# KINDER SCOUT *SPHAGNUM* TRIALS: 2020 UPDATE REPORT

## MONITORING *SPHAGNUM* GROWTH FROM PROPAGULES APPLIED TO RE-VEGETATE DEGRADED BLANKET BOG

MoorLIFE 2020

Prepared by:

Moors for the Future Partnership, November 2021

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# 1. Summary

Two trials were set up in re-vegetated degraded blanket bog areas on Kinder Scout in March 2015: the *Sphagnum* Propagule Trial and the Dense Plug Plant Trial. Four headwater micro-catchments were treated with one of four different *Sphagnum* propagule types: beads, gel, plugs and translocated clumps for the *Sphagnum* Propagule Trial; a fifth micro-catchment received no treatment and provided a control. These five micro-catchments were replicated three times. The Dense Plug Plant Trial sampled an area where 36,550 *Sphagnum* plugs had been planted at a density of ~5 per $m^2$ to deliver comprehensive *Sphagnum* cover within three years.

The aim of the *Sphagnum* Propagule Trial was to compare the establishment, survival and growth of different *Sphagnum* propagule types on re-vegetated bare peat. The aim of the Dense Plug Plant Trial was to evidence how quickly comprehensive *Sphagnum* cover can be achieved in re-vegetated areas, on undulating ground and hag tops. Different positions within gullies were additionally surveyed in autumn 2020, to assess the cover of plug-derived *Sphagnum* as well as species.

Establishment of *Sphagnum* and expansion of area cover of *Sphagnum* within quadrats was observed from all propagule types. In the Dense Plug Plant Trial, *Sphagnum* was planted within quadrats on both hag tops, lower undulating ground, as well as planting of the wider Nogson area and within gullies.

*Sphagnum* derived from plugs was identified to species level and area cover of the individual species was assessed 68 months after planting. Nine species had established from plugs in the Propagule Trial quadrats; five species had established on hag tops and nine species had established on lower undulating ground in the Dense Plug Plant Trial quadrats.

Key findings from the trials include:

- *Sphagnum* derived from plugs, translocated clumps, and gel, respectively, established and grew well over time: mean percentage *Sphagnum* cover at 68 months was 24-fold for plugs than on day zero and 5-fold for clumps. The gel plants grew to almost 17 % mean area cover at 68 months, from 0 % on day zero (undetectable).
- The most successful propagule types in terms of area coverage were plugs and clumps: each covered greater than 40 % mean area of the quadrats by 68 months.
- Over the same time period beads showed limited success: *Sphagnum* derived from beads had a 2.4 % mean area cover at 68 months (beads were undetectable upon application).
- When both *Sphagnum* coverage and cost were taken into account the most successful propagule type was gel, followed by clumps, plugs and beads.
- Whilst the priority is rapid colonisation for Ecosystem Services benefits, however, plugs are MFFP's preferred option.

- The dense plug study demonstrated that comprehensive *Sphagnum* cover can be achieved in a minimum of 68 months when plug planting was delivered at a density of ~10 plugs per $m^2$* on undulating ground in re-vegetated areas.

- Much faster growth was observed when *Sphagnum* was located in lower areas with a higher water table and better protection from desiccation relative to the hag-top areas.
- The study suggests that environmental conditions were sufficient for *Sphagnum* to survive and grow slowly on hag tops.

Gully transect survey findings:

- Comprehensive *Sphagnum* cover derived from plugs was achieved on the gully floor and lower gully sides, with additional establishment on the mid-gully sides and upper gully sides.
- Six species were found to have established from plugs in all four situations in the erosion gullies: *S. capillifolium*, *fallax, fimbriatum*, *medium*, *palustre* and *papillosum*, showing that revegetated erosional gullies are suitable for *Sphagnum* reintroduction.
- There were effects of topography on plug-derived *capillifolium*, *cuspidatum, fallax,* and *palustre*:
  - (i) Plug-derived *cuspidatum* was most frequently established on the gully floor;
  - (ii) Plug-derived *capillifolium* grew faster on the lower gully side situation than the upper gully side and gully floor, indicating that conditions were more favourable on the lower gully side;
  - (iii) Plug-derived *palustre* grew faster in the lower and mid-gully side situations than on the gully floor, where conditions were likely wetter, indicating a preference for the conditions in this drier zone;
  - (iv) The trend for plug-derived *fallax* to grow slower at each step change from gully floor up the gully side indicated that *fallax* preferred wetter conditions. Whilst this species is common in many habitats, it had greater success growing in the microclimate of the gully floor, which was also the flattest area.

* In the sampled area, mean plug density was 10 per $m^2$ following the general application of 5 plugs per $m^2$ to the Nogson catchment area

# 2. Introduction

The active blanket bog of the South Pennine Moors Special Area of Conservation (SAC) have been formed predominantly by *Sphagnum* moss species (Lindsay 2010). *Sphagnum* reintroduction to these degraded blanket bog sites is considered an important next step towards favourable condition, improving biodiversity, following previous bare peat stabilisation works. *Sphagnum* restoration works, importantly, have been shown to have the greatest ability of three different blanket bog species typical to UK blanket bogs to reduce the loss of carbon from peat (Dunn *et al.* 2016). This resilience is important in the face of climate change: The Centre for Ecology and Hydrology estimated that UK peatlands are emitting around 23,100 kt CO2e $yr^{-1}$ greenhouse gas in total (ONS, 2019). Also importantly, *Sphagnum* reintroduction works set out to improve peatland biodiversity towards favourable condition. A host of species are known to have specialised to thrive in waterlogged, nutrient-poor and acidic peatland conditions, including a rich breeding bird assemblage (Littlewood et al. 2010).

In recent years, in the absence of sufficient source *Sphagnum* material to harvest locally for translocation, Moors for the Future Partnership (MFFP) have been using propagated *Sphagnum* to enable a mix of species to be produced and reintroduced over the vast areas of work across the Peak District and South Pennines (Roberts & Fry, 2021). Caporn's review of progress of *Sphagnum* reintroduction to degraded peatlands concluded that micropropagated *Sphagnum* offers an effective source for reintroduction. Establishment and survival of *Sphagnum* plugs was 99% successful and beads were partially successful (12 % survival) (Caporn et al., 2018).

An opportunity arose in 2015 as part of the MFFP's Peatland Restoration project (Crouch *et al.* 2015) to trial a number of different *Sphagnum* propagule types, including BeadaGel™ (*Sphagnum* gel), BeadaHumok™ (*Sphagnum* plugs), BeadaMoss® (*Sphagnum* beads) and translocated *Sphagnum* clumps, on the north Edge of Kinder Scout, Peak District. At that time, only lab trials, small scale field trials or less robust 'opportunistic' monitoring of landscape scale delivery had been carried out to test the merits of the propagated material. No definitive 'optimal' solution for *Sphagnum* reintroduction had thus been proven, nor had the relative 'successes' of the different *Sphagnum* propagules been robustly tested in a 'real-life' scenario. Two trials were set up: the *Sphagnum* Propagule Trial and the Dense Plug Plant Trial. Table 1 lists the species mix that were propagated in *Sphagnum* gel, plugs and beads.

**Table 1. Species mix of *Sphagnum* beads, slime and plugs**

| ***Sphagnum* species** | **% of total mix** |
|---|---|
| *fallax* | 30–50 |
| *palustre* | 20–40 |
| *papillosum* | 20–40 |
| *capillifolium* | 10 |
| *cuspidatum* | 10 |
| *fimbriatum* | 5–10 |
| *subnitens* | 5–10 |
| *denticulatum* | ~1 |

| | |
|---|---|
| *squarrosum* | ~1 |
| *russowii* | ~1 |
| *tenellum* | ~1 |
| *medium* | ~1 |

The aim of the *Sphagnum* Propagule Trial was to compare the establishment, survival and growth of different *Sphagnum* propagule types on revegetated bare peat. The aim of the Dense Plug Plant Trial was to evidence how quickly comprehensive *Sphagnum* cover could be achieved. The aim of the gully transet trial was to evidence establishment and growth of different *Sphagnum* species from the Moorland Mix plugs in four different gully situations: gully floor, lower-gully side, mid-gully side and upper gully side.

## Study sites

Both trials were located on the north Edge of Kinder Scout, within the Ashop River catchment, in the Upper Derwent Valley, Derbyshire (Figure 1). The Ashop catchment is 2,705 ha in size, of which 2,406 ha (89 %) is classified as moorland. Moorland is defined as land located within the Rural Payments Agency (RPA) Moorland Line (England) dataset (available to download from the MAGIC website:
https://magic.defra.gov.uk/Dataset_Download_Summary.htm

