnum* and classed as one of the most degraded areas of blanket bog within the UK (Ferguson & Lee, 1983). A loss of *Sphagnum* leads to altered hydrology with the bare peat becoming extremely susceptible to drying and wind erosion. Over time, this reduces the water-table to below that of the acrotelm layer, making the system vulnerable to flash flooding during heavy rain events as there is no or very little vegetation present capable of holding water. A consequence of this has been the formation of large erosional gullies as throughflow and storage decreases, and surface runoff increases (Pilkington *et al.*, 2016). Drier conditions promote the growth of grasses and dwarf shrubs, further making the conditions less suitable for *Sphagnum* re-establishment and effectively creating heathland (Thom *et al.*, 2019).

Due to the severity of the ecological damage that has occurred in the Peak and the Pennines, re-establishing *Sphagnum* has been problematic. Despite *Sphagnum* dispersing long-distance by air-blown spores, it has been argued that a lack of local source material has meant that *Sphagnum* could not recover naturally in many areas even as pollution decreased and conditions improved (Caporn *et al*., 2018). Consequently, emergency action plans were developed to deliver landscape scale restoration on degraded areas of blanket bog that were presumed to be beyond natural recovery (Carroll *et al*, 2009). A variety of propagules were developed as ways to reintroduce source material: plugs, clumps and beads with gel have all been used. Survival monitoring trials showed effectiveness of 99%, 36%, and 0-12% respectively. However, cost is also an issue with plugs the most expensive at £10.44/m^2 per degraded bog area, clumps at £3.15/m^2 and beads and gel at £1.04/m^2; cost-benefit analysis indicates that clumps were the most effective at £9.00/m^2 of established *Sphagnum*. Nevertheless, due to the lack of donor material and worries over the potential impacts on donor sites, plugs were taken forward as the main propagule method (Caporn *et al.*, 2018).

The content of the main *Sphagnum* propagule used in restoration has differed between sites. Black Hill, the first Moors for the Future Partnership (MFFP) site to be restored, was predominately planted with beads containing Flat-topped Bog-moss *Sphagnum fallax* as it was the first species available in propagule form. Often used as one of the main species of *Sphagnum* in reintroductions, *S. fallax* is described as a pioneer species due to it being more tolerant to lower pH and higher nutrient levels (Hayward & Clymo, 1982). This is an effective way to quickly establish *Sphagnum* cover but can result in a high density of a single species becoming dominant. *Sphagnum* can occupy a variety of niches so a diverse mix of species can be found in a healthy blanket bog and a benefit of the plug propagule is that 11 or more moss species can be contained within the plug (Table 1). This potentially produces a more diverse *Sphagnum* cover rather than a predominance of one species (Caporn *et al.*, 2018). However, there are concerns that diversity within reintroduced *Sphagnum* areas will only increase if the different species within the plug are able to establish and colonise effectively.

Table 1. The composition of *Sphagnum* species in MFFP plug plants (Caporn *et al*., 2009)..

Sphagnum Species	**Percentage of total volume of sphagnum**		**Percentage of total volume of sphagnum**
S. fallax	20-30%	*S. subnitens*	5-10%
S. palustre	20-25%	*S. denticulum*	1-3%
S. capillifolium	8-15%	*S. magellanicum*	1-3%
S. cuspidatum	8-15%	*S. squarrosum*	1-3%
S. fimbratum	8-15%	*S. tenellum*	1-3%
S. papillosum	8-15%		

However, there are areas within the Peak where *Sphagnum* has re-established itself without the need for intervention. Studholme (1989) surveyed seventeen sites in the 1980s that had historical records of *Sphagnum* prior to its severe decline; three still had *Sphagnum*, one of which was White Path Moss on the western edge of Sheffield (Carroll *et al.*, 2009).

Vegetation trajectories produced by MFFP indicate that an initial increase in shrubs such as Heather on managed areas was due to increased nutrient input from the first stages of restoration, but this may decline as mosses become more abundant and nutrient input is lowered. (Many Pennine restoration areas were also initially restored with heather bales flown in by helicopter and spread over the bare peat. This meant an abundance of heather blown seed in the area.) Recognising how *Sphagnum* cover and species diversity vary on recovering sites and how *Sphagnum* reintroduction affects these, is therefore helpful in assessing recovery and guiding future conservation. Improved understanding can help guide further restoration and protection of UK blanket bog. This paper explores how *Sphagnum* cover and diversity differ between managed and unmanaged historically degraded upland blanket mires.

Methods

Representative study sites were selected and surveyed with 2m x 2m quadrats along carefully chosen transects. Random sampling of the area was not used as it would not provide a reliable overview of the site (Rochefort *et al.*, 2013). For each quadrat the number of *Sphagnum* species was assessed and the associated percentage cover of each evaluated. All other higher plants present were noted. *Sphagnum* guides such as the UKEconet online guide (UKEconet.org) and Liane *et al*., (2018) were used to assist identification. Site walkovers were undertaken to photograph areas rich in blanket bog species. At each site a series of detailed photographs was also taken along the route. Indicative pollutant levels were determined from analysis of bog pool samples (Table 2).

