Harvesting *Sphagnum* from donor sites

Pilot study report

Report to
Natural England:

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Summary

Sphagnum restoration works are essential to re-build the peat on the moors, towards a sustainable blanket bog habitat. Re-introduction of *Sphagnum* can halt the loss of erosion of peat on the moors and in turn the loss of carbon to the atmosphere. *Sphagnum* restoration works also importantly create a wetter environment on the moors, which is beneficial for water quality, reducing flood risk and the risk of wildfires.

To investigate of the recovery of *Sphagnum* hummocks following harvesting from donor sites for translocation, we recorded capitulum density measurements, area (hole) measurements, vegetation survey data and fixed point photography of fixed quadrats set-up on *Sphagnum palustre,* before harvesting in spring 2016, and after a recovery period, in winter 2018, as well as monitoring control (no intervention) quadrats. We assessed changes over time using paired-samples analyses of the capitulum count data and of the repeat vegetation survey data.

This pilot study has yielded evidence to suggest that *Sphagnum palustre*, a hummock-forming species, recovers from a 10 % harvesting rate. Based on the observed recovery rate of treatment quadrats, 57 % towards the original density over three annual 'growing seasons' (over 141 weeks), we estimate that full recovery could be achieved in less than twice this amount of time: within 250 weeks, or five annual 'growing seasons'. This assumes (i) that growth following harvesting is linear over time and (ii) growth isn't limited due to any interspecific competition for space, nor due to the spread of invasive species e.g. thistle spp. A repeat survey is recommended after five annual growing seasons (March 2021) to test that these assumptions hold true. A faster recovery rate was achieved when patting-back the holes immediately following harvesting, as per the best practice guidance; as opposed to leaving open spaces (holes) in the hummock. Harvest frequency could increase (more than once every five years) if weather following harvest is warm and wet.

This pilot study also indicates that harvesting *Sphagnum* at a 10 % rate produces similar outcomes to no intervention (control) over three annual growing seasons: *Sphagnum* was present in all quadrat grid squares after the recovery period (T1, T2 and control). Whilst there was an observed reduction in the number of capitula in the control quadrats over the study period, partial recovery was observed following harvesting, indicating growth.

1. Introduction

The project supports SSSI favourable condition by monitoring the recovery of *Sphagnum* following harvesting from donor sites for translocation. According to an advisor at Natural England, Efion Jones, the ultimate aim for *Sphagnum* restoration works on areas of open moor, where a background level of *Sphagnum* is absent or critically low, is to get 'hummock'-forming species[1] back on to the open moor. Hummock-forming species have greater water holding capacity than carpet-forming species and are more resistant to low water and pH levels (Carroll et al. 2009).

Sphagnum restoration works are essential to re-build the peat on the moors, towards a sustainable blanket bog habitat. Re-introduction of *Sphagnum* can halt the loss of erosion of peat on the moors and in turn the loss of carbon to the atmosphere. This is important in the context of climate change: in the Peak District alone, 20 million tonnes of carbon is stored in the peat (Moors for the Future Partnership website). *Sphagnum* restoration works also importantly create a wetter environment on the moors which is beneficial for water quality, reducing flood risk and the risk of wildfires.

The purpose of this project is to increase knowledge of the recovery of *Sphagnum* hummocks following harvesting. Firstly, this pilot project aims to evidence whether hummock forming species recover from a 10 % harvesting rate.

A suite of different methods have been trialled for *Sphagnum* growth monitoring in the literature:

Height growth measurements, using (i) cranked wires (Clymo, 1970), and (ii) an adaptation of the crank wire technique, using aluminium rod pushed well into the *Sphagnum* carpet (Buxton et al., 1996), which proved more reliable than the 1970s method. Dorrepaal (2005) used a further modification of the crank-wire method: (iii) straight stainless wires with a ring of short bristles at the lower end were inserted ca. 10 cm into the *Sphagnum* carpet. A disadvantage of wires used for height growth measurements is that it is not possible to control for possible movements due to freezing and thawing when wires are left in place during the winter (Dorrepaal E., 2005). An advantage of the method is that it is non-destructive.

Capitulum mass (mg per mm stem length) was sampled by Robson et al. (2003), alongside density and height growth measurements. Whilst the bulk density values provided by Robson et al. (2003) importantly revealed that "what is often seen as relatively rapid recovery of *Sphagnum* in terms of height growth betrays the fact this regrowth is often less dense than the initial harvest", the methods used for assessing capitulum mass are destructive to the site and were not deemed possible to adapt for the sensitive site chosen for the NESD pilot study.

