Sphagnum re-introduction project:
A report on research into the re-introduction of *Sphagnum* mosses to degraded moorland

Moor for the Future Research Report 18

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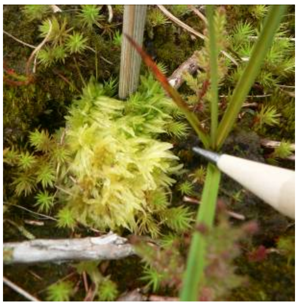
Executive Summary

Peat restoration works to date have been about stabilising the ground until peat forming vegetation can develop. The Moors for the Future Partnership have been and continue to be successful in bringing large areas of the Peak District moorland to this point. However, whilst the restoration of any vegetation will reduce erosion, the net loss of peat can be prevented by actively forming new peat, particularly from *Sphagnum* mosses. Thus the key factor in the long term, sustained maintenance of this landscape is the re-introduction of the peat-forming Sphagnum mosses to the degraded areas.

Sphagnum moss is the critical missing element of the Peak District (and many other) degraded peatlands. A major factor inhibiting re-establishment of *Sphagnum* in the Peak District is absence of material for colonisation. Development of large scale *Sphagnum* propagation and delivery methods has the potential to revolutionise peatland restoration.



This report details two years of research and development into Sphagnum establishment on restoration sites from small, medium and large scale trials on partially restored and denuded peat moorland at Black Hill, Holme Moss.

The project commissioned Micropropagation Services Ltd, a local small business, to research and develop an effective method of propagating sphagnum and supporting its establishment in the harsh moorland environment. Initial small scale trials, which have now been monitored for over two years have shown that *Sphagnum* beads (BeadaMoss) can establish and grow into significant robust pieces that can survive harsh winters and even the moderately severe drought this spring (2010).

Glasshouse trials have shown that *Sphagnum* beads have 100% viability under good conditions and perhaps with further development this can be repeated in the harsh moorland conditions. At present, although survival percentages on the moor are relatively low, they are at a sufficient level to enable the re-colonisation of *Sphagnum*, given a few years to develop.

Glasshouse trials have also shown that timing and the quantity of fertiliser and lime application needs to be carefully considered and further trials are planned.

Over 1 million beads were produced for the large scale helicopter planting trials. This demonstrates the success of the project in developing a methodology to produce the large quantities of beads that will be needed to re-introduce *Sphagnum* on a landscape scale. It also proved the principle of application by helicopter even though there were some teething problems. These will be overcome by developing a more appropriate and robust agitation system for the seeder.

Funding of this work by The Co-operative Foundation and Natural England has been critically important in enabling this ground breaking development in restoration to be scientifically tested. BeadaMoss has now shown sufficient success for it to be taken forward commercially. Further development and trials can now be continued alongside normal commercial production. Without this funding the Moors for the Future Partnership & Micropropagation Services could not continue development. Continuation of scientific trials and monitoring is now possible as part of PhD research at Manchester

Metropolitan University, also funded partly by The Co-operative Foundation and Natural England.

Additional funding may be required to elucidate the optimum time for application of *Sphagnum* in the overall restoration process and to improve understanding of the effects of water table/hydrology and local chemical composition of peatland in relation to the colonisation by *Sphagnum*.

Contents

1. Introduction

Large parts of the UK's upland blanket bog, particularly in the South Pennines Moors Special Area of Conservation (SAC), are degraded due to a range of historical factors including summer wildfire, atmospheric pollution and overgrazing all of which have reduced vegetation cover and exposed the underlying peat to erosion. In some areas of the South Pennines there are areas of bare and eroding peat that extend to several hectares.

The most significant historic factor has been acid rain from the industrial areas of Lancashire and Yorkshire, particularly from sulphur based acids, which has caused the loss of *Sphagnum* mosses. This loss is a critical factor as it is the sphagnum mosses that predominantly formed the original blanket peat. Losses across the Peak District have been so significant that there is very little *Sphagnum* remaining, leading to a shortage of source material for recolonisation.

The introduction of the Clean Air Acts and agri-environment schemes, such as the Environmentally Sensitive Area (ESA) scheme, which allowed the removal of livestock from many degraded blanket bogs, has made the restoration of extensive bare peat areas possible.

Much of the restoration works, from trials initially undertaken as the Moorland Management Project Phase 3 Report (Anderson, Tallis and Yalden, 1997) and continued in projects such the Moors for the Future Heritage Lottery Fund Project (Buckler, MSc thesis, 2007) and United Utilities Sustainable Catchment Management Programme (SCaMP) has focussed on reducing the loss of carbon from degrading bogs by stabilising soils to encourage vegetation cover and move towards a more natural moorland vegetation. This work has been very successful, with extensive areas of bare peat re-vegetated and diversified with moorland plants.

The stabilisation treatments used on areas of bare peat consist of spreading heather brash, laying geo-jute on slopes and the application of lime, fertiliser and grass seed. The heather brash acts to stabilise the peat, reducing loss through erosion, whilst the lime and fertiliser helps to produce a more hospitable environment allowing the nurse crop of grasses to establish. This vegetation cover is intended to gradually develop into cottongrass and dwarf shrubs, either through natural re-vegetation or the use of plug plants. Native species are selected for this, including cloudberry *Rubus chamaemorus*, crowberry *Empetrum nigrum*, bilberry *Vaccinium myrtillus*, hare's tail cottongrass *Eriophorum vaginatum* and common cottongrass *Eriophorum angustifolium*.

However, in order to take these, and other areas with less significant erosion but an absence of moorland bryophytes, particularly *Sphagnum*, into Favourable condition, a method of collecting, spreading and establishing *Sphagnum* was required.

As *Sphagnum* mosses are the key species in the formation of peat on blanket bogs, they have an important role to play in restoration work. It is hoped that their reintroduction to damaged blanket bogs will help to return these habitats, which are currently sources of carbon, to functioning ecosystems that are actively sequestering carbon;.

A previous report by Moors for the Future, funded by Natural England and United Utilities (Carroll *et al*, 2009) suggested that the dominant factor causing an absence of *Sphagnum* mosses in the Peak District is simply absence and a consequent lack of source material. The other factors that were suggested were the low pH and the absence of a stable, high water table.

Most of the work that has been undertaken to establish a *Sphagnum* dominated sward has taken place on cut-over raised bogs, damaged by peat extraction. These sites differ from Peak District restoration sites as they have a source of appropriate material close by which can be spread easily into adjacent areas with appropriate conditions (Quinty and Rochefort, 2003).

Because of the lack of source material on the Peak District moors, it was first of all necessary to develop a method to increase the quantity of *Sphagnum* that could be made available for application. Moors for the Future had used micro-propagation to do the same work for higher plants and an Expressions of Interest document was released seeking companies willing to undertake research on propagating *Sphagnum*.

Research was carried out by Micropropagation Services (EM) Ltd, who developed an *in-vitro* production system for locally sourced *Sphagnum* moss. Chopped pieces of moss were encapsulated in a gel bead to enable easy distribution and to help prevent them drying up and dying. This has now developed into the production of 'BeadaMoss'; an easily handled and distributed bead containing growing diaspores (fragments) of moss. 'Beadamoss' has other useful features. The beads contain only a single species of locally sourced *Sphagnum*, identified from the initial sample collected and it allows a known amount of *Sphagnum* to be applied (at its simplest, in beads m^{-2}).

One of the aims of the project is to assess various *Sphagnum* species to understand which species can be applied and established over a large area. The species that have been propagated successfully to date are *Sphagnum fallax, S. cuspidatum, S. capillifolium, S. palustre, S. papillosum, S. sub-nitens, S. fimbriatum*, which are the most regularly encountered species in the Peak District. For the early work on assessing whether the beads work better than bare propagules and how the beads can be made more effective, *Sphagnum fallax* has been used most frequently because it is the most common species in the vicinity, it is the easiest to propagate in large volumes and is one of the most tolerant species.

Sphagnum reintroduction field trials were set up in two places at Holme Moss, an area of degraded blanket bog in the Peak District (South Pennines). One received treatment as part of the Moors for the Future Heritage Lottery Fund (HLF) project on Black Hill and a second experimental area was established closer to the Holme Moss transmitter. Propagated pieces of moss were spread onto different areas on the peat surface and the establishment of the propagules was monitored. Trials began in June 2008 and have continued to the present, with plot sizes being scaled-up and different techniques introduced as the research has progressed. The results of these field trials are summarised within this report

The establishment of initial plots, their monitoring and analysis of results formed part of a Manchester Metropolitan University MSc project (Hinde, 2009). PhD research by Angus Rosenburgh at Manchester Metropolitan University has followed on from this work. This began in October 2009 and is currently ongoing.

The rationale and any available results are discussed in the following sections, although the field trials are slow to yield results due to the challenging environmental conditions. A further report will be produced towards the end of Angus Rosenburgh's PhD in addition to his thesis submission in 2012.