Table 2. Test method for pollutants tested from bog pool samples.

Test	Reactant Tablet	Test Method
Phosphorous	Phosphorous No1 and No2	Palintest
Ammonia	Ammonia No1 and No2	
Sulphur	Sulphate	
Nitrate	Nitratest powder and Nitricol	

Case Study 1: Severely degraded site with managed *Sphagnum* reintroduction

This site is located in the Heyden Head area of Black Hill, the most northerly of the three gritstone plateaux that dominate the Dark Peak at over 500m in elevation (Figure 1). It forms a large dome between the Longdendale Valley and the road from Saddleworth to Holmfirth and is deeply cut by three large streams within Crowden Great Clough, Crowden Little Clough and Heyden Clough (Twynham, 2019). The location of the transect line coincides with the location of early *Sphagnum* reintroduction on the site. The summit's trigonometric point known as 'Soldier's Lump' lies at 582m AOD. However, since its construction circa 1970 considerable drainage, pollution, and subsequent peat erosion have exposed the trig point foundations. The extent of peat and vegetation loss from when MFFP started work is shown (Figure 2a).

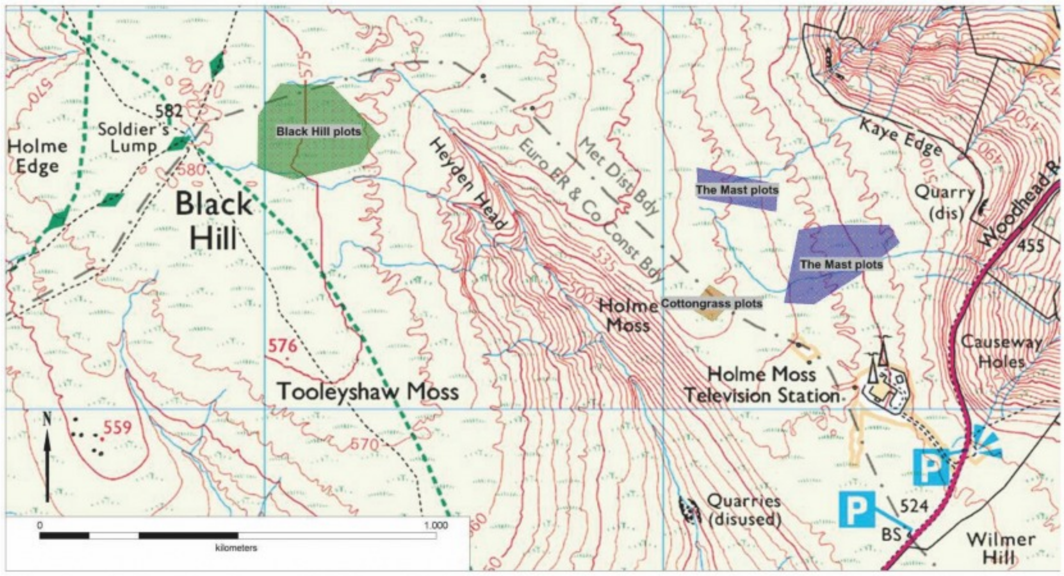

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Figure 1. The MFFP plots at Black Hill (Wittram, et al., 2015)

(2a) 2003	(2b) 2008

Figure 2. Views of Black Hill (SD 78198 36665) showing recovery. See Back Cover for an image from 2017.

The subsequent images (Figure 2b and Back Cover) show the temporal improvement after restoration where fifty million *Sphagnum* fragments were spread across the plateau (Twynham, 2019). The site runoff was also impeded through grip blocking.

Case Study 2: Previously degraded site with no management

White Path Moss located on the south-western edge of Sheffield lies at 400m in altitude and occupies a shallow depression to the north-east of Stanage Edge. A detailed investigation into this site in 1947 by Conway identified it as 'modified' blanket bog with a dominance of Common Cottongrass *Eriophorum angustifolium*. However, analysis of peat cores revealed the base for the peat was *Sphagnum* (Tallis, 1964). A survey conducted at the time found that the dominant *Sphagnum* was *S. fallax* with a note made of the eastern area of the bog being more degraded than the western side. The only drainage outlet for the bog is Burbage Brook that cuts through the middle, running from the north-west to the south east. Bore-hole samples showed that the water table was at surface level, nearly all the existing water channels on site were younger than the main peat mass, meaning that they were man-made and had been dug for drainage purposes over time (Conway, 1947).

Gas pipeline construction during the 1970s meant a region of the south-western part of the bog was heavily disturbed and drained, encouraging dwarf shrubs to become established where the site was drier. However, Conway (*loc. cit,*) suggested that the bowl-like shape of the underlying gritstone limits the extent of drainage, encouraging peat saturation and ideal conditions for *Sphagnum* growth (Conway *loc. cit,*). No *Sphagnum* reintroduction has taken place and there has been no active restoration work or grip blocking. Perpendicular transect lines were used to place the survey sample quadrats to help assess topographic variation.