[1] Hummock forming species include *S. capillifolium* (*); *S. subnitens*; *S. papillosum* (*); *S. palustre*; *S. medium* (formerly *magellanicum*) (*) (BBS, 2019)
Carpet forming species include *S. capillifolium* (*); *S. fallax*; *S. cuspidatum*; *S. fimbriatum*; *S. tenellum*; *S. denticulatum*.
* An important peat-forming species (FSC,2012)

Capitulum density (stems per m^2) was measured non-destructively by Smolders et al. (2001) and by Robson et al. (2003). Smolders et al. (2001) counted the number of *Sphagnum* capitula in a 120 x 120 mm area and six randomly assigned counts per plot were taken at the beginning and the end of the field season.

Biomass and biomass production (g per m^2): Buxton et al. (1996) measured recovery after harvesting by weight; where (i) samples were divided into *Sphagnum* and litter fractions, oven dried at 80°C and then weighed to obtain dry mass. The researchers reported that *Sphagnum* yield in re-harvested plots was significantly less than initial biomass. (ii) To calculate biomass increase per stem, Robson et al. (2003) removed a random sample of 14 *Sphagnum* capitula from each plot. Samples were oven dried at 65°C for at least 72 h and subsequently weighed. Again, this method is destructive to the site.

Area measurements: Rydin (1993) reciprocally transplanted patches of the hummock species *S. fuscum* and the hollow species *S. balticum* and *S. tenellum* in a long-term study (up to 11 years); species interactions were monitored by measuring the area covered by each species. Smolders et al. (2001) measured the diameter of 25 randomly selected capitula, the density of the capitula, by counting the number of capitula for a surface of 10 x 10 cm (in triplicate) and the length of the branches at 2 cm below the capitulum, for 30 *Sphagnum* plants at the end of the laboratory experiment. Smolders et al. plotted increase of surface area at x weeks, expressed as a percentage of the value at 0 weeks.

Volumetric density of capitula (g per dm^3) was calculated from height growth, density, and biomass data (Robson et al. 2003). Calculating volumetric density of capitula traditionally relies on biomass data, which is destructive to the site.

2. Approach and Methodology

A suitable site, Robinson's Moss, was identified on United Utilities / RSPB land for this trial. This site has extensive areas of *Sphagnum palustre,* a hummock forming species that is found in sites that are moderately enriched with nutrients, for example wet woodland, ditches, stream margins and flushes (Atherton et al., 2010). The site is located in the Peak District, approximately 6 km north of Glossop (Figure 1a). A walk-over survey of the site was undertaken on 17th November 2015 to identify the extent of hummock-forming *Sphagnum* patches. The survey confirmed that there were enough large patches of *Sphagnum* to install 20 quadrats at this site.