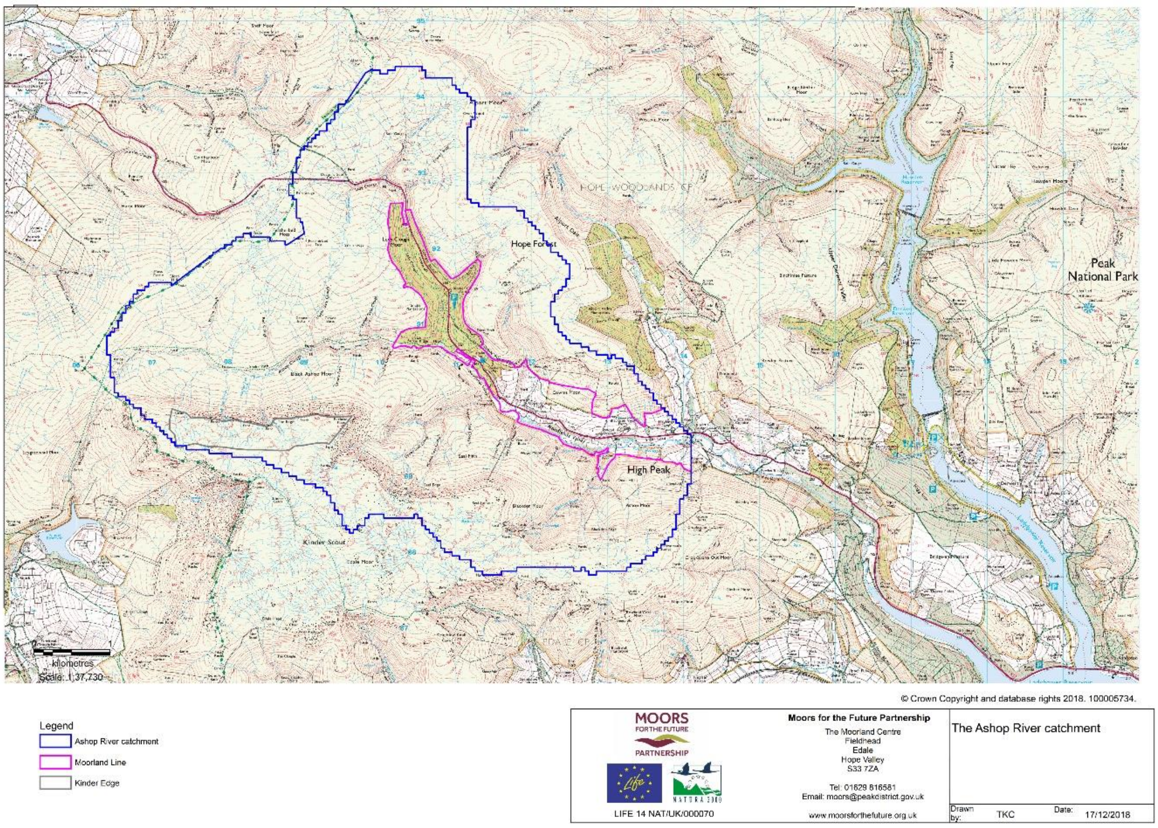



**Figure 1.The River Ashop catchment**

Initial bare peat revegetation was completed on the Edge under an Environmentally Sensitive Areas (ESA) Scheme and the Making Space for Water project (Pilkington *et al.* 2015). The Peatland Restoration project continued bare peat revegetation through the application of heather brash, lime and fertiliser; installed additional timber and stone dams in gully systems; and applied *Sphagnum* propagules into the developing sward.

Heather brash was used to halt the erosion of the bare peat in the short term. To ensure that this continued, vegetation was re-established. This was achieved through the application of lime, seed and fertiliser. Gully blocking was used to reduce the flow of peat sediment along erosion channels, reducing the loss of peat downstream and raising water tables, helping to re-wet degraded areas (Buckler *et al.* 2013). This work was completed between February 2011 and July 2013.

# 3. Methodology

All trials used micropropagated *Sphagnum* produced by Micropropagation Services (EM) Ltd. (Leicestershire, UK). *Sphagnum* propagules were applied to the area between 6th and 20th March 2015. Baseline data was recorded for the two trials between 12th March and 7th April 2015.

The design associated with applications one and two was based on 1ha micro-catchments. Fixed quadrats were set-up within each of the 1ha micro-catchments to monitor the success of *Sphagnum* propagule development. The quadrats were marked with two wooden stakes located in the south-west and north-east corners. When locating quadrats, areas of existing *Sphagnum* were avoided; this was to ensure that *Sphagnum* within quadrats from applied propagules was not confused with existing *Sphagnum*. Photographs were taken both for monitoring purposes (to illustrate change over time) and to help in locating quadrats should the stakes be lost.

A standard amount of *Sphagnum* propagules were applied to each quadrat; however, hummocks were not identical in size, therefore, the length, width, depth and circumference of each hummock were also recorded. Each plug / hummock within a quadrat was numbered and its position within the quadrat recorded in a sketch. Plugs and hummocks were identified to species where possible. A visual estimate of percentage cover was made for all *Sphagnum* propagule types. In addition, the percentage cover of dwarf shrub, cotton grass, other grasses, mosses (including any existing *Sphagnum*), bare peat and standing water, as well as the proximity to nearest standing water / pool outside of the quadrat was recorded.

## 3.1. Application 1 – *Sphagnum* Propagule Trial

Four headwater micro-catchments (1ha) were treated with one of four different *Sphagnum* propagule types; beads, gel, plugs and translocated clumps. A fifth micro-catchment received no treatment and provided a control. These applications were replicated three times (areas 1, 2 and 3). Ten quadrats were located within each of the micro-catchments (Figure 2). Quadrats were located on flat ground to reduce the likelihood of *Sphagnum* propagules washing down the catchment during heavy rain events. *Sphagnum* propagules were applied to quadrats by the surveyors, not by the contractors. This ensured that each quadrat received a standard amount of propagules.

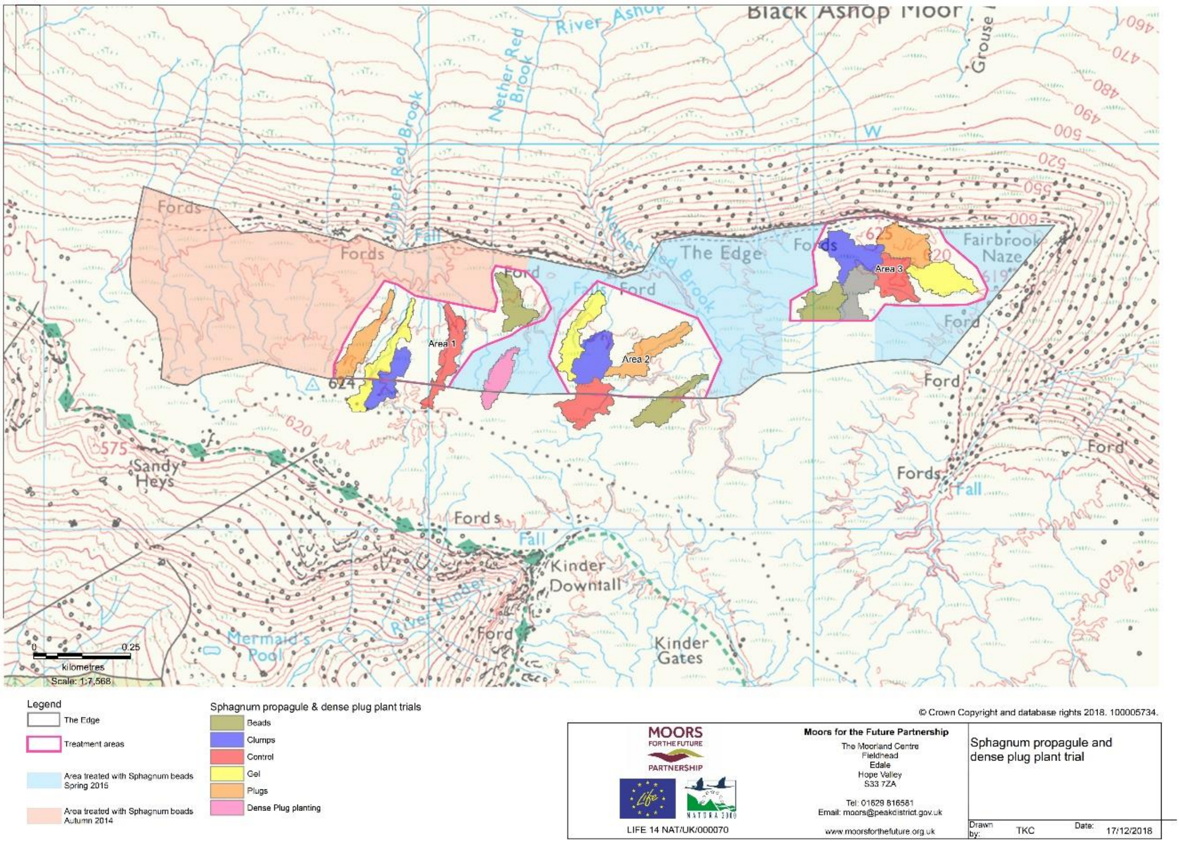



**Figure 2. The *Sphagnum* Propagule and Dense Plug Plant Trials**

The quantities of propagules that were applied to each quadrat are presented in Table 2. It is worth noting that this is a higher application rate than would normally be used in restoration, where standard application rates are: 35 L beads per ha (0.0035 L per $m^2$); 20 L gel per ha (0.0020 L per $m^2$); 1250 plugs per ha (1 plug per 8 $m^2$); and 625 clumps per ha (1 clump per 16 $m^2$). The costs per $m^2$, presented in Table 2, were based on the production and application costs presented in Table 3; these costs were applicable to *Sphagnum* production and application for the Peatland Restoration Project trials in 2015. Table 4 shows the quantities of propagules that were required for application in quadrats.

**Table 2. Quantity of propagules applied to quadrats and cost**

| Propagule type | No. of propagules per quadrat | Vol. of propagules per quadrat | Cost of production (£ / m²) | Cost of spreading (£ / m²) | Total cost (£ / m²) |
|---|---|---|---|---|---|
| BeadaMoss® | 420 | 0.07 (L) | £1.03 | £0.01 | £1.04 |
| BeadaGel™ | 18 * | 0.072 (L) | £1.03 | £0.01 | £1.04 |
| BeadaHumok™ | 9 | | £6.30 | £4.14 | £10.44 |
| Clumps | 4 | | £1.25 | £1.90 | £3.15 |

* 72ml of BeadaGel™ was applied to each quadrat in 18 x 4ml measures

**Table 3.** ***Sphagnum*** **production and application costs**

| Propagule type | Production cost | Application cost |
|---|---|---|
| BeadaMoss® | £14.75 per litre | £60.00 per hectare |
| BeadaGel™ | £12.50 per litre | £60.00 per hectare |
| BeadaHumok™ | £0.70 per plug | £0.46 per plug |
| Clumps | £0.25 per hummock | £0.38 per hummock |

**Table 4. Number / volume of propagules applied to quadrats**

| Propagule type | No. / vol. of propagules per $m^2$ | No. of quadrats | Total no. / vol. propagules |
|---|---|---|---|
| BeadaMoss® | 0.07 (L) | 30 | 2.1 (L) |
| BeadaGel™ | 0.072 (L) | 30 | 2.2 (L) |
| BeadaHumok™ | 9 | 30 | 270 |
| Clumps | 4 | 30 | 120 |
| Control | N/A | 30 | N/A |
| Plug plant trial | N/A | 20 | N/A |

Identification and assessment of the area cover of the plug-derived species in the 30 plug plant quadrats in the Propagule Trial was undertaken in autumn 2020.