Case Study 3: Healthy blanket bog site as a control

This site is at Migneint bog on the Migneint Arenig- Dduallt SAC in North Wales. The area is fed by two main lakes: Llyn Conway and Llyn Serw. The origin of the name 'Migneint' gives clues to how rich the site is in *Sphagnum*; 'migwyn' is Welsh for *Sphagnum* and 'nant' is the name for stream so it equates to '*Sphagnum* stream'. Around 8,100 ha of the SAC is designated blanket bog, making it one of the largest blanket bog areas in Wales (Evans *et al*., 2008). Due to the scale of the site only a small area near Llyn Conway was visited. A transect route was planned based on previous site investigations over an area of the blanket bog currently classed as in favourable condition. Quadrat data were taken at the intervals shown and quantities determined from photographic evidence after returning from site. This avoids locations where past management, particularly peat cutting and drainage for agriculture, has damaged the site resulting in two thirds of the area being listed as 'in unfavourable recovering' condition (Evans *et al., loc. cit,*).

Results

Migneint had the highest total number of species at thirteen compared with ten at White Path Moss and four at Black Hill (Table 3). Migneint also had the highest number of hummock (peat-building) species. While present in small patches, there was a distinct lack of the minerotrophic species such as *S. fallax* and *S. fimbriatum* at Migneint compared to the Ringinglow and Black Hill sites where large carpets of these were present.

Only two ecological niches were present at Black Hill: carpets and aquatic carpets. *Sphagnum* ranged from 0 to 40% per quadrat (Figure 3, p8). *S. fallax* dominated with presence of Fringed Bog-moss *S. fimbriatum* in some quadrats. The small areas of Blunt-leaved Bog-moss *S. palustre* were confined mostly to the hagg tops. The first propagule to be used on Black Hill was *S. fallax* in bead form; due to their lightness these beads can easily be moved from their original planting zone by the wind. A high cover of *S. fallax* was noted in some of the surrounding gullies in the unmanaged area of the degraded upland mire on the approach to the transect site, which may be caused by this process.

Table 3. The percentage cover and *Sphagnum* species at each site.

Section	Ecological Niche	*Sphagnum* Species	Black Hill	Ringinglow Bog	Migneint Bog
Acutifolia	Hummocks, carpets	*S. capillifolium*		x	x
		S. capillifolium subsp. *rubellum*		x	x
		S. fimbriatum	x	x	x
		S. quinquefarium			x
		S. russowii		x	x
		S. subnitens		x	x
Cuspidata	Aquatic, carpets	*S. angustifolium*			x
		S. cuspidatum		x	x
		S. fallax	x	x	x
Sphagnum	Low hummocks, carpets	*S. magellanicum*			x
		S. palustre	x	x	x
		S. papillosum		x	x
Subsecunda	Flushes, carpets	*S. denticulatum*			x
		S. inundatum			x
Total *Sphagnum* cover in the quadrat			10-20%	40-80%	>90%

Table 4. Additional vegetation species present at each site.

	Species	Black Hill	Ringinglow Bog	Migneint Bog
Dwarf shrub/ Graminoid	*Calluna vulgaris*	Abundant	Occasional	Occasional
	Vaccinium myrtillus	Abundant	Rare	Rare
Grasses	*Deschampsia flexuosa*	Frequent	Rare	Rare
	Eriophorum angustifolium	Occasional	Frequent	Frequent
	Holcus lanatus	Occasional	Occasional	Rare
	Molinia caerulea	Frequent	Occasional	Occasional
Other Mosses	*Campylopus introflexus*	Rare	Rare	Occasional
	Polytrichum commune	Frequent	Frequent	Occasional
Healthy Bog Indicators	*Andromeda polifolia*	Absent	Rare	Absent
	Drosera rotundifolia	Absent	Rare	Rare
	Narthecium ossifragum	Absent	Occasional	Frequent
	Vaccinium oxycoccos	Absent	Frequent	Frequent

Key to descriptors by area covered: Dominant = >70%, Abundant = 50-70%, Frequent = 25-50%. Occasional = 10-25%, Rare = <10%’

There was a high percentage of dwarf shrubs such as Heather and Bilberry *Vaccinium myrtillus* (Table 4), indicating a lower water table. The pollutant levels were the highest of all three sites (Table 5, p10) and the pH the most acidic, presumably a result of past sulphur deposition.