2. Summary of research

2.1 Small scale trial plots

These were the initial field trials undertaken at various sites between Holme Moss and Black Hill, primarily by Micropropagation Services and as the fieldwork for Steph Hinde's MSc. All plots are still in place and are still being monitored.

2.1.1 Small trial plots at Black Hill and the Mast

Sphagnum was introduced to two distinct areas of degraded bog on Holme Moss: at Black Hill, where restoration techniques had already been employed, and at an area of sparser vegetation near to the radio transmitter (the 'Mast' site).

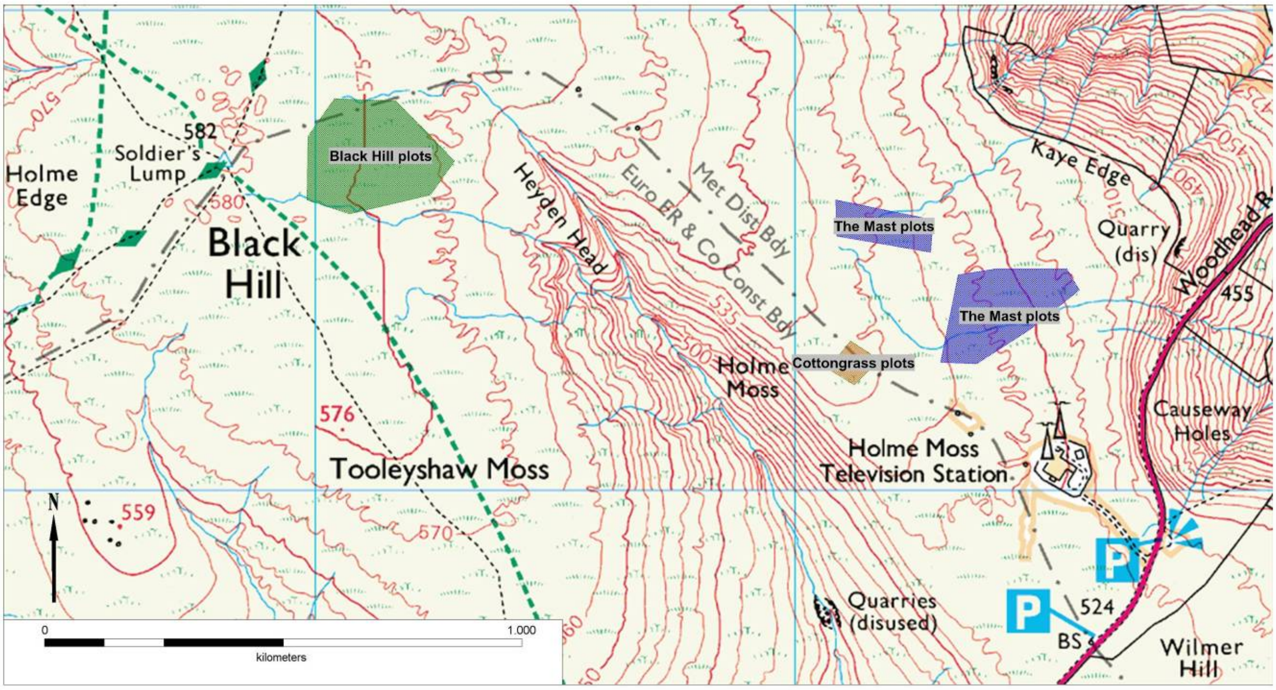


Figure 1: *Map showing the location of the various trial plots*

On Black Hill, the stabilisation treatment for bare peat, which started in 2005, has produced a protective layer of vegetation and therefore a different landscape to that of the Mast areas.

At the Mast, heather brash had been spread but no other treatments applied so there was very little vegetation already growing in this area. This area also appeared to be drier than Black Hill.

Focussing on both of these sites enabled a comparison of results on two different substrates.

In addition, trials have also been established on areas with existing vegetation cover, dominated by common cotton-grass (*Eriophorum angustifolium*) to assess the success of the propagated mosses in areas of degraded, but not bare peat. This is the dominant issue across the South Pennines. No data is available from these trials yet due to the difficulty of finding the beads in the existing vegetation.

Further *Sphagnum* trials, for example on sites that have been recently flailed to control purple-moor grass, are in preparation.

Figure 2: *the 'Mast' site where quadrats were established on an area of degraded bog which had been treated with heather brash.*

Figure 3: *the Black Hill experiment site where quadrats and larger-scale plots were established. Treatments of lime, fertiliser and grass seed have resulted in a nurse crop covering the bare peat.*

Two different forms of *Sphagnum fallax* (strands and beads) were introduced to both of these sites. Monitoring results were able to compare the establishment success of each of these types of propagules at each of the chosen sites.

The first field plots were established from June 2008 – May 2009. A series of permanent 0.5m x 0.5m quadrats were set up, into which were placed an equal number of *Sphagnum* strands and beads. Since these quadrats were set up over successive months it was possible to analyse monitoring results over time, i.e., to see what effect (if any) the weather or wetness of the ground had on the successful establishment of the moss.

Results from these plots were monitored until June 2009, statistically analysed and written up as part of Stephanie Hinde's MSc, giving results on the effect of *Sphagnum* propagule type, site and time of planting on the success of establishment. In addition, further monitoring of these plots was carried out over the following year, from September 2009 – August 2010. Regular visits were made to photograph and take notes on the ongoing development of *Sphagnum* in these plots. These results are all summarised below.

Monitoring results

<u>June 2008 - June 2009</u>

Results from plots set up at Black Hill and the Mast sites between June 2008 and June 2009 were collected in June 2009. Each quadrat was methodically checked and the *Sphagnum* strands or beads found were counted and named either 'white' or 'green' depending on their condition. 'Green' denoted Sphagnum that was still healthy and active whereas 'white' Sphagnum was desiccated and appeared dead. The moss had little time to physically grow during the period of the project and so this was the best means of assigning a relative health score to the moss pieces.

A summary of results and observations are as follows:

- The hot, dry weather of June 2008 prevented the establishment of any of the pieces laid out in the field on this visit. With the exception of June, *Sphagnum* was recorded in all other plots, with green pieces still evident in June 2009 in plots set up in September 2008. This shows that, although little growth was seen, *Sphagnum* can remain viable for several months under suitable conditions, and can successfully survive a cold winter.

- March was shown to be the most successful month for sowing *Sphagnum*, with most pieces recorded in plots set up in this month. Although comparison of results with weather data from the Holme Moss weather station was inconclusive, it is likely that the high rainfall and warmer temperatures of spring allowed the moss to gain a foothold better than in other months.

- *Sphagnum* beads are more successful than *Sphagnum* strands in field trials, i.e., more beads were recorded and they remained green for longer than *Sphagnum* strands, although differences were not very statistically significant from this study; the protective gel of the beads may help prevent desiccation and improve the chances of the moss establishing.

- Significantly more *Sphagnum* propagules were recorded at Black Hill than at the Mast site. This could have been due to this area being wetter, having a covering of vegetation which protected the moss pieces, or a different (less acidic) soil chemistry due to previous additions of lime and fertiliser.

- A protective layer of heather brash was applied to some of the plots, over the top of the *Sphagnum* pieces. This was not shown to have any effect on the added *Sphagnum* pieces but may act as an additional source of *Sphagnum* – small pieces of *Sphagnum* were seen establishing outside of experimental plots at Black Hill, possibly introduced by previous brash applications.

<u>September 2009 – August 2010</u>

Further monitoring was carried out on these plots from September 2009 to August 2010. Because the moss pieces are slow growing (particularly in a moorland environment), further monitoring was essential to establish if the 'green' moss pieces seen actually remained alive and grew in size after their first few months. Monitoring visits were carried out in September and November 2009, April, June, July and August 2010. Individual *Sphagnum* pieces were not counted on these visits but general observations made (i.e. monitoring was not carried out to the same level of detail as in June 2009). Fixed point photos of moss pieces were taken from April 2010, to monitor the appearance and growth of healthy *Sphagnum* pieces that looked as if they had established successfully.

The prolonged cold winter of 2009 meant that the plots were under a layer of snow for several months; however this did not generally appear to affect the *Sphagnum* pieces to a damaging degree. A dry, warm spell in June 2010 made for less than ideal conditions for *Sphagnum* growth. The monitoring visit carried out in July 2010 after this dry spell recorded the ground as being very dry and many of the *Sphagnum* pieces appeared to be becoming dry and pale. A wet spell through August followed this period of dry weather. This appeared to help the *Sphagnum* to regain its vitality despite the period of drying, as the moss pieces within the quadrat plots were observed to be greener and healthier than when photographed in August (Fig. 6).

2.1.2 Black Hill

<u>Topography and ground cover</u>

Obvious differences became apparent between different ecological zones on Black Hill at an early stage in the trials.

On the higher drier area quadrats had been set up on the top of a hummock (or degraded peat hag). Here there was a 100% covering of vegetation, mainly low-lying spreading *Hypnum* mosses. This is indicative of drier conditions. This area was clearly unsuitable for *Sphagnum*. Very little was recorded here in September 2009, and less on subsequent visits until none at all was seen by April 2010. This area was not monitored after this visit and no fixed point photographs were taken as no *Sphagnum* could be found.