## 3.2. Application 2 – Dense Plug Plant Trial

Application 2 investigated a concentrated application of *Sphagnum* propagules on one of the Making Space for Water micro-catchments. The application took place between 6th and 20th March 2015. The site (Nogson) has been revegetated, using heather brash, lime, seed and fertiliser, and was also gully blocked. Within the catchment 36,550 *Sphagnum* plugs (~5 per $m^2$) were planted to deliver comprehensive *Sphagnum* cover within three years. A revegetated and a non-revegetated micro-catchment were available for comparison.

### 3.2.1. Plug-derived species on undulating ground or hag tops

Two types of plugs were used: individual *Sphagnum* plugs with peat bases, referred to as 'plugs' (31,750), and plug carpets split into individual 'micro-plugs' without peat bases (4,800). Twenty 1 x 1 m quadrats were located according to two main criteria: (a) on flat ground to reduce the likelihood of *Sphagnum* propagules washing down the catchment during heavy rain events, and (b) within two categories of topography (i) undulating ground (10 quadrats) and (ii) depressions / hollows on hag tops (10 quadrats).

Identification of plug-derived species and an assessment of cover of the *Sphagnum* by species in the Dense Plug Plant Trial quadrats was undertaken by a Consultant Ecologist, during the autumn 2018 survey and again in autumn 2020.

### 3.2.2. Plug-derived species in revegetated erosional gullies

Identification of plug-derived species and an assessment of area cover in 40 1 x 1m fixed quadrats of the established *Sphagnum* placed along transects that spanned gullies was undertaken by a Consultant Ecologist, during autumn 2020. *Sphagnum* species and area cover were recorded in four situations: gully floor, lower gully side, mid gully side and upper gully side at each transect stop point. Two records were taken in each gully floor section as well as one either side of the gully.

## 4. Results

All statistical tests were carried out in IBM SPSS Statistics version 19.

### 4.1. Application 1 – *Sphagnum* Propagule Trial

Changes in the percentage cover of *Sphagnum* within quadrats were observed for all propagule types. Plugs and clumps expanded to the largest cover of *Sphagnum*. *Sphagnum* was present in untreated control quadrats by autumn 2020 however cover remained very low (1 %). Plugs and clumps had a higher initial cover of 2 % and 7.9 % respectively than gel and beads (0 % for both propagule types: undetectable) (Figure 3). Mean percentage *Sphagnum* cover at 68 months was 24-fold for plugs than on day zero (application) and 5-fold for clumps. The gel plants grew to almost 17 % mean area cover at 68 months, whilst beads showed more limited success and grew to 2.4 % mean area cover from undetectable.

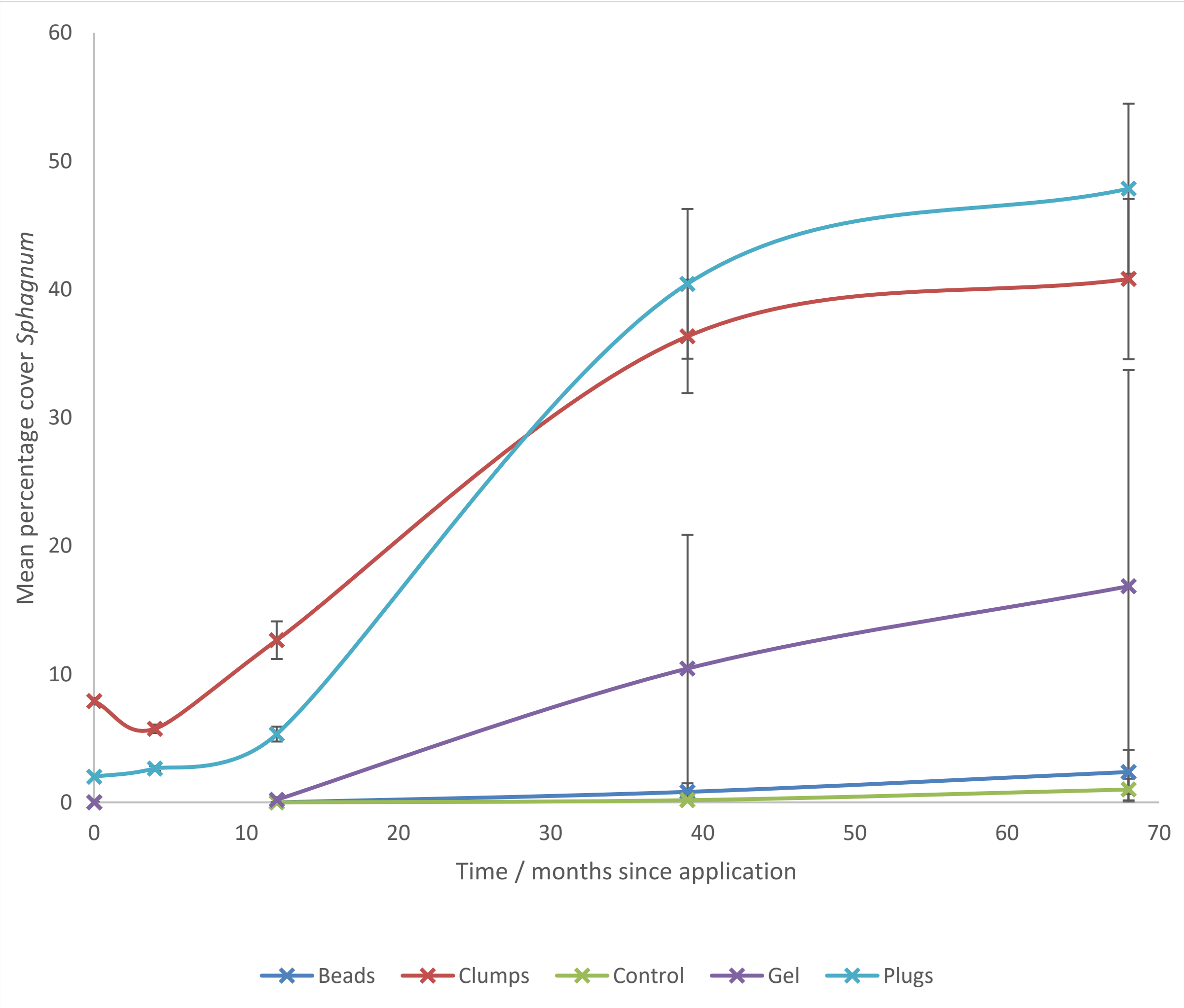



**Figure 3. *Sphagnum* growth from propagules (n = 30 quadrats per propagule type). Error bars represent standard error of the mean.**

Percentage *Sphagnum* cover in the quadrats in autumn 2020 survey (68 months after planting) differed between the five propagule applications (Kruskal-Wallis: H = 86.894, n = 30, n = 30, n = 30, n = 30, n = 30, $P < 0.001$). Bars in Figure 4 were assigned different letters to represent significant differences at $P < 0.05$ (post-hoc Dunn-Bonferroni).

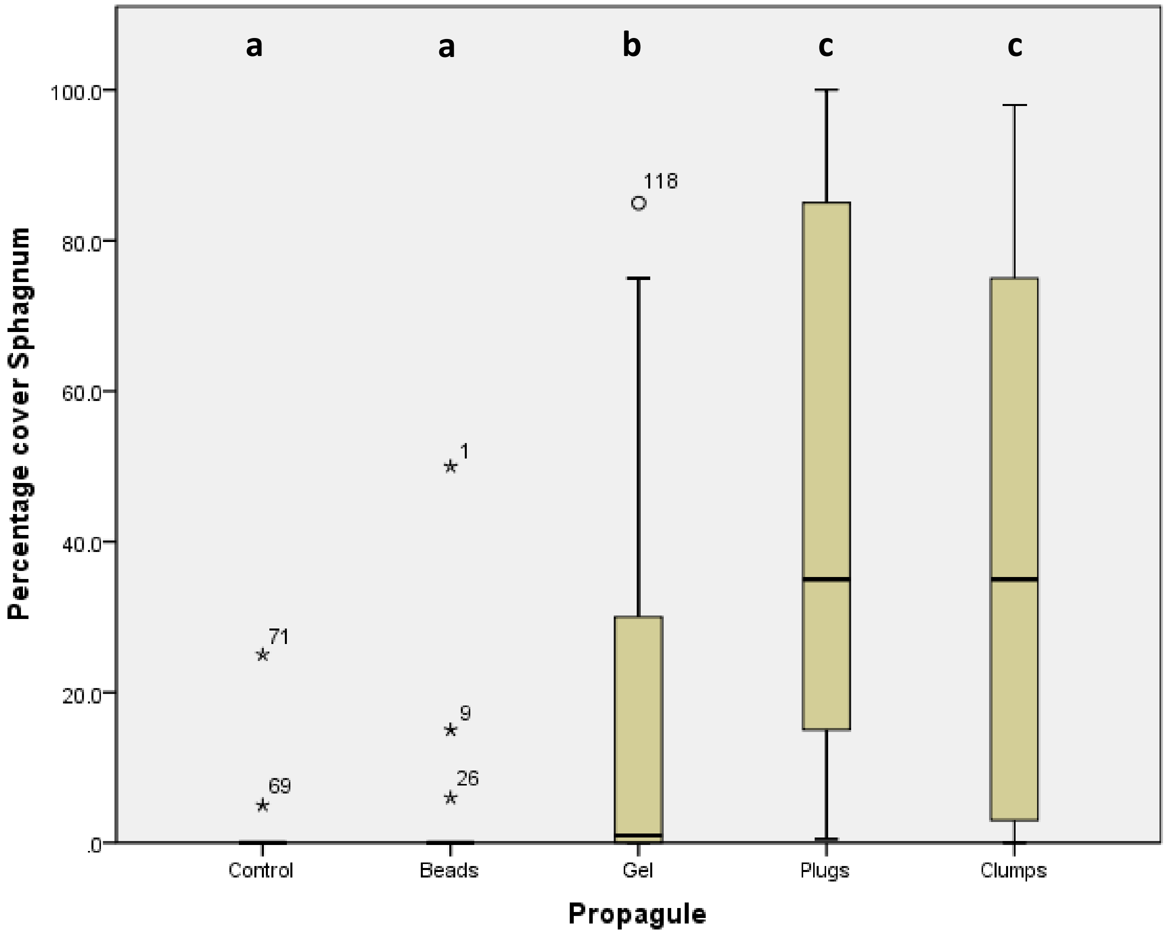



**Figure 4. Box-plots to show the differences in percentage cover of *Sphagnum* in quadrats in autumn 2020 between the five propagule types, 68 months after application**