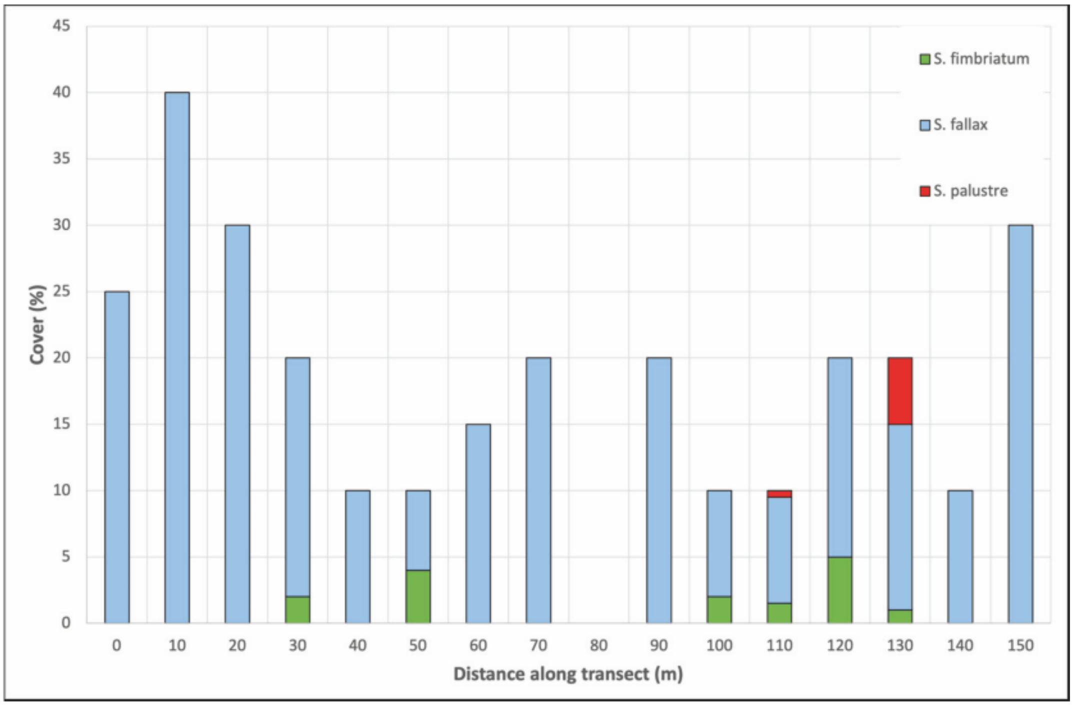

Figure 3. The *Sphagnum* cover and species at Black Hill.

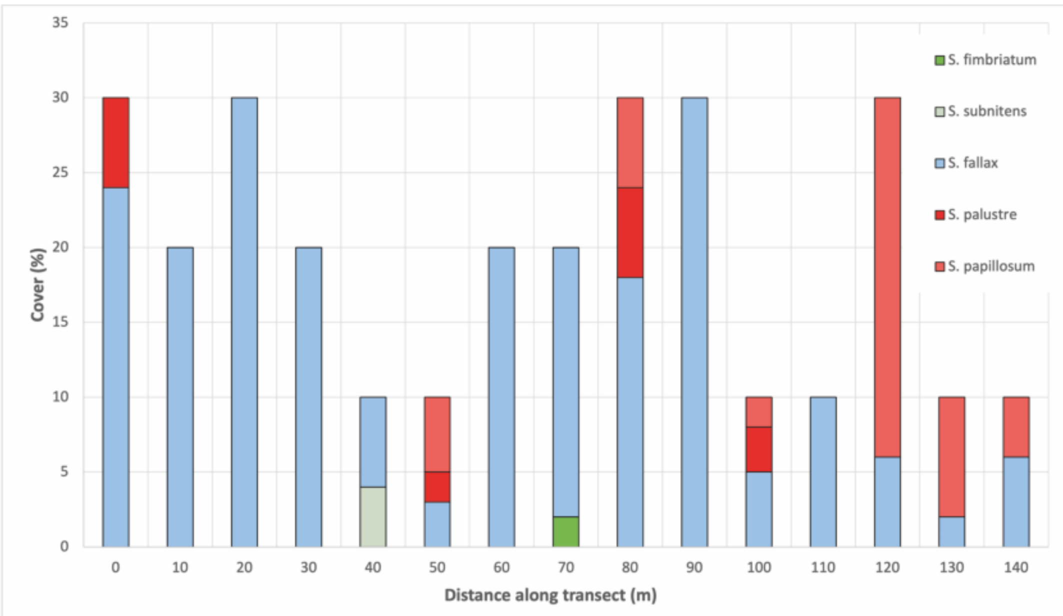

Figure 4. The *Sphagnum* cover and species at White Path Moss; vertical transect (south east to north west).