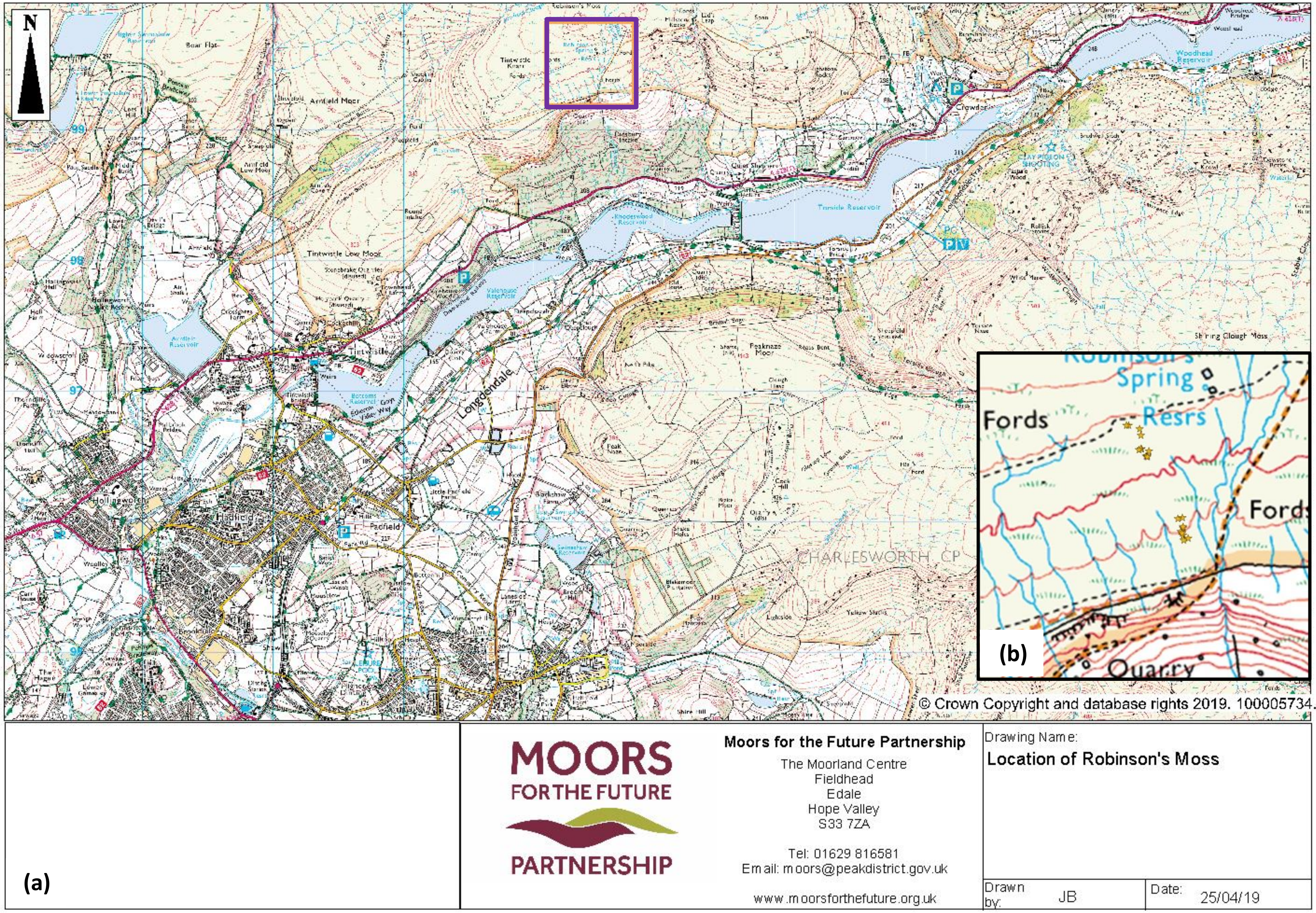


Figure 1: (a) Location map of the monitoring site on Robinson's Moss (purple square) and insert (b) location map of NESD quadrats on Robinson's Moss site (orange stars)

Best practice guidelines recommend patting *Sphagnum* down following harvesting (Hanley, 2014), however this may impact monitoring by photogrammetry. Twenty 1 x 1 m quadrats were set up between 17th and 31st March 2016. In five quadrats ten handfuls of *Sphagnum* were harvested evenly across the quadrat and the *Sphagnum* around the hole was patted back together (treatment 1), as per the best practice guidelines. In ten quadrats, ten handfuls of *Sphagnum* were harvested evenly across the quadrat and the *Sphagnum* around the hole was not patted back together (treatment 2). In five quadrats no *Sphagnum* was harvested and these quadrats provided a control. All quadrats were set up on vegetation dominated by *Sphagnum palustre*.

In light of the limitations of the methodologies presented above from the literature, the monitoring methods we considered for the pilot study were those that are non-destructive to assure only minimal damage to the site: a combination of capitulum density measurements and area measurements. A third methodology was developed specifically for this pilot project: fixed point photography and close-range photogrammetry, which was used in preference to the traditional volumetric measurements.

Quadrats were subdivided into 100 squares using a metal grid laid over the quadrat which served as a guide for harvesting 10 % (10 squares). Numbering the grid square ensured that the harvesting location could be accurately identified in subsequent surveys. The south-west and north-east corners of the quadrat were marked with one flat head and one raised head ground marker. Each grid square was numbered from 1 to 100 (starting at the top/north-west corner, reading left to right, finishing at the south-east corner).

2.1. Field measurements

A vegetation survey was carried out for each quadrat before harvesting in 2016; this recorded the percentage cover and dominant species for the following four vegetation categories: dwarf shrub, cotton grass, other grasses and bryophytes. The approximate distance to the nearest standing water was also noted. The vegetation survey was repeated in the November-December 2018 survey.

The measurements included capitulum density counts, i.e. for each quadrat the number of *Sphagnum* capitula in ten 10 x 10 cm grid squares was counted. *Sphagnum* capitula were counted, rather than the stems. As well as this being the easiest method in situ, it also allowed for multiple capitula per stem to be counted where there was more than one per stem. These measures were taken before harvesting in March 2016 and again in November-December 2018. This time allowed for three main growing seasons outside of the winter months (2016, 2017 and 2018). Krebs (2016) reviewed the literature regarding the growth of *Sphagnum*. He concluded that *Sphagnum* growth varies during the year; it is fastest in wet and humid seasons, starts at temperatures above freezing and increases with temperature (tested up to 30 degrees Celsius). In addition, Carroll et al. (2009) concluded after reviewing the literature that a high and stable water table was an essential requirement for successful *Sphagnum* regeneration, but most of the work carried out has been on raised bogs at lower altitude. However, Carroll also noted that there is some indication that at high altitude, under conditions of high humidity and rainfall, this condition may not always need to be met.

In the March 2016 count, the ten grid squares were split into quarters and the number of capitula in a quarter of the square was multiplied by 4 to estimate the full single grid square count. This ensured that the survey could be completed in the time available in the field as there was a high density of capitula per 10 x 10 cm square. In the November 2018 survey time allowed for a full count of each square to be undertaken, which was important whilst the capitula were found to be less evenly distributed across the square post-harvesting and whilst there appeared to be fewer capitula to count in the repeat survey.