#### 4.1.1. Plug-derived *Sphagnum* species

Nine species established in the re-vegetated blanket bog area from the plug plants (Figure 5). The dominant species by mean area cover were *S. fallax* and *S. palustre.*

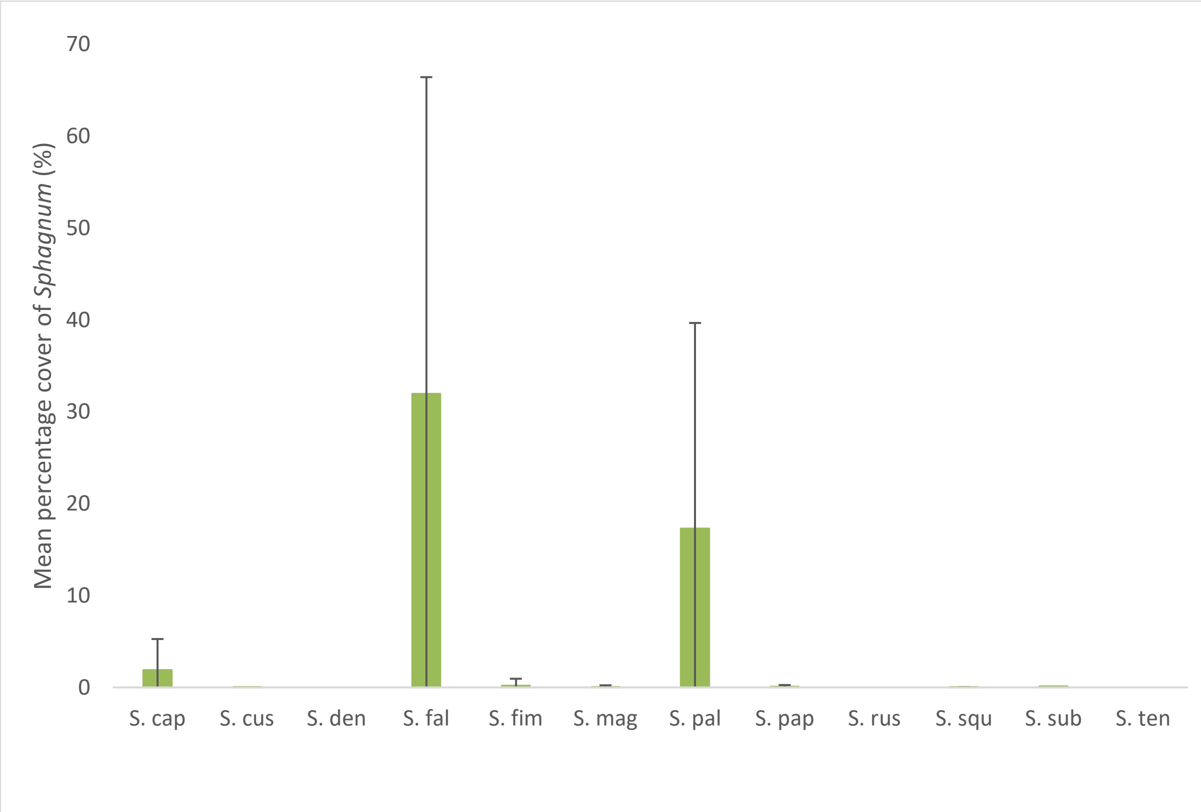



**Figure 5. Mean percentage cover of the *Sphagnum* species derived from 'moorland mix' plugs* that were present in quadrats in the Autumn 2020 survey, 68 months after planting (n = 30). Error bars represent standard deviation. *Proportion of species in the plug mix varied according to table 1.**

### 4.1.2. Cost-benefit comparison of propagules

At 68 months after planting, by mean percentage cover measure, clumps and plugs were the most successful propagule types (Figure 6).

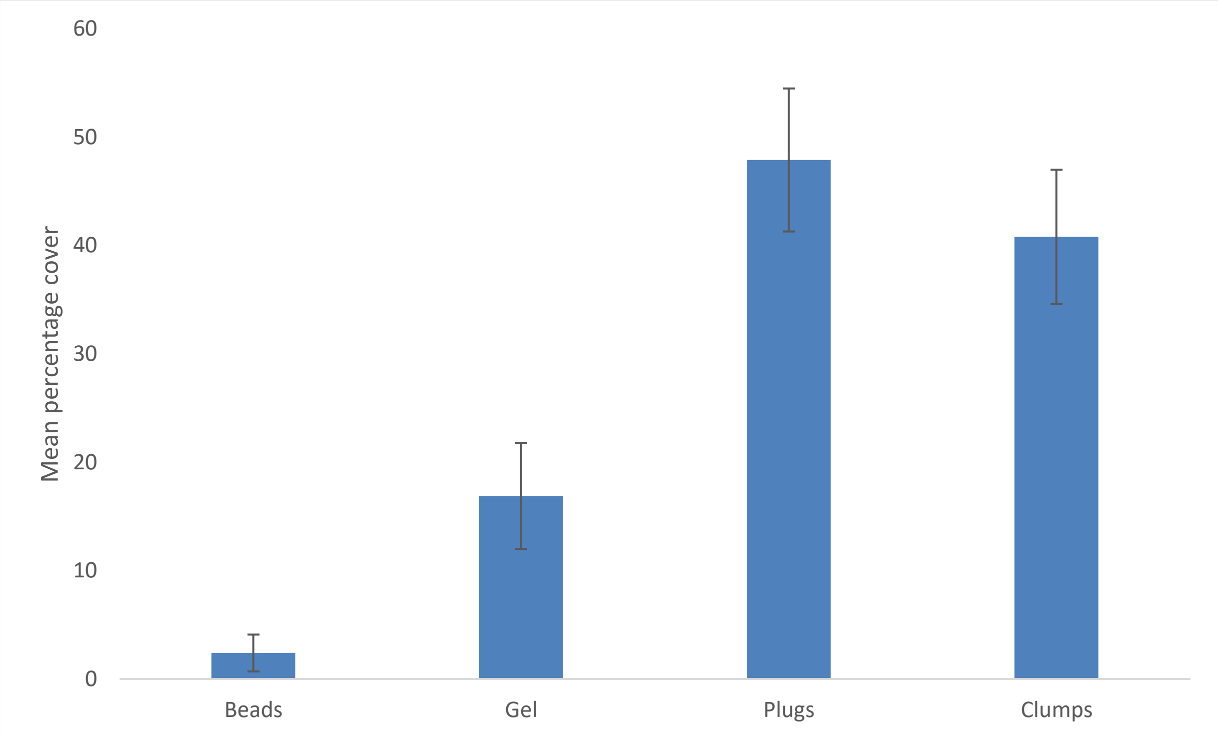



**Figure 6. Mean percentage cover of each propagule type 68 months after application**

An assessment of cost (production and application) per quadrat showed that plugs were the most expensive, followed by clumps and then beads and gel (Figure 7; Table 5).

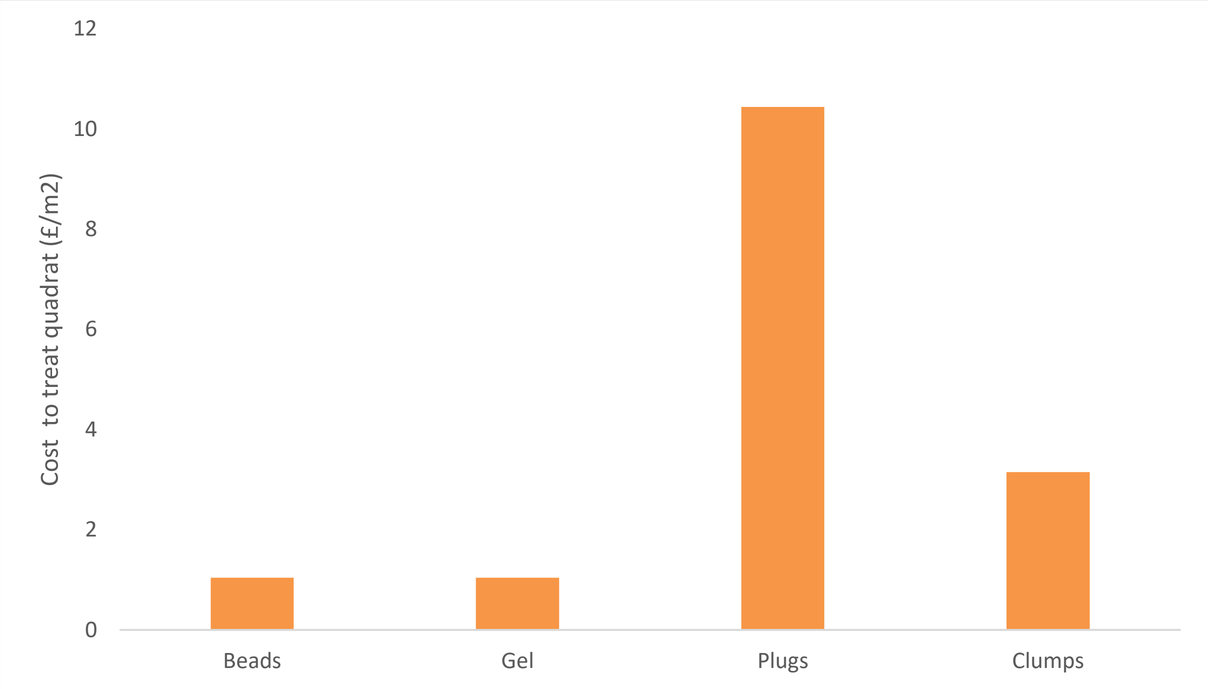



**Figure 7. Cost of production and application of the 4 propagule types per m2 quadrat area**

The cost per one percent cover (100 $cm^2$) of established *Sphagnum* provided a cost-benefit comparison across all propagule types. With both *Sphagnum* coverage and cost taken into account, the most successful propagule type was gel, followed by clumps, plugs and beads. Table 5 details the cost per one percent cover of *Sphagnum* for each propagule type 68 months after application.