The drier conditions may make this area less suitable for *Sphagnum*. It could also be the case that a tight low-growing covering of vegetation prevents moss pieces from having continued contact with bare peat and the water table, causing them to dry out and die.

On the lower, wetter slopes close to gully bottoms at Black Hill, the covering of vegetation was less complete and *Sphagnum* pieces seemed to be growing well. This is probably due to the increased wetness and the shelter offered by surrounding vegetation or when they had fallen into cracks within the peat.

Figure 4: *Photographs (taken in August 2010) demonstrate the general ground cover across the two zones where the* Sphagnum *established successfully at Black Hill.*
It appears a general 'crust' of vegetation such as this, made up of grasses as well as mosses and small heather seedlings, with gaps where Sphagnum can gain a foothold is most beneficial for the pieces to become successfully established.

Figure 5: Sphagnum *beads and strands soon after their introduction (to the Mast site) to give an idea of their initial size, in September 2008. Figure 6 below shows the growth of similar* Sphagnum *pieces over the timescale of the trial.*

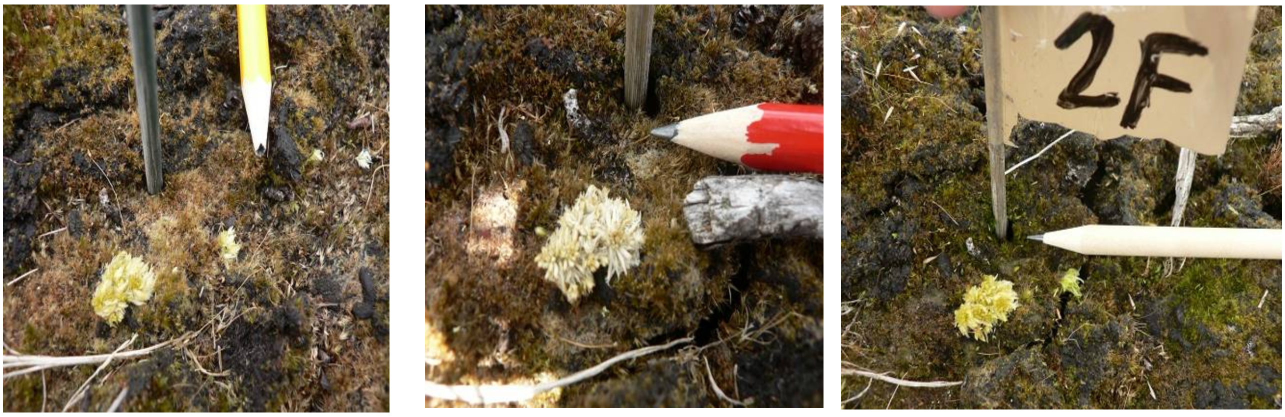


Figure 6: *Fixed point photographs of a* Sphagnum *colony, from a quadrat established at Black Hill in September 2008. Photos illustrate (left to right) April 2010, July 2010 and August 2010.*

Figure 7: *Fixed point images of several successfully established* Sphagnum *pieces around the marker cane in a quadrat at Black Hill set up in March 2009. This was a quadrat which had brash applied on top of the* Sphagnum *pieces.*

It is clear that these pieces have successfully established and spread since their application in 2008 / 2009. As seen from Figures 6 and 7, the fixed point photographs taken to monitor *Sphagnum* growth did not show a huge amount of change, since they were set up in April 2010 and ran only until August 2010, and so little actual growth was seen over these four months. Nonetheless, the photographs have been useful in comparing the colour of the moss pieces and the surrounding ground cover. Note how pale the moss pieces above were in July 2010, but how they recovered well after a period of wet weather to become green again in August 2010.

2.1.3 Mast site

Very few *Sphagnum* pieces were seen within plots at the Mast site, despite thorough searching. The surface here was bare, loose peat with a brash covering and it was possible that the small *Sphagnum* pieces had become buried and difficult to see, resulting in lower counts in the June 2009 analysis. For this reason it was judged worthwhile to continue to monitor this area.

However, the vast majority of *Sphagnum* introduced to quadrats could not be found when the Mast site was revisited, and only three pieces could be found to establish fixed point photographs in June 2010, all of which were small and fairly pale in colour. Changes were seen when visited in August after a period of wet weather, with all three pieces (despite being small) appearing greener.

Figure 8: *(left) small, pale piece of* Sphagnum *June 2010, and (right) the same piece in August 2010.*

Generally, it seems that the ground at the Mast site was largely unsuitable for mass *Sphagnum* establishment, being too dry, unprotected by surrounding vegetation cover and possibly also too acidic for the *Sphagnum* to grow.

2.2 Large trial plots at Black Hill, the Mast and Heyden Head

In November 2008, March 2009 and May 2009 *Sphagnum* introduction trials were scaled up and new plots established at Heyden Head, near Black Hill. Each new plot was approximately 3 m x 25 m in size and marked with labelled canes at each corner. A 2kg tub of *Sphagnum fallax* beads was spread by hand evenly throughout each plot. A fourth plot was set up in May 2009, into which 2kg of beads of a different *Sphagnum* species (*Sphagnum palustre*) was spread.

Each plot covered an undulating area of degraded bog, of varying aspects and wetness so that the success of the beads could be monitored across this terrain. Their establishment was monitored in the following months and fixed point photographs of individual *Sphagnum* pieces within these plots were taken on monitoring visits between September 2009 and August 2010.

Monitoring results

Some large (approx 20-30cm diameter) natural clumps of *Sphagnum* were observed growing at the gully bottoms in the November, March, and June *S. fallax* large plots and the May *S. palustre* plot,. While it is encouraging to see that the conditions were suitable for *Sphagnum* growth, it was difficult to establish if the moss pieces observed during monitoring were from beads spread as part of these trials, or naturally spreading from these larger, naturally occurring patches.

There was little obvious 'natural' *Sphagnum* growth within the large *S. fallax* plot established in May 2009 and so we can be confident that any small pieces seen in this particular plot are from trial beads.

Figure 9: *An example of 'natural' Sphagnum establishment within the large plot set up in March 2009 (photo taken August 2010).*

General observations made of these larger plots drew the same results as observed at the initial small-scale trials at Black Hill.

Topography and ground cover

Most *Sphagnum* was observed growing on wetter areas and of that seen, the greenest was in these areas rather than on the higher ground dominated by hypnoid mosses or bare peat. It is a feature of the site's topography that these wetter areas are at the bottom of slopes where gullies have eroded through the peat. Therefore, more *Sphagnum* was observed growing at the bottom of slopes. However, this result may not just be due to the wetness of these areas, it could also be because the *Sphagnum* beads are relatively mobile (especially when first spread) and wind and rain may have blown or washed them downhill.

Most pieces observed as establishing well (appearing greener) were spotted in cracks within the peat where they appeared to be sheltered and remain moist. The following photos show a well-established *Sphagnum* bead growing well within the large plot set up in May 2009.