Length (North-South), width (East-West), and depth of the hole were measured following harvesting. Some of the earlier harvested quadrats on 18th April were measured in either orientation however, until a firm rule was established. The depth of the hole was measured from the height of the surrounding/neighbouring *Sphagnum* capitula.

2.2. Photogrammetry

Conventional photogrammetry uses precise knowledge of the 3D location and pose of cameras, or the 3D location of a set of control points located in the scene of interest, to reconstruct scene geometry (Smith et al., 2015). Conventional photogrammetry is the closest existing technique to Structure from Motion with Multi-View Stereo (SfM-MVS) (Smith et al., 2015); this is the technique that was intended to be used for the project. A 3D topographic survey was conducted using Structure from Motion (SfM). A series of photographs (20-30) was taken of each quadrat before harvesting and after harvesting (photogrammetry), as well as one ‘close-up’ and one ‘overview’ photograph per quadrat (fixed point photography). This number of photographs is crucial to guarantee enough image overlap across the dataset (M. Smith, personal communications, 17 December 2015).

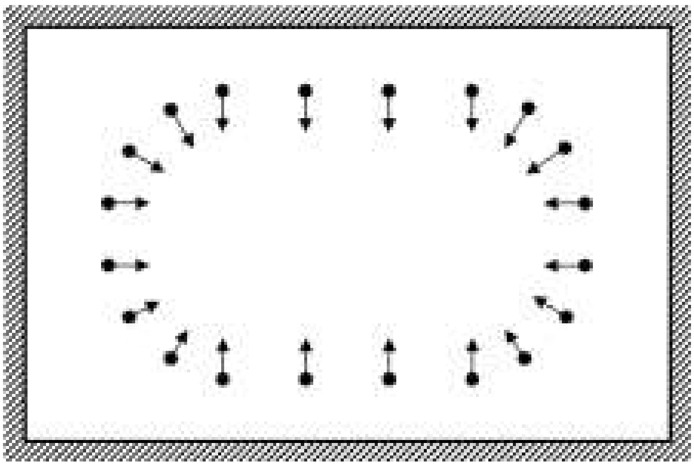


Figure 2: Interior shooting scenario (taken from Agisoft Metashape User Manual, Standard Edition, Version 1.5)

Four ground control points (GCPs) were located in the four corners of the quadrat. The south-east and north-west corners of the quadrat were marked with wooden stakes, installed at different heights. This gave additional height reference points for the purpose of photogrammetry. The stakes were removed once photographs had been taken. A differential Global Positioning System (dGPS) was used to record the x, y and z coordinates of each GCP. Photographs were due to be processed using the Agisoft Photoscan (http://www.agisoft.com/) software package. Processing of images includes the following main steps:

- **Feature detection** - features (or 'keypoints') in each image are identified and assigned a unique identifier
- **Keypoint Correspondence** - correspondences between keypoints in multiple images are identified
- **Keypoint Filtering** – a filter is applied to remove erroneous matches
- **Structure-from-Motion** – the camera position and orientation for each photo are estimated and a sparse, unscaled 3D point cloud in arbitrary units is built
- **Scaling and Georeferencing** – the model is referenced using real world coordinates of at least three ground control points, camera coordinates, or both
- **Multi-View Stereo** – following the input of ground control coordinates the Structure-from-Motion stage can be re-run to improve image alignment
- **Georeferenced Dense Point Cloud** – Algorithms are applied to the georeferenced sparse dense cloud to create a dense point cloud (Smith et al., 2015)

It is then possible to extract three-dimensional information from the point cloud, for example topography or volumes.

The series of photographs for photogrammetry that were taken during the baseline survey were due to be processed using the Agisoft Photoscan (http://www.agisoft.com/) software package to create a three-dimensional topographic model, from which three-dimensional information could be extracted, e.g. topography or volumes. It was hoped that this application could be used to measure the volume of the hole created by the removal of *Sphagnum* and to monitor recovery over time. However, the collection of photographs caused significant trampling around each quadrat and for that reason photogrammetry was not repeated in future surveys, therefore we did not process the baseline survey series of photographs. Moors for the Future had hoped instead to collect the photographs using an Unmanned Aerial Vehicle (UAV) but due to technical issues and land owner permission this was also not possible.

3. Results

3.1. *Sphagnum* capitula density counts

In March 2016, before harvesting took place, *Sphagnum* capitula were counted in a total of 200 grid squares (in 10 squares per quadrat across 20 quadrats). Four quadrats were not located in the repeat survey in November 2018, therefore the full dataset represents 160 grid squares. One grid square was excluded from the analysis due to the presence of standing water in the square, where capitula could not be counted under the water, therefore there are 159 paired data points in the analysed data set: before harvesting at week 0 and at 137 - 141 weeks after harvesting, split further by quadrat type: treatment 1 (T1), treatment 2 (T2) and control.