**Table 5 Cost-benefit comparison of four propagule types: beads, gel, plugs and translocated clumps 68 months after application to re-vegetated degraded blanket bog areas**

| Propagule type | Mean % cover 68 months after application | Cost (£ / $m^2$) to treat quadrat | Cost (£) per 1 % cover of *Sphagnum* at 68 months |
|---|---|---|---|
| Beads | 2.4 | 1.04 | 0.43 |
| Gel | 16.9 | 1.04 | 0.06 |
| Plugs | 47.9 | 10.44 | 0.22 |
| Clumps | 40.8 | 3.15 | 0.08 |

## 4.2. Application 2 – Dense Plug Plant Trial

Limited growth of *Sphagnum* from plugs was found on hag-top areas relative to undulating, lower ground by mean percentage cover (Figure 8). By autumn 2020, plug-derived *Sphagnum* on lower undulating ground, expanded to cover almost 80 % of the quadrats.

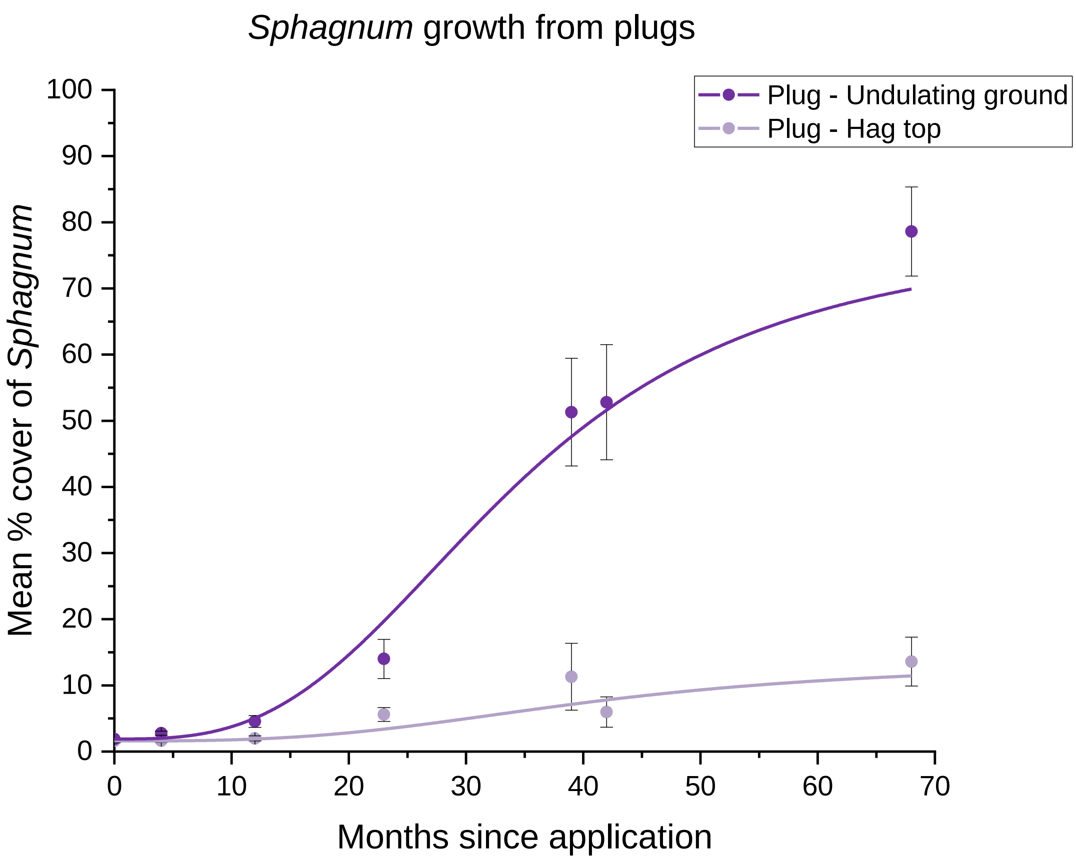



**Figure 8. Mean percentage cover *Sphagnum* growth from 'moorland mix' plugs over time on hag tops and lower, undulating ground in the Dense Plug Plant Trail quadrats (n = 20), where mean plug density was 10 per m². *Autumn 2018 survey data was provided by a Consultant Ecologist, whilst all other survey data was recorded by MFFP surveyors. Error bars represent standard error of the mean.**

In the sampled area, mean plug density was 10 per m$^2$ (following the general application of 5 plugs per m$^2$ to the Nogson catchment area). At this density of planting, comprehensive *Sphagnum* cover on the lower, undulating ground was achieved by 68 months (Figure 8).

### 4.2.1. Plug-derived *Sphagnum* in two distinct areas of topography

A Shapiro-Wilk Test for normality showed that the data for lower, undulating ground deviated significantly from a normal distribution, therefore a non-parametric Mann Whitney U test was carried out. *Sphagnum* cover significantly differed between the two situations surveyed ($U = 1.5$, $n = 20$, $n = 20$, $P < 0.001$) (Figure 9).

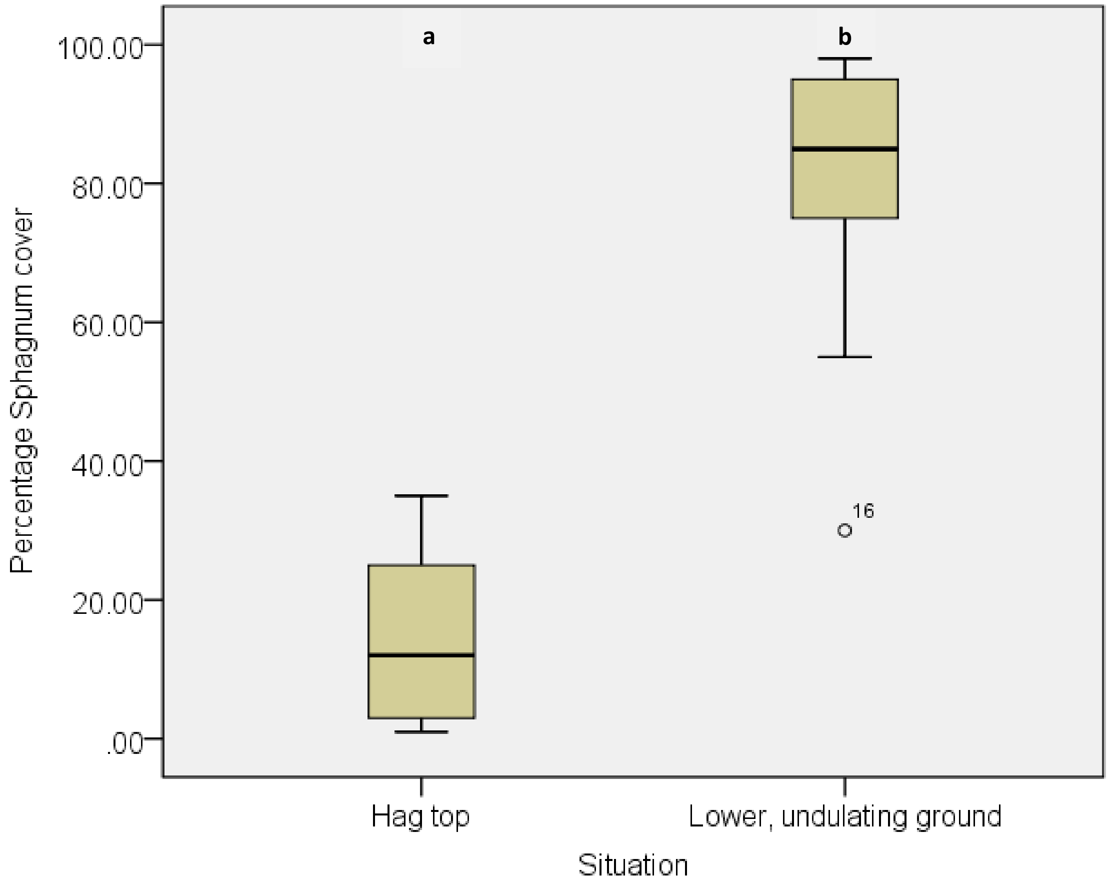



**Figure 9. Box-plots to show the differences in percentage cover of plug-derived *Sphagnum* in quadrats on hag tops and on lower, undulating ground in autumn 2020, 68 months after application**

Nine species had established on undulating ground and five species had established on hag tops by autumn 2020, 68 months after planting. The dominant species by mean area cover in both situations were *S. fallax* and *S. palustre* (Figure 10), which were two of the three dominant species in the moorland mix. *S. fimbriatum and S. papillosum* were present on hag tops in the 2018 survey (<1 % cover) and did not survive to autumn 2020.