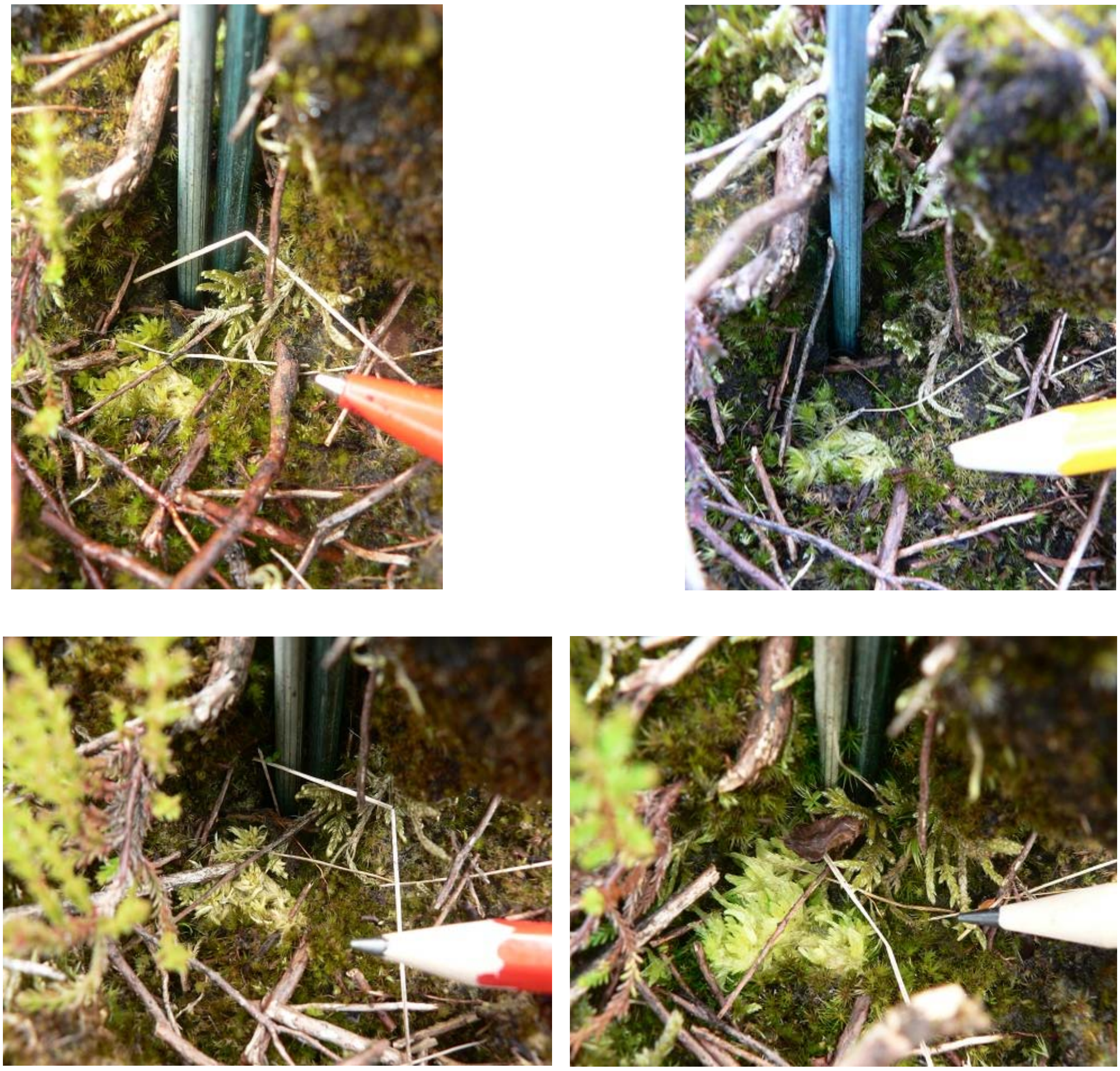


Figure 10: *photographs taken in April, June and (bottom row) July and August 2010.*

As with the small scale field trials, not a lot of growth is seen over this timescale but the effect of the dry weather is evident in the July picture, and rewetting in August. Note the fact that the *Sphagnum* has established within a gap between ground vegetation and is growing successfully, in contact with the water table, surrounded and protected by other species growing around it.

The plots spread with *S. palustre* (May and June 2009) had very few *Sphagnum* pieces observed within them. This could have been due to the fact that these plots encompassed a flat, bare peat pan area with cottongrass surrounding it. This area could have flooded in heavy rainfall, washing the pieces away from the plot, or into the surrounding vegetation where there were harder to spot. It could also be the case that *S. palustre*, as a hummock-forming species, was less well-suited to establishing in a wet area such as this.

2.3 Sphagnum development trials

One of the fundamental questions relating to the re-introduction of *Sphagnum* was which *Sphagnum* species to use, where they should be applied and when. Moreover, the length of time and cost of the current remedial measures are both considerable. If an area could be converted directly to *Sphagnum* dominance then both could be significantly reduced, with the ultimate aim being similar in both cases. This formed the basis of a series of experiments that began in November 2009.

2.3.1 Species and seasonality trials

Beads of five species of locally sourced *Sphagnum*, *S.fallax*, *S.fimbriatum*, *S.cuspidatum*, *S.palustre* and *S.papillosum*, were sown onto both bare peat surface and surfaces that had been subjected to stabilisation treatments. Multiple species were used to determine whether any were more suited to such environments. *Sphagnum* species can survive in a range of conditions, due to their individual features and adaptations; e.g. *S.fallax* is widely accepted as a pioneer species, whilst *S.cuspidatum* is more commonly found in pools and ditches.

The objective of planting *Sphagnum* beads on both bare and restored areas was to see if this normal restoration treatment could be accelerated and a shortcut to *Sphagnum* cover found. Research into restoration on lowland bogs has concluded that a high and stable water table is required for the successful growth of *Sphagnum*. In those locations, revegetation of degraded areas is essential as this helps to raise the water table. However, lowland mires are bottom-up systems, i.e. to raise the water table the overall amount of water must increase, like filling a bucket whereas upland bogs are ombrotrophic, or rain-fed, systems and so are theoretically not restricted by this. If an upland bare area were to receive sufficient moisture through precipitation or cloud cover, then conditions could easily be wet enough to support *Sphagnum*.

The *Sphagnum* beads were spread over $400m^{-2}$ in 4m x 1m strips, with five species strips and a control strip per block. Each block was replicated three times on bare peat surface and on an area previously treated using the method described above.

The timing of such a management strategy is extremely important to maximise efficiency and success. To date, the multi-species trial was carried out in November 2009, April 2010 and September 2010; with a reduced version (two species) of this set-up in August 2010. This should help to illustrate any difference in seasonal application of the *Sphagnum* beads. This information will also be related to meteorological data for the area, which should further aid in the development of management programmes.

2.3.2 Topography Trial

The topography trial was designed to cover a range of topographical features, such as ditches and raised areas. This was achieved using a larger plot size than in the other trials; 12.5m x 2m. The same five species were applied, with the expectation that the different species would preferentially establish themselves, and so could help to inform a more 'targeted' approach to *Sphagnum* restoration. Particular species could be selected for the specific environmental features of the area being treated, e.g. certain aquatic species may be more suited to revegetation of gullies and the hardier species reserved for the more challenging raised areas.

2.3.3 Hardened beads trial

Hardened beads were developed in response to observations from the initial field work where the beads appeared to shrivel and dry significantly before becoming established. Micropropagation Service Ltd. produced a 'hardened' bead which had already been subjected to a water-stress procedure in the hope of making it more likely to germinate following a period of drought. Four species of hardened beads were produced and sown onto treated areas in two replicate blocks in a similar fashion to the species trial.

2.3.4 Sphagnum propagule source trial

Following the results of the small scale field trials at Black Hill and the Mast *Sphagnum* beads were used in all the above experiments. However, trials on lowland bogs in various countries have seen results from applying chopped up *Sphagnum* to degraded areas. These sites differ from the region we are working in by having a large supply of *Sphagnum* adjacent to where it is required. Applying this source of moss is beneficial in that establishment should be more rapid as plants will be growing from larger 'chunks' as opposed to the 'fragments' within the beads. There will also be a similar stabilising effect as heather brash when this is added to a bare peat surface. As stated previously, heather brash may also prove to be a further source of *Sphagnum*, with instances of this occurring near to our experimental sites.

It was therefore decided to further test the applicability of a variety of propagule sources and trial plots were established in April 2010 on bare peat and treated surfaces. These were larger than in the previous experiment at 12.5m x 2m, with the aim of introducing some topographical variation within an experimental space. Four strips within each block were spread with either beads and heather brash, *Sphagnum* mulch and brash, brash only, and a control strip with no covering. Variations in microclimate should become apparent, with some areas appearing more successful in supporting *Sphagnum* establishment than others. In addition, the *Sphagnum* mulch may well contain several species and so there could be some visible differentiation where plants of different species become established in their specific ecological niches.

Figure 11: *Setting up the Sphagnum mulch and brash trial.*

Monitoring Results

Fixed point photographic monitoring points were set up within the trial areas. Monitoring has not yet yielded results, as recent plots have not been established long enough and earlier plots growth has been held back by the moderately severe drought in the spring/summer period. The relatively slow growth of *Sphagnum* on the moor is problematic in getting results in a short timeframe, however, these plots and others to be set up will be monitored over the long term and will yield results in future reports.

2.4 Pre-treatments and coatings

In May 2010, additional trial plots were set up in a different area further east of Black Hill and to the north of Heyden Head. Three 1m x 3m plots were established and spread with different *Sphagnum* propagules: 'normal' beads as used in all previous plots set up so far, 'coated' beads treated with a waxy covering to reduce water loss, and 'minced' beads which had been chopped up, increasing surface area. These plots were visited and monitored with fixed point photography in June, July and August 2010.

This was the first time beads were planted with any form of coating. Since then many more coatings and pre-treatments have been examined to improve the drought tolerance and/or cold tolerance of the beads immediately following planting.

Figure 12: *photo of plots at Heyden Head area (June 2010)*

Monitoring results

These plots were visited in June, July and August 2010 and fixed point photographs taken. All pieces seen within these plots (normal, coated and minced beads) were very dry and shrivelled when observed during all three monitoring visits, including in August after wet weather appeared to have rejuvenated *Sphagnum* pieces at the Black Hill plots. It can probably be assumed that these pieces have died and are unlikely to recover, having suffered from a combination of being spread during hot, dry weather on a site perhaps unsuitable to moss growth. The ground cover surrounding these plots is largely grass species and hypnum moss indicative of drier soils.