A Shapiro-Wilk test was used to test the normality of the differences between pairs in this 'before' and 'after' study (number of *Sphagnum* capitula before harvesting and at 137 - 141 weeks after harvesting). The differences between pairs of data in both the control and T1 datasets were found to be normally distributed (S-W test(40) = 0.968, $p > 0.05$ and S-W test(50) = 0.985, $p > 0.05$, respectively). The T2 dataset however, was not normally distributed (S-W test(69) = 0.920, $p < 0.005$).

A paired t-test was used to assess the change in capitula counts for control and T1 quadrats and the Related-samples Wilcoxon signed-rank test was used to assess the T2 quadrats, which is the non-parametric equivalent of the paired samples t-test.

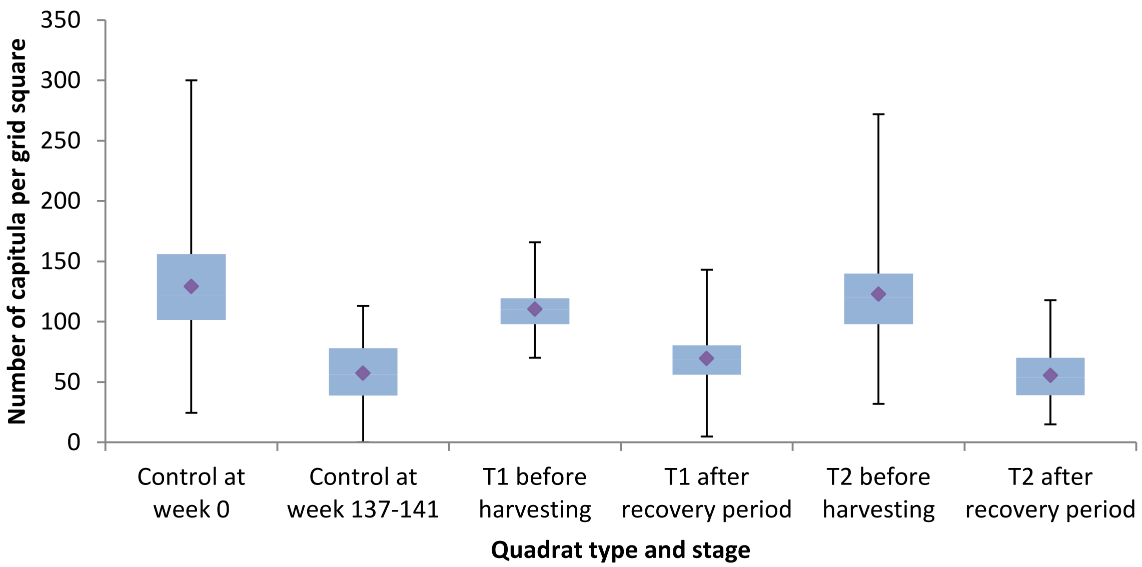


Figure 3: Box plots to show change in capitula counts for the three quadrat types before harvesting at week 0 and following a period of recovery, 137-141 weeks after harvesting

T1 quadrat grid squares

T1 quadrats contained significantly fewer capitula in 2018 compared with the pre-harvesting count in 2016 (Paired t-test(49) = 8.7, $p < 0.0005$), with -41 capitula per square, where n = 50 (Figure 3). The average count before harvesting in the T1 squares was 110 capitula. There was a mean recovery of 64 % towards the original capitula count (Figure 4).

T2 quadrat grid squares

A Wilcoxon signed-rank test indicated that the T2 quadrats contained significantly fewer capitula in 2018 compared with the pre-harvesting count in 2016 (Z = -7.02, $P < 0.005$), with -67 capitula per square, where n = 69 (Figure 3). The average count before harvesting T2 squares was 123 capitula. There was a mean recovery of 50 % of the original capitula count, half way towards a full recovery (Figure 4).

Control quadrat grid squares

Control quadrats contained significantly fewer capitula in 2018 compared with 2016 (Paired t-test(39) = 7.5, $p < 0.0005$), with -72 capitula per square, where n = 40 (Figure 3). The average count in week 0 of the study was 129 capitula. There was a 44 % reduction in the mean number of capitula per grid square over the study recovery period, which equates to 56 % of the original count (Figure 4).