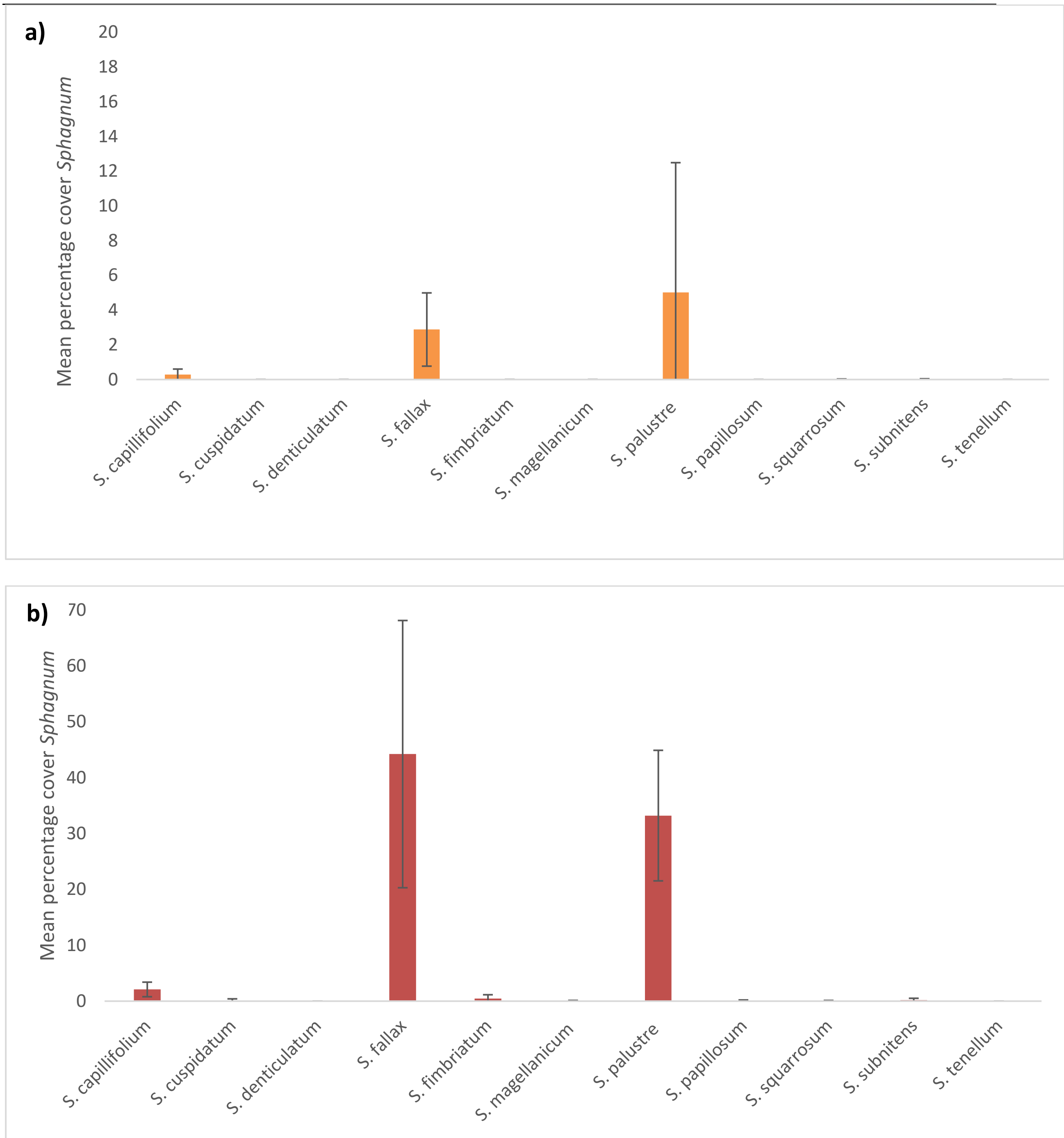



**Figure 10. Mean percentage cover of *Sphagnum* species in quadrats present 68 months after planting the 'moorland mix' plugs* on Nogson on a) hag tops (n = 10) and b) undulating, lower ground (n = 10). Error bars represent standard deviation. Note the different y-axis scales. *Species varied in their proportions in the plug mix according to table 1.**

### 4.2.2. Effect of topography on plug-derived *Sphagnum* in revegetated erosional gullies

A Shapiro-Wilk Test for normality showed that the data for the upper gully side situation and gully floor deviated significantly from a normal distribution, therefore a non-parametric Kruskall-Wallis test was carried out. *Sphagnum* cover significantly differed between the four situations surveyed (H = 21.033, n = 10, n = 10, n = 10, n =10, P < 0.001) (Figure 11). Bars in Figure 11 were assigned different letters to represent significant differences in percentage *Sphagnum* cover at P < 0.05 (post-hoc Dunn-Bonferroni).

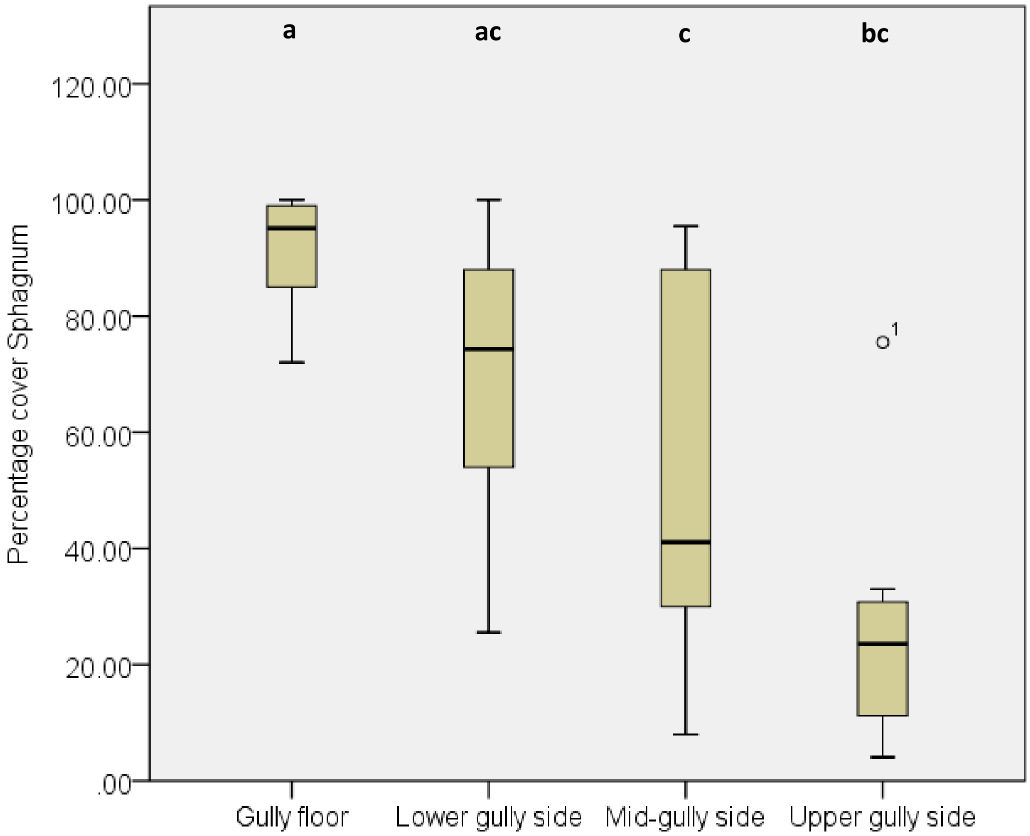



**Figure 11. Percentage cover of plug-dervied *Sphagnum* split by topographical situation 68 months after planting the 'moorland mix' plugs* (n = 10) *Species varied in their proportions in the plug mix according to Table 1.**

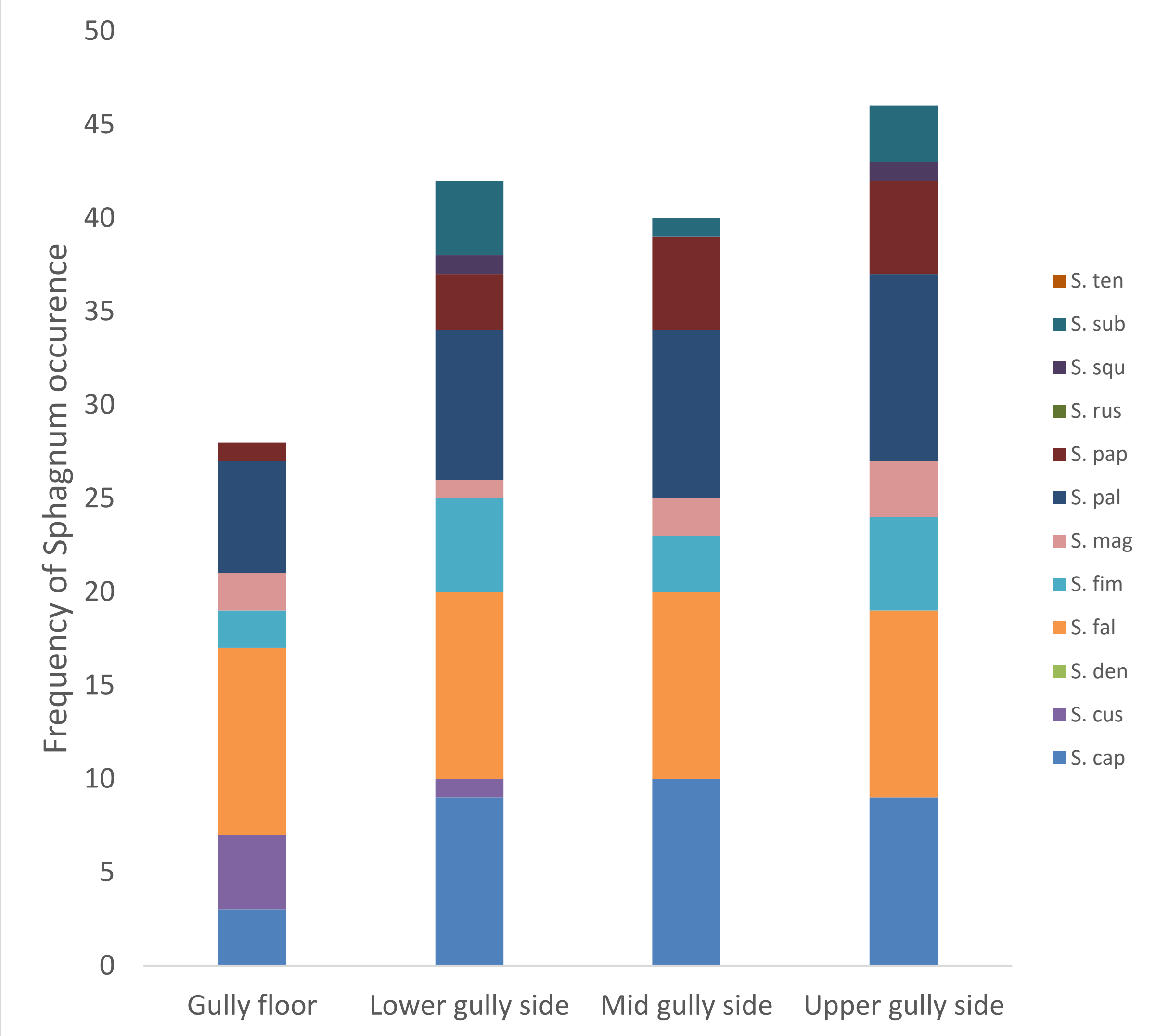



**Figure 12. Frequency of plug-derived species by topographical situation along gully transect 68 months after planting the 'moorland mix'*. Measured as how many quadrats each species was found in (n = 10). *Species varied in their proportions in the plug mix according to table 1.**