Figure 13: *minced bead in August 2010 (at pencil tip), evidently white and possibly dead.*

2.5 Helicopter application

Figure 14: *Helicopter trials at Black Hill, May 2010*

2.5.1 Heyden Head aerially spread strip – helicopter and air assisted seeder

On 11th May 2010 the first helicopter planting of *Sphagnum* moss was attempted in front of press and cameras. This was a success from the point of view of getting good pictures and publicity, and also producing sufficient beads to allow the trial to take place, but there were teething problems with the seeder being used for planting the moss beads. Bridging of the beads over the outlets of the seeder prevented the continuous flow of beads.

The addition of a temporary agitation device to the seeder allowed a further trial planting to take place on 21st May. This was more successful than the first and proved that an appropriate agitation device may solve the problems encountered with the seeder. Success was limited by the partial failure of an electrical system, but the principle of application on a very large scale, potentially over large areas by helicopter was proven to be possible. Significant work is required in order to improve existing delivery mechanisms. A robust and reliable seeder with agitation for the beads will need to be developed for future planting.

2.5.2 Production system for beads

Over 1 million beads were produced for this trial - over 900,000 more than had been produced up to this time! This tested and proved the ability of the lab to produce large quantities of beads.

Unfortunately, the period before, during and for some time after the helicopter planting trial was the driest and hottest period for some time in the Holme Moss area. This has caused severe stress to the beads planted and we are concerned that it may have been fatal to the majority. Continued monitoring over a longer period of time will demonstrate if the observed dried up beads will recover.

This highlights the need for flexibility in planting time, and perhaps earlier planting, even though planting in May 2009 proved very successful. Much time and effort has and is being devoted to better understanding and improving the ability of beads to withstand drought, at least for short periods. Unfortunately long periods of drought are always going to be detrimental to the growth and establishment of *Sphagnum*, as they would for any other plant.

Figure 15: *Flags marking the Sphagnum pieces observed within the aerially spread strip.*

Monitoring results

This area was monitored in June, July and August 2010 and very few beads were found. The strip was walked to observe and photograph any beads seen, but over most of the area, none were found. Only one small area was found to contain some *Sphagnum* beads, and three fixed point photographs were taken. They appeared pale white and dried up. Little change was seen between the first and second monitoring visit.

A period of dry, hot weather followed the aerial seeding, which may have desiccated the beads. Around both the June and July monitoring visits the weather had remained relatively dry and so the beads had not had the opportunity to become greener with added moisture. There was higher rainfall between the July and August visit but, as with the three plots nearby at Heyden Head, the additional rainfall does not appear to have changed the pieces or made them greener and it is likely that they have not survived.

Figure 16: *One of the aerially spread beads (white piece at fingertip) very white and apparently lifeless at Heyden Head - photo taken August 2010.*

2.6 Controlled environment experiments

The difficult climatic conditions of the exposed moorland would appear to be the limiting factor in terms of the establishment and rapid growth of the *Sphagnum*. In order to generate results more rapidly, some indoor trials were established, eliminating this problem.

2.6.1 Greenhouse trials

Between November 2008 and February 2009 a trial was set up under the controlled conditions of a greenhouse to test the growth response of *Sphagnum* propagules on peat with applications of lime and an NPK fertiliser. This trial was designed to explore whether the *Sphagnum* pieces would grow under ideal warm, wet conditions, and also to examine their growth responses under different levels of lime and fertiliser. Treatments were applied up to levels required in the field to establish nurse grass crops (a technique which is a likely practical precursor to adding *Sphagnum*).

Shallow trays filled with peat had different quantities of lime and fertiliser scattered evenly over the surface. The quantities applied were 0%, 50% and 100% of the lime and fertiliser amounts spread for restoration purposes in the field, and all possible combinations of these treatments were tested. Control trays with no treatments were set up as well as trays with no lime and fertiliser but with an additional covering of heather brash. *Sphagnum* beads and chopped strands were then also added to the peat surface and the growth of these pieces was regularly monitored. At the end of the greenhouse experiment the moss pieces were dried and weighed to give an indication of their relative growth under the different treatments.

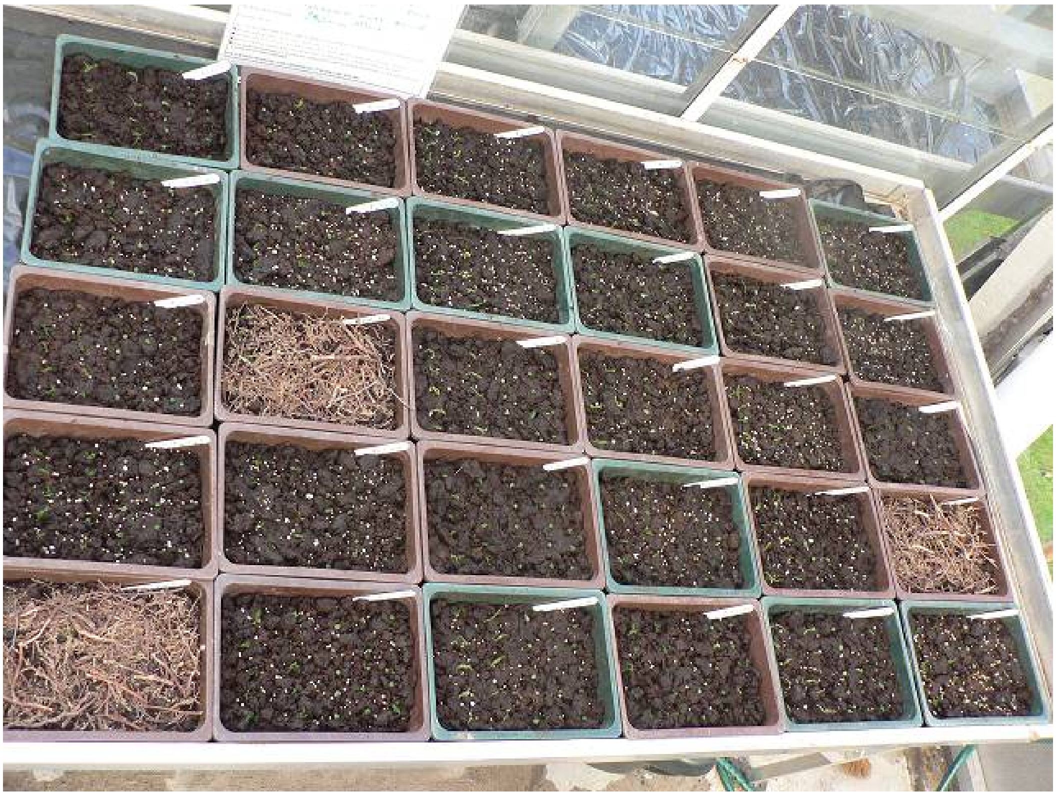


Figure 17: *greenhouse trial trays set up in November 2008.*

Monitoring Results

Results from the trials in the greenhouse demonstrated that both the *Sphagnum* pieces and beads were viable and grew well in the warm, wet conditions of the greenhouse. The growth seen on control trays was faster and more extensive than that seen in the field, where conditions would be sub-optimal for growth on exposed moorland sites.

Figure 18: *showing the growth of* Sphagnum *within the greenhouse over 3 months (Nov 2008 – Feb 2009) in control trays with no lime or fertiliser treatment applied. Photograph to the left is of* S. fallax *beads, and right* S. fallax *strands (not to same scale).*

Lime was not shown to have a statistically significant positive or negative effect on *Sphagnum* growth, although the pieces seen to be growing in trays with lime additions were noticeably paler than where no lime had been applied. This observation is in keeping with observations in the field, where lime pieces have landed on or near growing *Sphagnum* and bleached it to a paler colour. However, application of lime has been shown to be highly significant in enabling any plants to establish on the bare peat of the Peak District (Caporn *et al*, unpubl.).

Fertiliser was shown to have a negative effect on *Sphagnum* growth, with growth decreasing as fertiliser concentrations increased, to a level where the fertiliser concentration was toxic and the mosses were killed. However, it was concluded from these results that there were limitations to how well the greenhouse trial was able to replicate hydrological conditions in the field. There is less opportunity for lime and fertiliser to leach from peat in the greenhouse trays than there would be from peat on the moor. While trays were regularly misted and remained moist, they were not subject to heavy rainfall, likely to cause wash through or run-off from the soils in the field , and dilution of ions within the peat to lower levels. The fact that there were relatively large patches of growing *Sphagnum* seen within several of the large trial plots at Black Hill, assumed to have pre-dated the aerial application of lime and fertiliser on the restored site, demonstrates that it is unlikely that these concentrations are damaging to *Sphagnum*.

Spreading brash on top of the *Sphagnum* was not shown to have any effect on growth within the greenhouse, but other moss species were seen to be growing within trays where brash had been added. This supports the fact that small pieces of moss or other species can be introduced via heather brash, and it is possible that some of the growth observed and monitored within plots in the field was not from *Sphagnum* added as part of the trials, but had been introduced on brash spread as part of the wider restoration of the experiment areas.