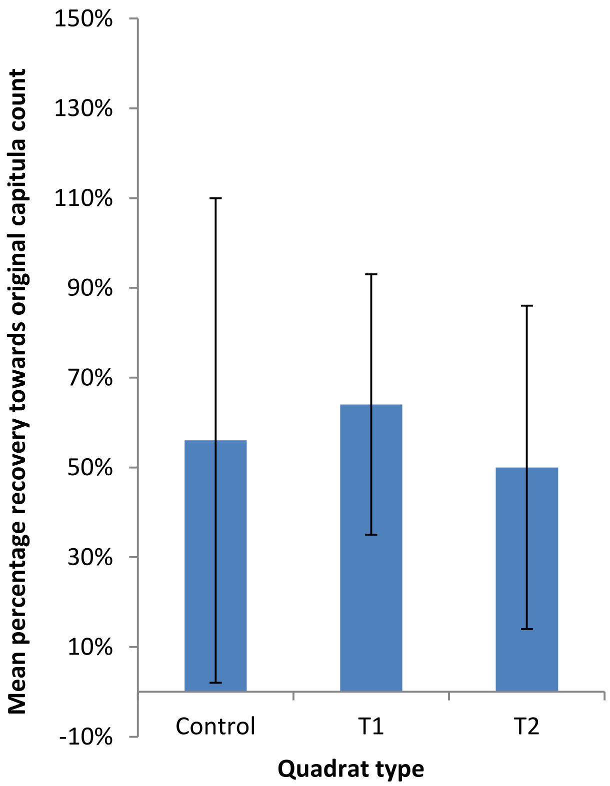


Figure 4 : Bar chart to show mean percentage recovery of capitula for the three quadrat types, after a period of recovery at 137-141 weeks following harvesting (T1 and T2) and for the same time period with no intervention (Control). Standard deviation error bars.

3.2. Hole measurements

The repeat survey at 137 - 141 weeks, in November 2018, revealed that 94 % (47 of 50) of the T1 grid squares and 99 % (68 of 69) of the T2 holes were no longer present following the recovery and growth of vegetation. Water was present in one of the T1 holes, so the surveyor could not ascertain whether there were any capitula growing underneath the water. No holes had formed in the control grid squares by the time of the repeat survey.

Sphagnum capitula were present in 100 % of the grid squares in all three quadrat types. There were only four grid squares with a hole remaining after the period of recovery following *Sphagnum* harvesting (table 1). In all cases the remaining holes were notably smaller than the original hole left behind at the time of harvesting and before patting back took place at week 0.

Quadrat and grid square ID	Volume of hole (cm^3) immediately after harvesting at 0 weeks	Volume of hole (cm^3) after a period of recovery at 137-141 weeks
T1 Q2 S7	1452	180
T1 Q4 S4	1694	75
T1 Q4 S9	1229	16
T2 Q10 S9	990	30

Table 1: Volume of the hole left after harvesting immediately after harvesting at 0 weeks and after a period of recovery at 137-141 weeks, where a hole was present at the time of the repeat survey

3.3. Vegetation cover changes

Bryophyte percentage cover was high in all three quadrat types before harvesting (between 90 - 100 %). The change in percentage cover from 0 to 137 - 141 weeks, following a 10 % harvesting rate, ranged between -5 and +10 % for the control quadrats (n = 4), -10 and +10 % for the T1 quadrats (n = 5) and between -10 and 0 %, for the T2 quadrats (n = 7). The dominant bryophyte species before harvesting was *Sphagnum palustre,* and this was still the case after the period of recovery.

A Shapiro-Wilk test was used to test the normality of the differences between bryophyte data pairs in this 'before' and 'after' study (percentage cover of bryophyte at 0 and 137 - 141 weeks following harvesting). As the sample size (quadrat number) was small, T1 (n = 5) and T2 (n = 7) quadrats were grouped together to increase the power of the test. The differences between pairs of data were found to be normally distributed (S-W test(12) = 0.879, $p > 0.05$).

A paired t-test was used to assess whether these changes between percentage cover of bryophyte at 0 and 137 - 141 weeks following harvesting were statistically significant. Again, T1 and T2 data were grouped together to increase the power of the test. The test confirmed that there was no significant difference between bryophyte percentage cover before and after harvesting (with/without patting back the hole) (Paired t-test(11) = 1.8, $p = 0.094$). This result is an indicator of *Sphagnum* recovery, assuming that the bryophyte species composition did not change. The dominant bryophyte species before harvesting was *Sphagnum palustre,* and this was still the case after the period of recovery.

All four control quadrats contained a high bryophyte percentage cover (90 – 100 %) after the same period of time (137 – 141 weeks), indicating no change in percentage cover from the original percentage cover at week 0. The sample size was not large enough however to perform statistical analysis to be able to check the significance of this observation.

3.4. Fixed point photography

Tables 1, 2 and 3 display close-up photographs for all 20 quadrats: immediately following harvesting at 0 - 2 weeks (March 2016); at 36 - 38 weeks, following a period of recovery (December 2016); 86 - 88 weeks, after a second period of recovery (December 2017); and at 137 - 141 weeks, after a third period of recovery (November- December 2018).

In 2016 the repeat surveyor noted that generally the vegetation and specifically the *Sphagnum* looked to be in good condition. There were a couple of indentations in the *Sphagnum* hummock in quadrat 'T2 Q10'.