Six species were found to have established from plugs in all four situations in the gully transect surveys: *S. capillifolium*, *fallax, fimbriatum*, *medium*, *pallustre* and *papillosum*. Whilst *S. subnitens* occurred on the lower gully side, mid gully side and upper gully side it did not establish on the gully floor. *S. cuspidatum* occurred on the gully floor and occurred once on the lower gully side. There was one occurrence of *S. squarrosum* on the gully floor and one occurrence on the mid-gully situation. *S. dentiulatum, russowii* and *tenellum* were absent. Figure 12 shows the frequency of each species 68 months after planting (autumn 2020 survey).

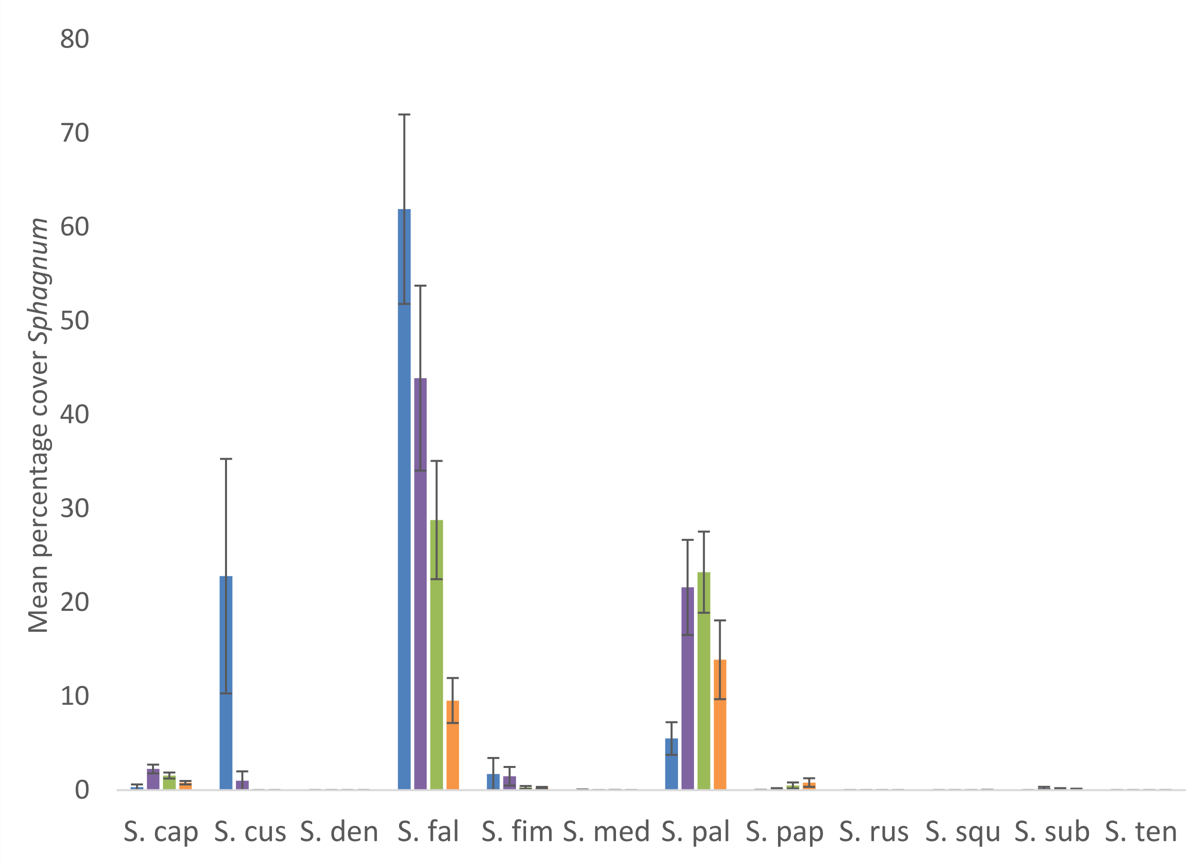


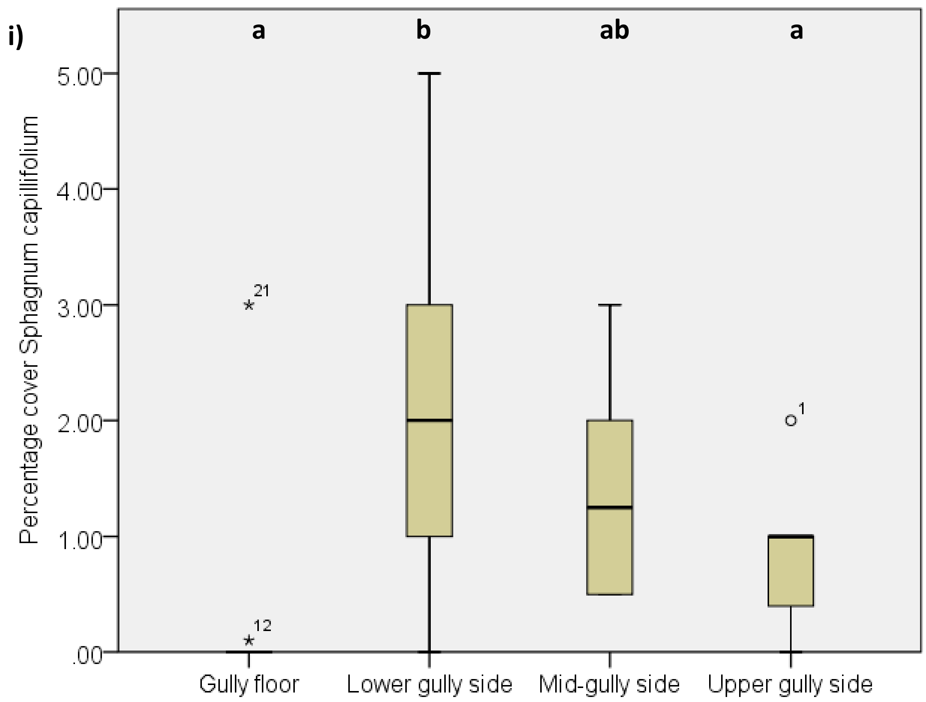

**Figure 13. Mean percentage cover of plug-derived species split by topographical situation: gully floor (blue), lower gully side (purple), mid gully side (green) and upper gully side (orange), 68 months after planting the 'moorland mix' plugs* (n = 10). *Species varied in their proportions in the plug mix according to Table 1.**

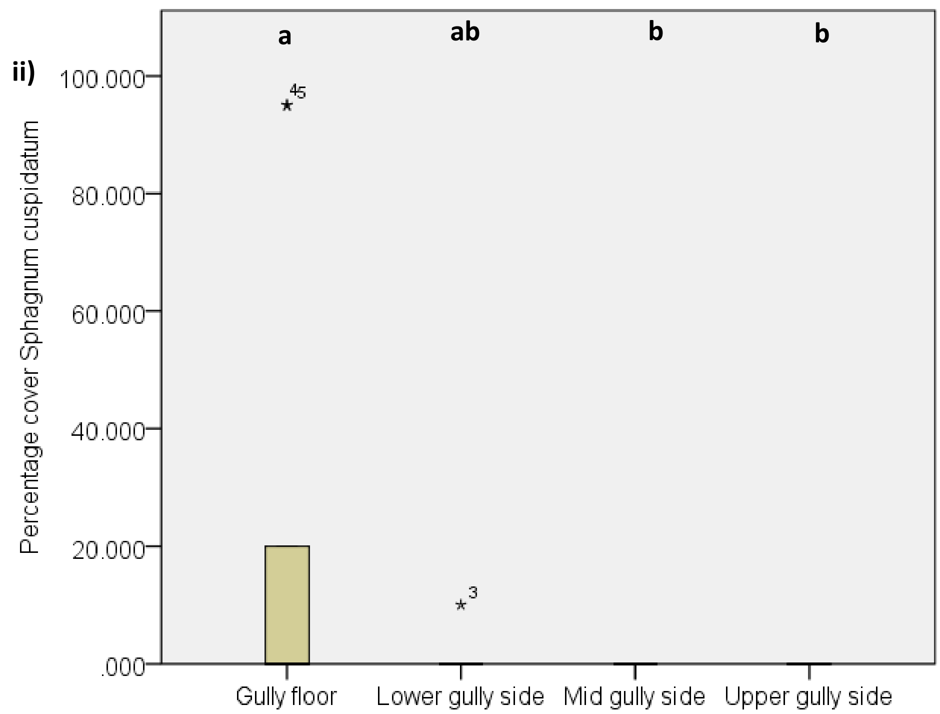
It appeared that *S. capillifolium* and *palustre* had both expanded to cover larger areas in the lower and mid-gully side situations than on the gully floor and upper gully sides (Figure 13). One-way ANOVA suggested that *S. capillifolium* differed between the four gully transect situations (F(3, 36) = 6.365, p = 0.001) A post-hoc Turkey test was significant between the upper gully side – lower gully side (P = 0.019) and lower gully side – gully floor (0.001) (Figure 14i). Levene's statistic based on a comparison of means was significant for the *S. palustre* area cover data, thus a non-parametric Kruskall-Wallis test was used. Kruskall-Wallis suggested that *S. palustre* differed between the four gully transect situations (H = 10.063, $n_1$ = 10, $n_2$ = 10, $n_3$ = 10, $n_4$ = 10, *P* = 0.018) (Figure 14iv). Pairwise post-hoc analysis showed that *S. palustre* cover on the gully floor was significantly different from the lower gully side (0.035) and the mid-gully side (0.040).