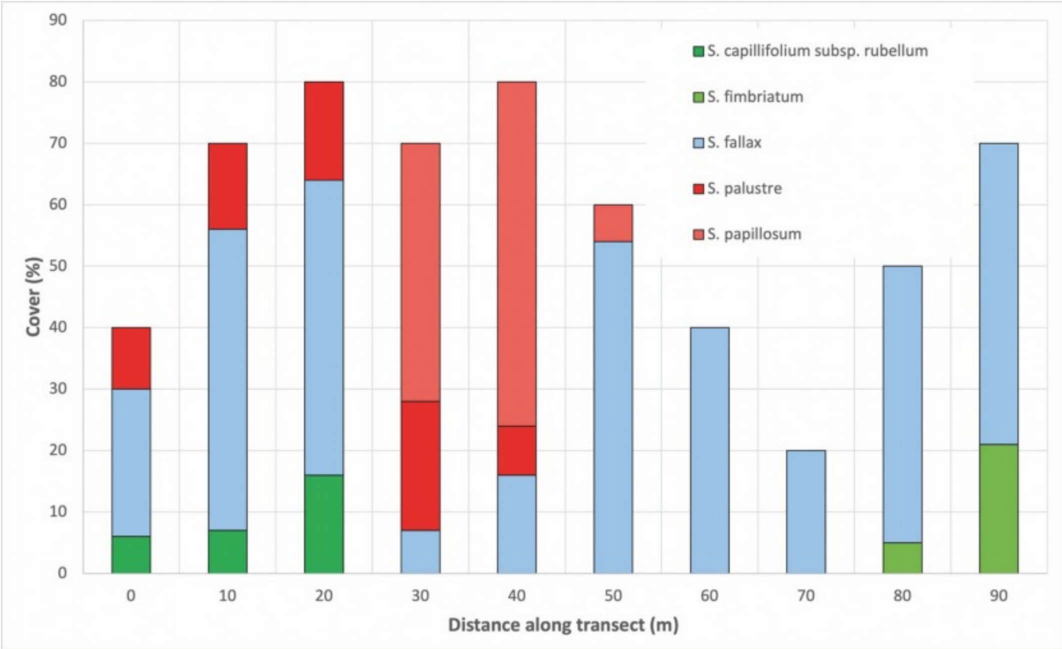

Figure 5. The *Sphagnum* cover and species at White Path Moss; northerly horizontal transect (west to east).

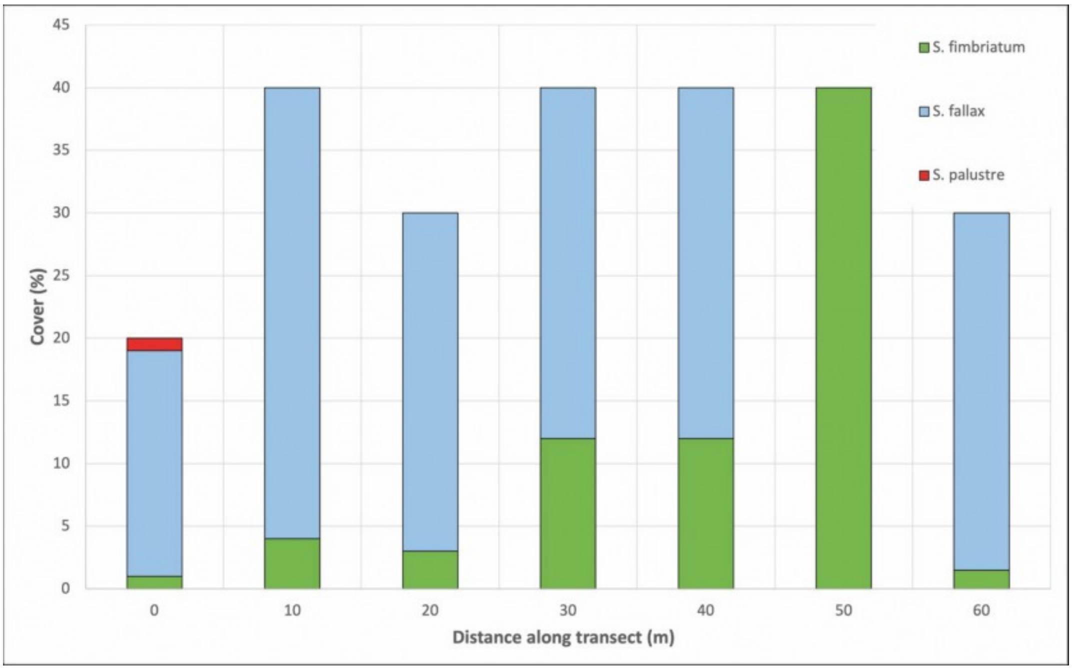

Figure 6. The *Sphagnum* cover and species at White Path Moss; northerly horizontal transect (west to east).

Most likely due to the topography, White Path Moss has the first three niches present (Table 3, p7) but not flushes or carpets. There is still a high proportion of *S. fallax* with it being in all but one of the quadrats. Other mosses that were identified include Red Bog-moss *S. capillifolium* subsp. *rubellum* and the hummock peat-building Papillose Bog-moss *S. papillosum*. Dense areas of Heather lined the boundary of the bog with sedges such as Common Cottongrass within the mire. There was also a high concentration of Cranberry *Vaccinium oxycoccos*, a healthy bog indicator species, within the *Sphagnum*. Pollutant levels and pH were in between the two other sites, perhaps reflecting White Path Moss's status in terms of recovery.

Migneint had the greatest *Sphagnum* cover of all three sites with >90% cover (Figure 7) and all ecological niches represented (Table 3). The remaining 10% was composed of healthy upland blanket mire indicator species (Table 4, p7), which means a high-water table can be inferred. There was a low dominance of *S. fallax* and a high presence of *S. capillifolium* and *S. papillosum* (Figure 7, p12). Heather and other dwarf shrubs were present in low numbers. Pollutant levels were the lowest of all three sites; this is attributed to the site's remoteness from any industrial centres and its Atlantic coast situation with wet, westerly prevailing winds.