2.6.2 Substrate trial

This trial focussed on the suitability of the substrate. The pollution of the southern Pennines has been well documented and so the legacy of this is of great importance in the restoration of *Sphagnum*. With this in mind, two trials were set up; a species experiment, and a *Sphagnum* mulch and brash experiment.

In the species trial beads were applied to trays of Holme Moss peat and commercial Irish peat moss (referred to as commercial peat), with the aim of illustrating any differences in growth due to the substrate. The *Sphagnum* mulch and brash trial followed similar reasoning, with brash and *Sphagnum* mulch applied separately to Holme Moss and commercial peat.

The use of a glasshouse would have been ideal for this, however a particularly hot summer lead to unsuitably high temperatures. A butterfly house was used a replacement, with lighting and air-conditioning to regulate temperature (referred to as 'growth room').

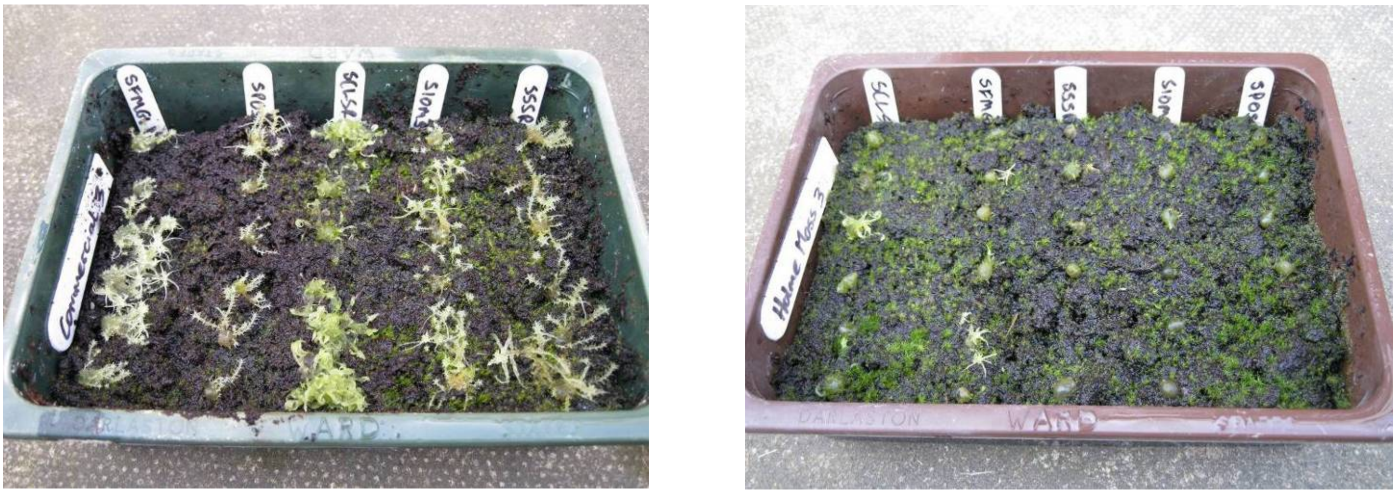


Figure 19: *Beads growing on commercial (left) and Holme Moss (right) peat.*

Figure 20: *Heather brash growth on commercial (left) and Holme Moss (right) peat.*

Experimental results

The establishment and growth of beads shows a marked difference between commercial and Holme Moss peat.

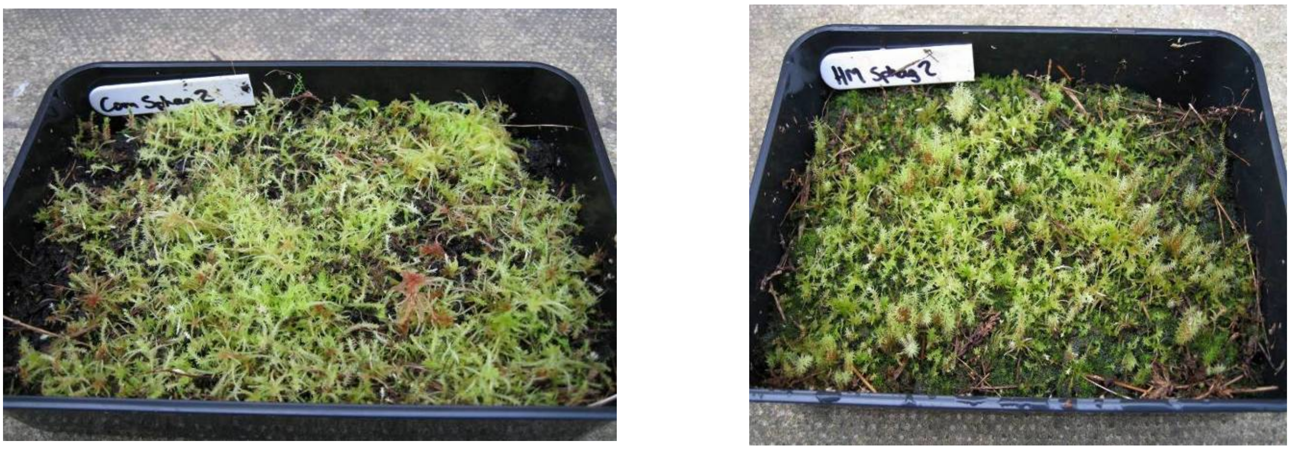
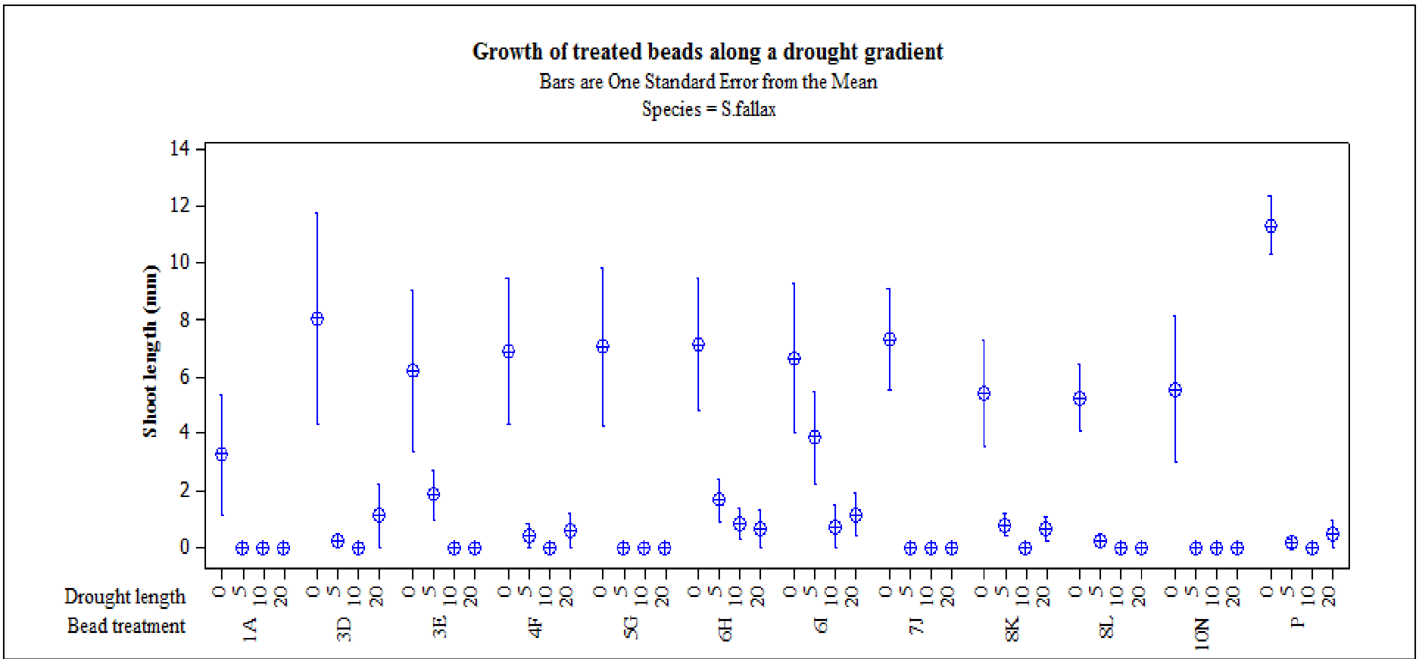
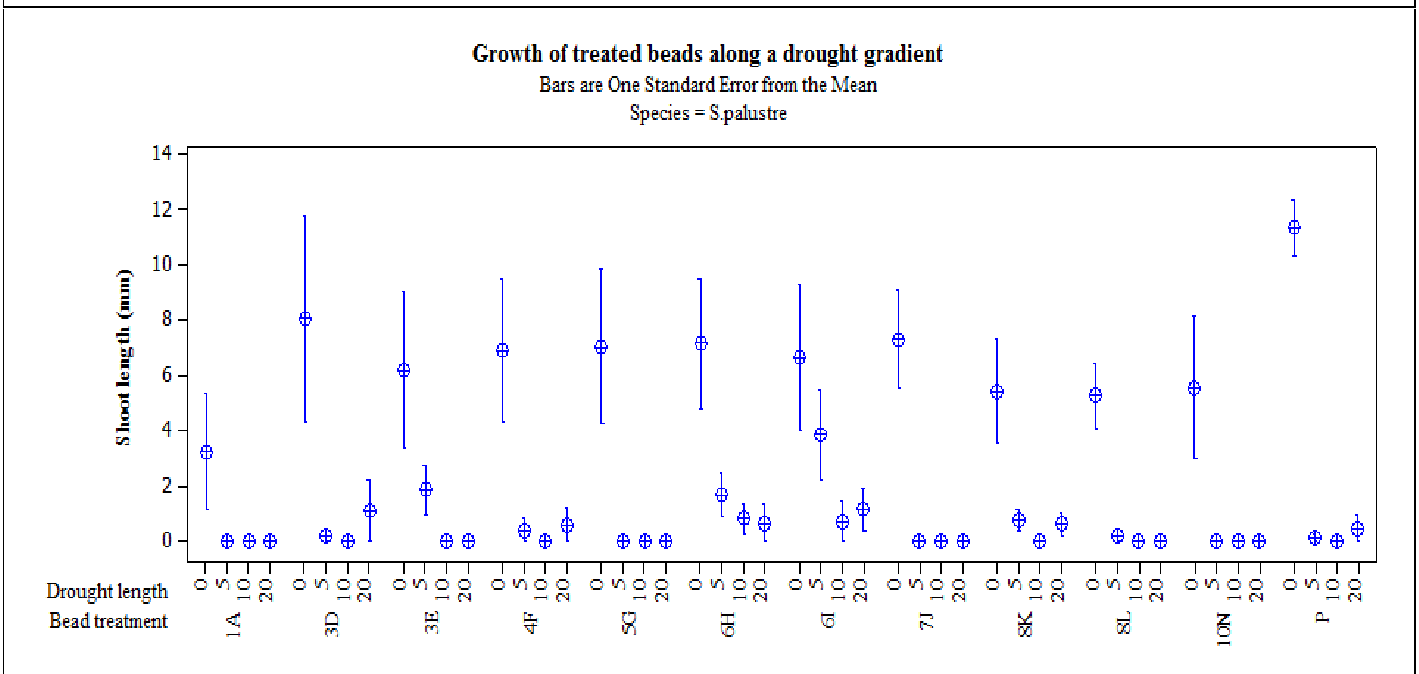