In the 2017 survey the vegetation and *Sphagnum* continued to look to be in good condition. The indentations in the *Sphagnum* hummock in quadrat 'T2 Q10' had disappeared and the hummock covered the majority of the quadrat. Quadrat 'T1 Q3' was noted to have a couple of indentations. One of the quadrats 'T2 Q8' was not located as the vegetation has grown significantly, covering the ground marker. Indentations were seen to occur generally in patches of *Sphagnum* across the site.

In the 2018 survey the vegetation and *Sphagnum* continued to look to be in good condition. An additional three quadrats: 'T2Q6', 'T2Q7' and 'T2Q8' were not located as the vegetation has grown significantly, covering the ground markers. A metal detector was used in an attempt to locate the ground markers but the terrain/vegetation mosaic caused false positives.

Table 2: Fixed point photography of NESD Treatment 1 quadrats (ten handfuls of *Sphagnum* was harvested evenly across the quadrat and the hole <u>was</u> patted back together) at 0 – 2 weeks (immediately following harvesting, before patting back), and after a period of recovery at 36 – 38, 88 – 90 and 137 – 141 weeks

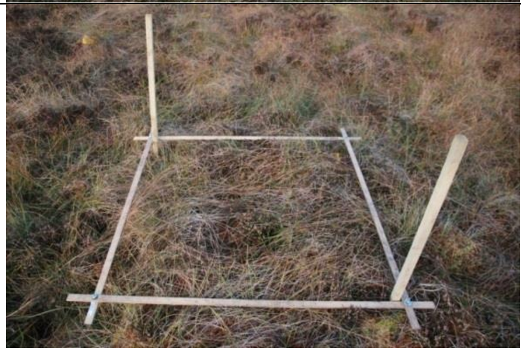
T1 Quadrat ID	Close-up photograph at 0-2 weeks, immediately following harvesting, <u>before</u> patting back the holes	Repeat survey: close-up photograph at 36 – 38 weeks (December 2016)	Repeat survey: close-up photograph at 88 - 90 weeks (December 2017)	Repeat survey: close-up photograph at 137 – 141 weeks (November – December 2018)
T1-Q1				
T1-Q2				

T1-Q3				
T1-Q4				
T1-Q5				

Table 3: Fixed point photography photographs of NESD Treatment 2 quadrats (ten handfuls of *Sphagnum* was harvested evenly across the quadrat and the hole was not patted back together) at 0-2 weeks (immediately following harvesting), and after a period of recovery at at 36 – 38, 88 – 90 and 137 – 141 weeks

T2 Quadrat ID	Close-up photograph at 0 - 2 weeks, immediately following harvesting (March 2016)	Repeat survey: close-up photograph at 36 – 38 weeks (December 2016)	Repeat survey: close-up photograph 88 - 90 weeks (December 2017)	Repeat survey: close-up photograph 137 - 141 weeks (November – December 2018)
T2-Q1				
T2-Q2				

T2-Q3				
T2-Q4				
T2-Q5				

T2-Q6				
T2-Q7				
T2-Q8				

T2-Q9				
T2-Q10				

Table 4: Fixed point photography photographs of NESD Control quadrats (no *Sphagnum* harvesting) at 0 – 2, 36 – 38, 88 – 90 and 137 – 141 weeks

Control Quadrat ID	Close-up photograph at 0 - 2 weeks (March 2016)	Repeat survey: close-up photograph at 36 – 38 weeks (December 2016)	Repeat survey: close-up photograph at 88 - 90 weeks (December 2017)	Repeat survey: close-up photograph at 137 - 141 weeks (November – December 2018)
C-Q1				
C-Q2				

C-Q3				
C-Q4				
C-Q5				

4. Discussion

The absence of holes is one indication of *Sphagnum* hummock recovery in this pilot study, which first became apparent in the fixed-point photography sequence. This observation is backed-up by the hole measurement data showing almost 100 % recovery. Additionally, the result of the *Sphagnum* capitula count data set confirms that there was *Sphagnum* re-growth present in all grid squares, where *Sphagnum* had been harvested.

A key limitation of the field methodology for this pilot study included positioning the metal 100 x 100 grid squares over the quadrat. The grid was in four pieces and it was balanced on its edges on top of the wooden quadrat. A more accurate way of positioning the quadrat is desirable to assure accuracy whilst monitoring at this level of detail (10 x 10 cm grid squares).

The indentations observed in the fixed-point photography survey were often associated with thistle growth, either caused by this growth or allowing it. This may mean that some indentations may be due to this natural community coexistence. Furthermore, on closer inspection during the *Sphagnum* capitula density count in 2018, there were many indentations in grid squares, where the *Sphagnum* re-growth appeared shorter than the surrounding *Sphagnum* capitula height, indicating good progression towards recovery, but not yet full recovery between the survey dates.