General views of each site are shown (Figures 8Ai, 8Bi & 8Ci, p13). Photographic evidence illustrates that areas of Black Hill outside the managed areas are dominated by grassland and eroded peat haggs (Figure 8Aii). This clearly shows the potential importance of controlled intervention in promoting the recovery of severely degraded upland peat mires. The photographs taken at White Path Moss indicate there are small areas of recovering bog that are at the end point of a recovery trajectory for restoration (Figure 8Bii). Although relatively small in extent and not yet widespread, they signify that an unmanaged site does have the potential to recover and eventually become closer to a healthy, actively growing, blanket bog, as illustrated by Migneint (Figure 8Cii). In addition, plants such as Bog Asphodel *Narthecium ossifragum* and Sundew *Drosera rotundifolia,* indicative of healthy upland mire, were present. Bog Rosemary *Andromeda polifolia,* believed extinct in the area since the 1970s, was rediscovered.

Table 5. Chemical water quality indicators taken at White Path Moss and Black Hill with the values for Migneint taken from Caporn *et al*. (2006).

Pollutant	**Black Hill (2019)**	**Ringinglow Bog (2019)**	**Migneint (2006)**
pH	3.02	3.24	4.46
Sulphate (mg/l)	3.5	2.25	1.385
Nitrate (mg/l)	0.595	0.183	0.083
Ammonia (mg/l)	0.834	0.091	0.014
Phosphate (mg/l)	0.834	0.836	0.062

For the pollutants tested, Black Hill had the highest pollutant concentrations for sulphate and nitrate. It also had the lowest pH, a consequence of its past degradation by sulphur pollution. Migneint Bog had the lowest concentrations and the highest pH, showing its health compared to the other sites. White Path Moss fell in the middle of these two sites.

Discussion

The results indicate that *Sphagnum* at Migneint Bog was extensive and diverse, supporting previous observations (Caporn *et al*., 2006). A notable difference from the two other sites was the lower abundance of *S. fallax* and *fimbriatum* and the dominance of the hummock species including *S. capillifolium, S. papillosum* and Magellanic Bog-moss *S. magellanicum* as shown in figure 7, p12. One of the key distinctions in the recovery of heavily degraded sites has been the appearance of *S. fallax* and *S. fimbriatum* monoculture that re-establish as the bog conditions improve. In healthy sites, we expect this dominance to be reduced by the appearance of mixed species in large hummocks and the other niches such as carpets and flushes. One of Migneint's key distinctive indications of its good ecological condition is the large flushes of *S. magellanicum* that were present. Listed as a species of interest in the Migneint-Arenig Dduallt SAC management plan; it is a locally uncommon indicator of healthy blanket bog (Evans *et al*., *loc. cit,*).

It is clear that there is a greater *Sphagnum* diversity at White Path Moss compared to Black Hill and more of the typical plants of an upland mire ecosystem, for example Bog Asphodel and Bog-rosemary. This raises the question of why is this so. White Path Moss has had no restoration work or *Sphagnum* reintroduction but is healthier in terms of both its cover and diversity when compared to Black Hill. Identifying the factors that influence these differences in recovery may be informative in helping define the extent of restoration work required on degraded sites.

A range of factors could be influential; for example, the topography of an area will affect the water table and water storage in the mire system. This will influence the species supported. White Path Moss lies in a shallow depression with Stanage Edge to the north. The bog only has one drainage point where East Brook cuts through the bog and runs into Burbage Brook. This leads to a much wetter site with a high water table maintained throughout the year. Such conditions are important for healthy *Sphagnum* communities (Carroll, *et al.,* 2009). In comparison to this, the Black Hill *Sphagnum* areas are situated on top of a plateau. As Allott *et al*. (2009) state, it is a common misconception that such a flat location would promote water retention. In fact the opposite is the case here as steep side-slopes can result in water draining quickly, especially if erosional gullies have formed. This leads to a much drier ecosystem which is unsuitable for *Sphagnum* or other upland mire mosses. A problem with sites where the associated vegetation has been lost is that the exposed peat then dries and becomes susceptible to erosion. Over time this results in colonisation by dwarf shrubs, further changing the ecosystem dynamics of the site. Trying to retain water within such degraded sites when moss cover has been lost can be a difficult and lengthy process. This is one of the explanations for the lower diversity seen at Black Hill.