Figure 21: Sphagnum *mulch growth on commercial (left) and Holme Moss (right) peat.*

Heather brash growth shows the potential for incidental *Sphagnum* introduction, with a little growth on both substrates. However, growth is healthier on the commercial peat, with a green algae growth appearing on all the Holme Moss peat trays; presumably due to the higher nutrient content.





Sphagnum mulch produced; a rich, multi-species layer on the commercial peat, containing at least one of the 'chunkier' peat forming species. On Holme Moss peat, growth of *Sphagnum* is present but at a far lower intensity and is instead dominated by *Polytrichum* moss growth.

All the trays and treatments here indicate that Holme Moss peat is still affecting the growth of *Sphagnum*. It is hoped chemical analysis of the soils will help to explain this.

Incidentally, growth of the beads is greatly improved through the maintenance of a moist micro-climate. Initially, the beads were watered by regular misting, however upon adding a cover of plastic sheeting their performance and appearance improved dramatically.

2.6.3 Drought trial

Following a hard winter, where plots remained covered with snow for several months, and a dry summer with several weeks drought, the need to assess bead resilience was brought to the forefront. In June 2010, an experiment was established to track the effect of prolonged drought on the beads, but also to test the effectiveness of several bead treatments. These beads were subject to pre-stressing agents to try and improve their survival and performance following drought; there were 12 treatments in total, applied to *S.fallax* and *S.palustre* beads. The beads were grown in a growth cabinet; a chamber allowing total control over the environment within it. The beads were grown under very favourable conditions, following a period of drought of 0, 5, 10 and 20 days drought. Initial results show some differences between the treatments at different drought stages, although recovery times are thought to be long after drought.

Figure 23: Comparison of effects of drought on different bead treatments of two different Sphagnum species.

Experimental results

At present it seems a little too early to draw any firm conclusions about which treatment is the most suitable, but 6H and 6I (both hardened bead treatments) seem to be developing more rapidly than the other treatments. Further monitoring will be carried out to track their establishment and growth rates. Ultimately, the *Sphagnum* will be harvested and weighed to provide a better measure of success

Figure 24: *Tray of the treated beads showing differential growth between treatments (arrange in X shape).*

2.6.4 Recovery of dried-up beads from field trials

This was an experiment to see if *Sphagnum* beads from field trials that had a very dried up and apparently completely dead appearance were capable of recovering in the greenhouse. Beads were collected in April from a site originally planted in November on Holme Moss. They appeared to have desiccated completely over the winter month and were white in colour. They were placed in trays in the greenhouse and have since recovered and grown into substantial *Sphagnum* plants (see Fig. 25 below).

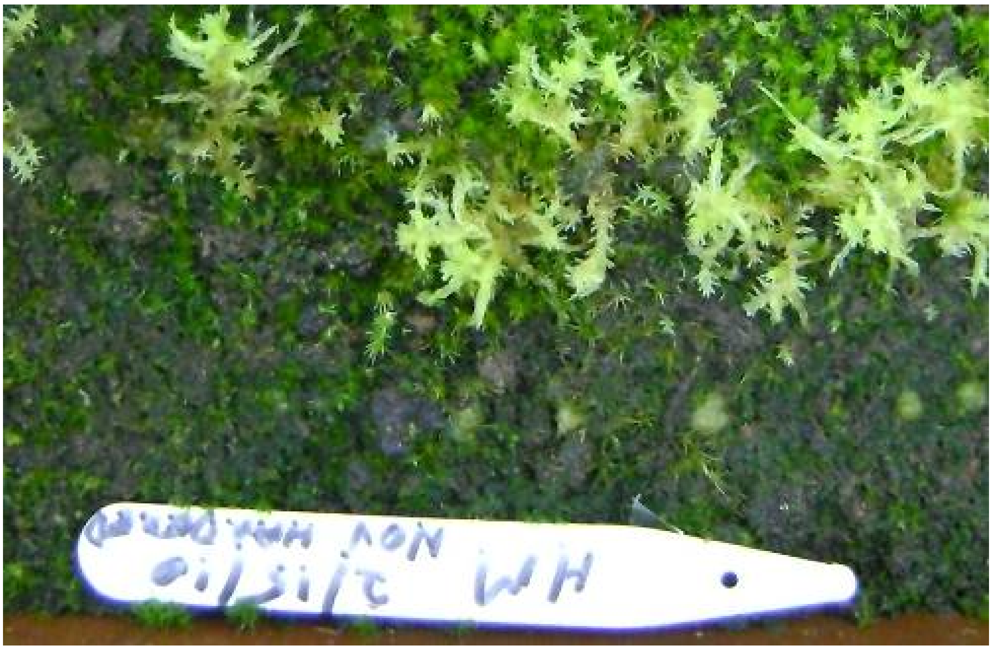


Figure 25: *Recovered dried-up beads; Planted November; Collected April; Photo July.*

2.7 Analysis of peat – commercial vs. Holme Moss

The above trials established that the effect of climatic conditions and chemistry of the peat are extremely important. Climatic data will be gathered from weather stations within the region. The majority of environmental data will come from analysis of peat samples collected from the plots of various trials. Whilst there is obviously a difference in the performance of *Sphagnum* on Holme Moss peat compared to commercial peat, some care was needed in order to highlight this. From the literature it became apparent that there is no standard method for the analysis of peat. Different authors use a variety of methods dependent upon the equipment and time available to them. A comparison of extraction techniques was carried out to illustrate which method would be most appropriate for future analyses. Extractions of Holme Moss and commercial peat using H_2O, KCl and $BaCl_2$ at 1% and 5% were compared.