Whilst the capitula count results, expressed as recovery towards the original average density, are promising for both quadrat types, T1 and T2, we observed a reduction in *Sphagnum* capitula density in the control grid squares over the same time period. Thus we would <u>not</u> expect the T1 and T2 quadrats to show a full recovery towards the original density before harvesting at 0 weeks, rather a percentage recovery yielding a similar outcome to that observed for the control quadrats. The T2 quadrat *Sphagnum* percentage recovery is similar to that observed for the control quadrats and the T1 quadrat result exceeds that for the control quadrats, when change over time is expressed as a percentage of the original count in both quadrat types.

The summer of 2018, provisionally, was the equal warmest on record for the UK (Met Office, 2018). The long period of dry and warm weather resulted in bleaching of *Sphagnum spp.* at other MFFP works sites (Yallop et al. 2019). This was not observed in the field at the Robinson's Moss study site as there was not a survey on site in the summer 2018, however we can assume similar conditions occurred at Robinson's Moss, which is local to the other MFFP sites in the Peak District. The repeat count was undertaken in November-December 2018, immediately following the record summer, meaning that the dry conditions and bleaching could have had an effect on both the reduction of capitula measured in the control quadrats, as well as speed of recovery in the treatment quadrats. Waddington et al. (2011) related differences in capitula density between *Sphagnum rubellum* mosses growing under varying hydrological conditions to water retention and bulk density (cited by Ketcheson et al. 2011). On the contrary, other theories as to why there was such a large drop in the density of capitula in the control grid squares is that the *Sphagnum* capitula may have grown in size, in which case fewer capitula would be spread across individual grid squares, or perhaps mature *Sphagnum* simply has fewer capitula, rather than larger capitula. We do not have any measurements for capitulum diameter however, or whether *Sphagnum* patch size has grown over time, to be able to evidence these theories.

Whilst the *Sphagnum* capitula counts in the control quadrats reduced over time, there remained a high percentage cover of bryophyte in three out of four control quadrats. The percentage cover result indicates that the *Sphagnum* may not have decreased in the control quadrats, as the count data may at first suggest. We have assumed that there were no changes in the species composition of this group in drawing this conclusion about percentage cover.

The T1 and T2 quadrats both showed recovery over time, in both assessments: (i) towards the original density count values before harvesting at 0 weeks, and (ii) towards the lower threshold average observed in the 'control' density count data.

5. Conclusion

This pilot study has yielded evidence to suggest that *Sphagnum palustre*, a hummock-forming species, recovers from a 10 % harvesting rate. Based on the observed recovery rate of the treatment quadrats (ten handfuls of *Sphagnum* was harvested evenly across each quadrat), which averaged 57 % recovery towards the original density over three annual 'growing seasons' (over 141 weeks), we estimate that full recovery could be achieved in less than twice this amount of time: in around 250 weeks, or five annual 'growing seasons'. This assumes (i) that growth following harvesting is linear over time and (ii) growth isn't limited due to any interspecific competition for space, nor due to the spread of invasive species e.g. thistle spp. However, a repeat survey is recommended after five annual growing seasons (March 2021) to test that the above assumptions hold true. Harvest frequency could increase (more than once every five years) if weather following harvest is warm and wet.

The pilot study also indicates that harvesting *Sphagnum* at a 10 % rate produces similar outcomes to no intervention (control) over three annual growing seasons: *Sphagnum* was present in all quadrat grid squares after the recovery period (T1 grid squares – the *Sphagnum* around the hole <u>was</u> patted back together; T2 grid squares - *Sphagnum* around the hole <u>was not</u> patted back together; and control squares – no *Sphagnum* was harvested). Whilst there was an observed reduction in the number of capitula in the control quadrats over the study period, partial recovery was observed following harvesting, indicating growth.

The pilot study concludes that a faster recovery rate is achieved when patting-back the holes immediately following harvesting, as per the best practice guidance; as opposed to leaving open spaces (holes) in the hummock.

Whilst accuracy in grid quadrat positioning presented a limitation of the pilot study, suggested improvements are (i) to fix the four metal grids together, to reduce any movement to the grid as the surveyor leans across the grid to take measurements and (ii) adopting a method of affixing the four corners into position into the vegetation, to further improve the error associated with grid movement and placement.

Improvements could also be made to the vegetation survey. The survey was simplified for the pilot study to allow for time to be able to focus on capitula counting. A suggestion for improvement would be to record all bryophyte species and their percentage cover, rather than the dominant species alone. This data would be useful to be able to confirm whether the dominant *Sphagnum* species still covers the majority of the quadrat after a period of recovery, as it did at the outset (before harvesting), when near 100 % *Sphagnum palustre* cover was chosen to site the quadrats.

Other questions that have been raised, which are not within the scope of this pilot project, include:

1. Does the size of the patch from which *Sphagnum* is harvested affect how it recovers?
2. Does the spatial pattern of harvesting affect *Sphagnum* recovery?
3. When harvesting from 'carpet' forming species; how much can be harvested / how little can be left?

6. References

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