Past pollution may be still affecting sites. The main cause of the initial *Sphagnum* decline was particulate air pollution deposited on the peat, which can stay in the system and still be affecting cover and diversity twenty years after initial deposition (Mylona, *loc. cit,*). This can be seen within the peat layers at sites around Sheffield; core samples taken from White Path Moss in 1999 showed increased levels of heavy metals such as lead, aluminium and iron from steel production in the city east of the site. Increased presence of associated heavy metals will displace lighter non-transitional metals such as sodium, magnesium and calcium that are more beneficial to ecosystem functioning. These are already in relatively lower abundance due to the area being inland and away from maritime influences and being geologically dominated by gritstone (Gao *et al.*, 1999). In the last few decades, sulphur emissions have dropped due to a decline in manufacturing and increased awareness of the damaging consequences of sulphur pollution on ecosystems (Tallis, 1964). In this context *Sphagnum* recovery in the Peak and South Pennines has been challenging; the legacy of pollution and land-use change has led to an altered hydrology and the consequential spread of heathland across the region.

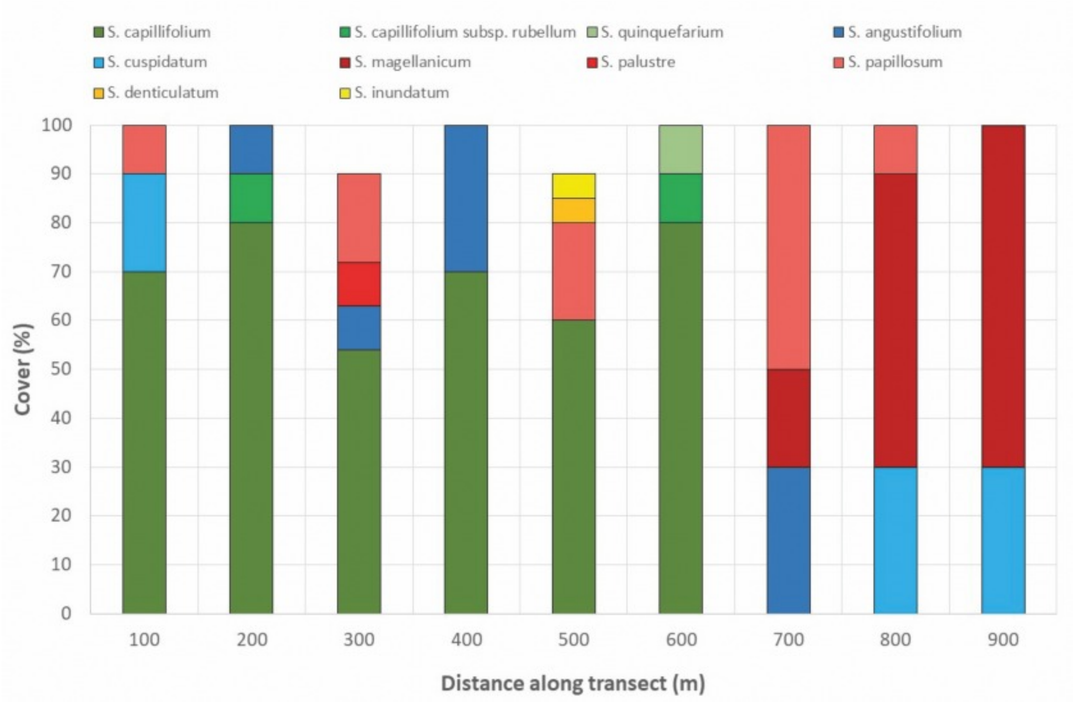

Figure 7. The *Sphagnum* cover and species at Migneint.

Another factor influencing differences in diversity could be the interactions between the *Sphagnum* and other plants. Current research has shown that *Sphagnum* growth can be enhanced by a low density of vascular plants which help provide shelter and generate more stable temperatures and humidity, but at the same time allow space for mosses (Benson *et al*., 2021). This especially favours hummock growth (Pouliot *et al.*, 2011). At White Path Moss, for example, dense dwarf shrubs such as Heather line the edges of the mire with sedges and grasses such as Common Cottongrass and Yorkshire Fog *Holcus lanatus* abundant in the main bog area. This vegetation structure was also noted by Goulder (2015), who commented on the abundance of Common Cottongrass within the main area of the bog. Being less dense in its vegetation compared to Heather, this grass-dominated vegetation creates shelter and temperature stability and has more space available to allow the *Sphagnum* to grow without being outcompeted. Common Cottongrass also favours similar conditions to *Sphagnum* and both decompose to form peat. Due to the drier nature of Black Hill, many areas are covered in Heather, Bilberry and Crowberry *Empetrum nigrum*. This dominance means that *Sphagnum* will be outcompeted in many areas and indeed is one of the reasons why most of the *Sphagnum* has been introduced in hollows where the cover of these forbs is lower and there is increased water availability.

	
Black Hill *Ai*	*Aii*
	
White Path Moss Bi	Bii
	
Migneint Bog Ci	Cii

Figure 8. Photographs showing similarities and differences in health between sites.