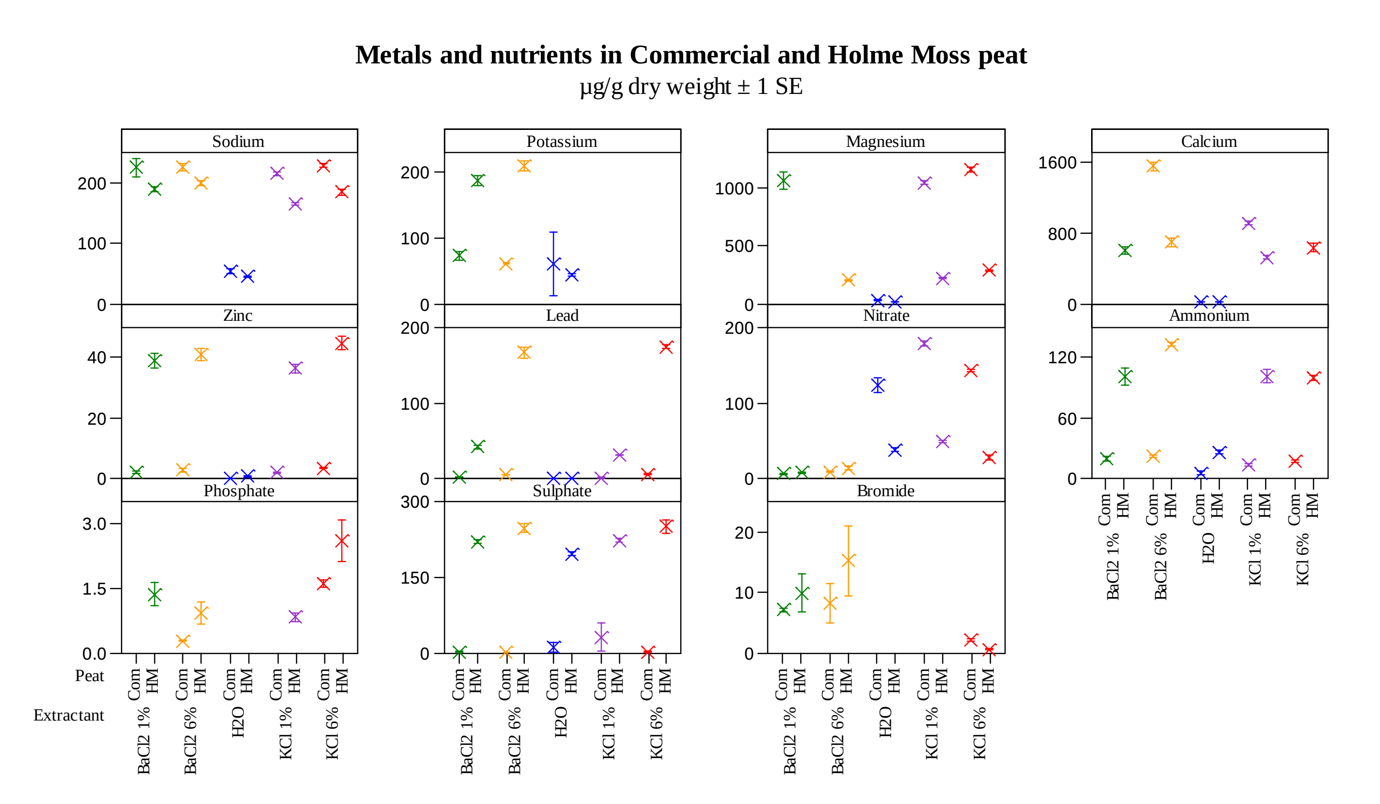


Figure 26: *Chemical characteristics of peat collected from Holme Moss study area and a commercially available moss peat*

The graphs above show there is an obvious difference between Holme Moss and commercial peat in terms of its chemical characteristics, but also that particular extractants are more suited to highlighting the difference than others. A water extract would be ideal since our method of analysis uses an ion chromatographer; however a water extract does not display any difference in sodium, magnesium, calcium or phosphate, and fails to highlight the scale of difference in ammonium between the two peats. On reflection, it appears that a KCl extract of 1% or 6% is of greatest use in this situation. Future sample analysis will use a KCl extract, with this experiment as reassurance of it being an appropriate choice.

3. Conclusions

3.1. Propagule type

Hinde's MSc dissertation asserted that in ideal glasshouse conditions there was no difference between strands of collected material and various different bead types. However, there were significant differences between the strands and the beads under field conditions. Because of this, and because of the lack of large-scale source material in the Peak District, we have concentrated our research on the beads developed by Micropropagation Services.

The initial monitoring of the quadrats at Black Hill and the Mast sites that took place over the months after these plots had been set up recorded the numbers of *Sphagnum* beads and *Sphagnum* strands in each plot. These results showed that *Sphagnum* beads appeared to be more successful than strands at remaining green and therefore having a better chance of successful establishment. It was not possible in further monitoring to be certain whether the growing pieces monitored by fixed-point photography were beads or strands of *Sphagnum* but given the preceding results, it is likely that most of those seen were beads since the strands were shown to turn white, dry out and die before becoming established in suitable areas and starting to grow. Beads were used in all later plots for this reason, and established well in the larger field trial plots where conditions allowed.

3.2 Weather conditions

The time of year is critical for *Sphagnum* spreading. The small trial plots demonstrated that spring and autumn appear to be the best times. Weather conditions need to be wet with high cloud cover to ensure the moss pieces remain green and can successfully establish and start growing before they completely dry out. In dry weather, sun or high wind the *Sphagnum* pieces (either beads or strands) turn white and dry out. While there is evidence that they can become white and dried and still remain viable for some time, greening up and growing on rewetting, the length of time they can remain in this state is limited. It appears that the *Sphagnum* propagules will tolerate drying and be able to re-green more successfully after drying, if they have had a chance to become established first. This requires a certain length of suitably moist weather directly after spreading. It was clear that the *Sphagnum* within the small and large field trial plots was slower to turn white and was able to become green again after rain much more successfully than the *Sphagnum* pieces which had been spread during unsuitable weather conditions at Heyden Head (the aerial strip and other plots).

3.3 Ground cover

Sphagnum appears to establish best where there is a ground cover of vegetation on the bare peat surface (i.e. at Black Hill rather than the Mast site). Having other species (mosses, cottongrass or small heather seedlings) growing in the area around *Sphagnum* pieces helps to protect them from the wind, as well as to stabilise the peat surface on which they are growing. Having said this, a 100% coverage of tight, low-growing species (as seen at the drier area of Black Hill) appears to be detrimental to *Sphagnum* growth, as it prevents the pieces from remaining wet by being in contact with the underlying peat, and gaining a foothold. In all plots monitored, *Sphagnum* was observed to establish well and remain greener in sheltered cracks in the peat, between other surrounding vegetation cover.

3.4 Water table

As well as suitably wet weather (rainfall and cloud), a wet site is required to keep the young moss colonies moist and green. *Sphagnum* was shown to grow best at the wetter lower parts of gully bottoms where the water table was higher. This factor is linked to vegetation cover, both in the nature of the vegetation growing in wetter sites (as described above) and also since it has been demonstrated that vegetation growth acts to draw up the water table to some extent. It is possible that the lower water table at the bare, brashed Mast site was too low to successfully support the growth of the pieces spread there to the same extent as at Black Hill, although it is difficult to separate this factor from others when drawing conclusions on the relative importance of each on *Sphagnum* growth.

4. Recommendations and further work

The project team have numerous recommendations to inform Best Practice for *Sphagnum* re-introductions in the future. These are:

Further monitoring of current plots is required:

> Long term monitoring is needed to follow up the development of the established plots.

Experiments at different starting points:

> Monitoring should continue on material put into an existing cotton-grass sward. Trials should also be undertaken wherever possible, for example when:
>
> - undertaking flailing of *Molinia*-dominated grasslands;
> - putting in place appropriate grip and gully blocking projects;
> - undertaking peat pan experiments.

Application methods:

Aerial spreading needs further trialling to establish the best ways of large-scale spreading of beads. This will require improvement of the air-assisted seeder, or development of alternative machinery for handling beads.

Ground based application systems also need to be looked at and developed for areas where access is possible with wheeled/tracked vehicles.

Effect of other treatments:

In the field, beads and *Sphagnum* mulch have been applied to bare and treated surfaces to see where establishment is most successful. In this situation, any vegetation already in place will help to provide a micro-climate, with increased humidity and temperature. However, it is not known if there are any other facilitation effects, e.g. release of nutrients into the peat. In order to test this, turves have been collected from a variety of surface types along the restoration pathway. Beads will be added to these in the growth room, where they will be grown under optimum conditions to remove any micro-climate differentiation between surfaces.

Based on observations in the growth room species trial, and to assess the provision of micro-climate, an experiment into cover is needed. This will take the form of a growth room trial, with various coverings added to trays containing beads, e.g. heather brash, cotton grass cuttings. The amount the trays will be watered will reflect what they would receive in the field based on meteorological data.

Measurements of water table and peat moisture, and / or survey of vegetation growth should be taken before spreading on any future plots is undertaken, to be able to compare the effect of ground wetness or to enable sites best-suited to *Sphagnum* establishment to be selected before spreading.

Increasing percentage survival of beads

Development of more drought tolerant beads and continued monitoring of the recently set up trials of coated beads.

5. Best Practice Recommendations

Current Best Practice recommendations for scaling-up *Sphagnum* application as a restoration technique on areas of bare peat are:

- *Sphagnum* should be spread during a wet / cloudy period in spring or autumn.

- Where significant locally harvested inoculating material is not available, propagated beads provide an effective source of material.

- Spreading to take place on sites where water table is suitable (i.e., where ground is likely to remain wet for much of the year, either from ground-water or precipitation).

- *Sphagnum* to be spread where previous restoration techniques have been carried out, ideally heather brashing, lime, fertiliser and grass seed applications, so a ground cover of protective nurse crop species have become established.

6. References

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