Vegetation trajectories produced by MFFP indicate that, as the cover of *Sphagnum* and Common Cottongrass increases over time, dwarf shrub cover should start to decrease (Alderson *et al.,* 2019). One of the key distinctions between a site beginning its recovery and when it is starting to move towards healthy active blanket bog is the increase in the numbers of *Sphagnum* species and a move towards large hummock growth. Current *Sphagnum* modelling trajectories estimate that a good level of cover can be achieved within four years but it could take more than twelve to see a notable diversification in *Sphagnum* (Alderson *et al*., *loc. cit*). It is important to develop knowledge that underpins these timescales, which are currently poorly understood. White Path Moss is at this stage of diversification. Although there is still a high presence of *S. fallax* within the bog there is also increasing cover of *S. capillifolium* subsp *rubellum* and the hummock-forming *S. papillosum* and *S. palustre*. One of the uncertainties with the vegetation recovery trajectories on previously degraded sites is whether the *Sphagnum* will follow its usual succession in species dominance and diversity. *S. fallax* and *S. fimbriatum* should gradually be outcompeted by the larger hummock species over time. This is indicated in some of the quadrats at White Path Moss where a transition is seen from a dominance of *S. fallax* to that of *S. papillosum* and *S. palustre* (Figures 4 and 5, p8-9).

At Black Hill there is currently a high dominance of *S. fallax*. This is expected as this was the only species available in propagule form when *Sphagnum* reintroduction was first started on the site. With transition from beads to plugs the numbers of species available increased up to eleven *Sphagna* contained in one plug which should encourage a higher diversity on site. However, these plug plants take longer to establish and need to be individually planted in sheltered areas to give them the best chance of establishing. Due to this, there will be a greater time lag between planting and the development of a higher diversity of *Sphagnum* mosses. The timescale for this is as yet unknown.

The presence and health of *Sphagnum* plays a crucial role in the way the entire ecosystem functions. When examining the relationship between cover and species diversity, as the *Sphagnum* grows and joins together to form carpets and hummocks, it should become less vulnerable to desiccation. This is because *Sphagnum* can effectively lock the water table around it to the surface (Robroek, *et al*., 2009). This encourages other upland blanket mire indicator species to return as conditions become less suitable for dwarf shrubs. Comparing White Path Moss to Black Hill there was a higher diversity of other wet moorland and mire indicators at White Path Moss including Sundew, Bog Asphodel, Bog Rosemary, Crowberry and Tormentil *Potentilla erecta*. The areas of Sundew were all concentrated in zones rich in *S. papillosum*.

While Black Hill did have a high cover of Crowberry and Bilberry with a drier landscape compared to White Path Moss, most vegetation around the *Sphagnum* was dwarf shrub. There was also a presence of grasses, mainly Common Bent *Agrostis capillaris* and Wavy Hair-grass *Deschampsia flexuosa*. This is most likely due to the initial grass mix that was introduced after the peat was first stabilised. MFFP trajectories estimate that over time this dominance should slowly decrease as the area of mosses increases and the conditions become less favourable for drier grasses and shrubs (Pilkington *et al*., *loc. cit*).

A final point to note relates to *Sphagnum* propagule introduction from donor sites away from the receiver locations, which is inevitable here because of the lack of suitable regional donor mires. However, this has raised concerns among bryophyte recorders and ecologists about this process of introduction masking natural distributions and recovery and the potential for the introductions of pests and diseases. In the South Pennines, whilst historical records were gathered this was not comprehensive and there was no detailed site survey across the region prior to introduction (Tom Blockeel pers. comm.; Paul Ardron pers. comm.). This was perhaps in part because it was felt that there was little *Sphagnum* presence or diversity to be found locally. White Path Moss and on-going surveys across the Peak District confirm that there is indeed a significant natural resource already colonising but not in the extreme conditions of Black Hill and the other MFFP sites.

In conclusion, this paper considers how *Sphagnum* recovery has varied between managed and unmanaged degraded sites using case study locations within the Peak and South Pennines. Both White Path Moss and Black Hill have been modified and degraded from past land use and pollution with a resulting loss of *Sphagnum*. A higher *Sphagnum* cover and species diversity is now seen at White Path Moss, but the site has been recovering for longer (since the 1940s) and was never as heavily impacted by pollution compared to areas like Black Hill that lie in the prevailing wind direction. Due to this, some areas of White Path Moss have transitioned from *S. fallax* to areas of hummock species. Migneint Bog is a very diverse site with a higher percentage of *Sphagnum* cover that is dominated by hummock growth; it represents what recovering sites are aiming to become. White Path Moss is moving towards this destination. It is still in its recovering phase, but the return of its blanket mire indicator species is a good sign for its recovery.

These observations suggest that not all sites require intervention for *Sphagnum* recovery to occur. Presenting the variations in the cover of each species at each location allows a greater understanding of the trajectory of a bog's recovery. However, severely degraded sites such as Black Hill have not recovered naturally in the timescales observed. This indicates the need for intervention in problematic sites. Once bare peat with a complete loss of *Sphagnum*, the plateau now has large carpets of *S. fallax* and thus a beginning in any future recovery towards a more diverse *Sphagnum* cover and bog functionality. Recognising the range of factors that cause this transition from a *S. fallax* dominated site to one with hummock building *Sphagnum*, and increased vegetation typical of upland mire, is important in guiding future recovery and restoration.

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