It appeared that *S. cuspidatum* covered a greater area of the gully floor than the lower gully side where it was also present (Figure 13). Again, Levene's statistic based on a comparison of means was significant for the *S. cuspidatum* area cover data. Kruskall-Wallis suggested that *S. cuspidatum* differed between the four gully transect situations (H = 10.081, $n_1$ = 10, $n_2$ = 10, $n_3$ = 10, $n_4$ = 10, *P* = 0.018). Pairwise post-hoc analysis showed that *S. cuspidatum* cover on the gully floor was significantly different from the mid-gully side (0.038) and the upper gully side (0.038) (Figure 14ii).

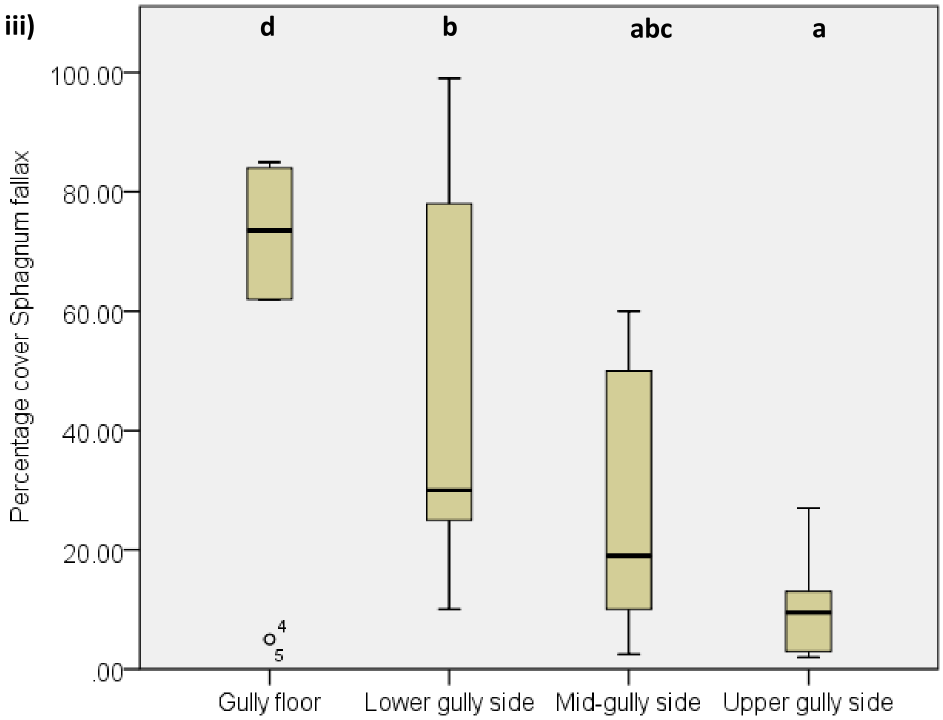
It appeared that *S. fallax* covered a greater area of the gully floor than any of the gully side situations, also decreasing in cover up the gully sides (Figure 13). Data was arcsine transformed and a one-way ANOVA showed that *S. fallax* area cover differed between the four gully transect situations ($F(3, 36) = 8.165$, $p = 0.000$). A post-hoc Turkey test was significant between the upper gully side – lower gully side ($P = 0.010$), upper gully side – gully floor (0.000) and mid-gully side – gully floor ($P = 0.025$) (Figure 14iii).

Additionally, Kruskall-Wallis suggested that there was no difference between *S. papillosum* cover in the four gully transect situations ($H = 6.209$, $n_1 = 10$, $n_2 = 10$, $n_3 = 10$, $n_4 = 10$, $P = 0.102$) (Figure 14v). *S. fimbriatum* data was arcsine transformed and a one-way ANOVA suggested that *S. fimbriatum* area cover did not differ between the four gully transect situations ($F(3, 36) = 0.462$, $p = 0.711$) (Figure 14vi).

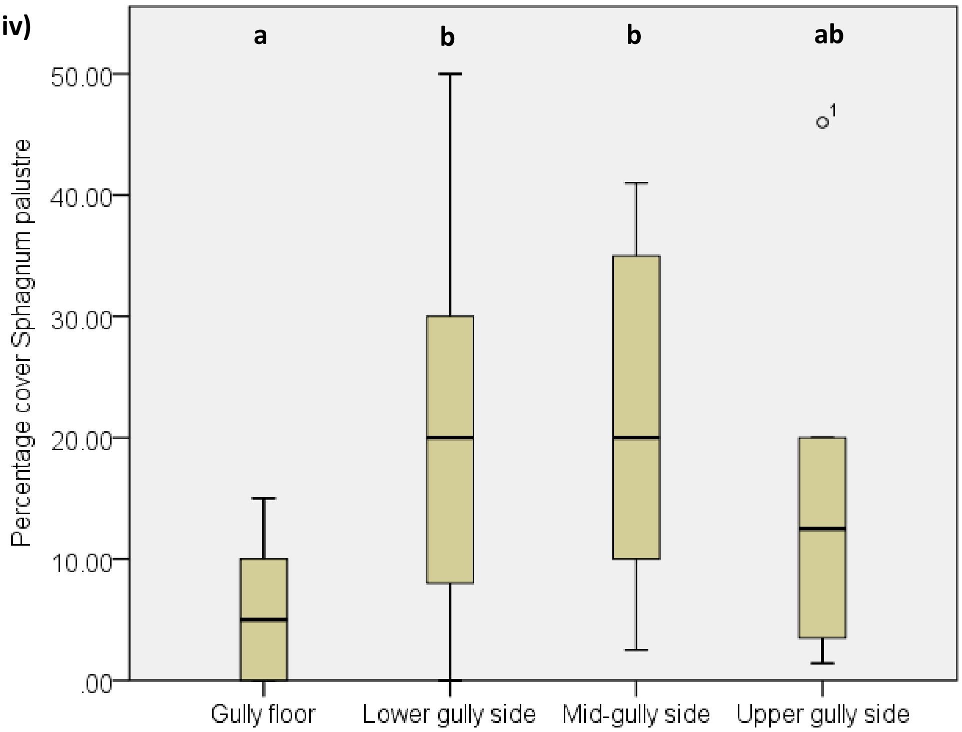

i)
a
b
ab
a
Percentage cover Sphagnum capillifolium
5.00
4.00
3.00
2.00
1.00
.00
21
12
1
Gully floor
Lower gully side
Mid-gully side
Upper gully side

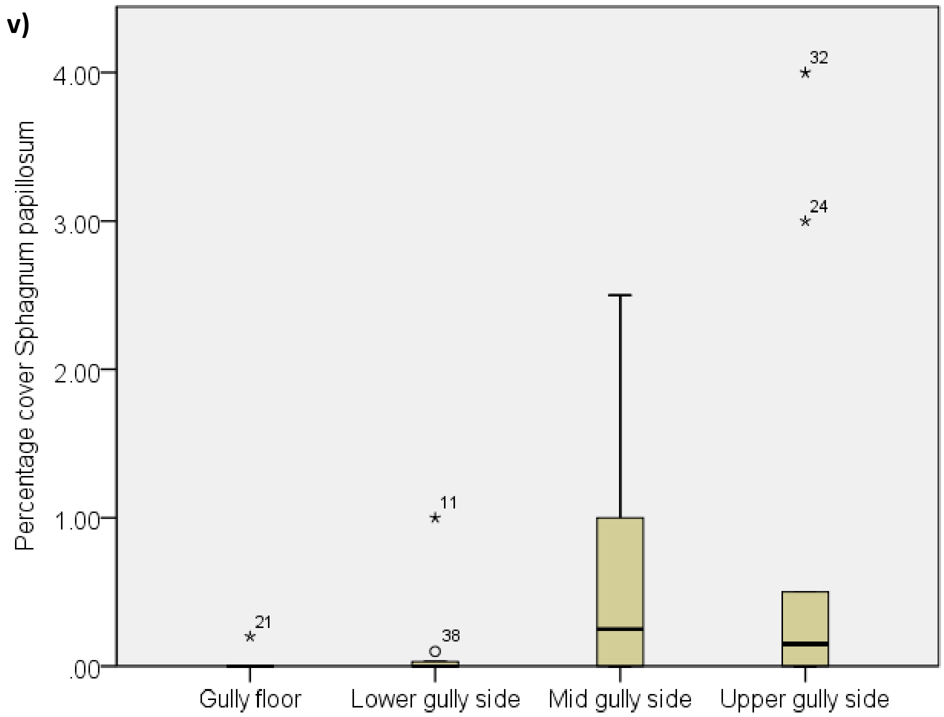

ii)
a
ab
b
b
Percentage cover Sphagnum cuspidatum
100.000
80.000
60.000
40.000
20.000
.000
45
3
Gully floor
Lower gully side
Mid gully side
Upper gully side

iii)


d
b
abc
a
Percentage cover Sphagnum fallax
100.00
80.00
60.00
40.00
20.00
.00
4
5
Gully floor
Lower gully side
Mid-gully side
Upper gully side

iv)


a
b
b
ab
Percentage cover Sphagnum palustre
50.00
40.00
30.00
20.00
10.00
.00
1
Gully floor
Lower gully side
Mid-gully side
Upper gully side



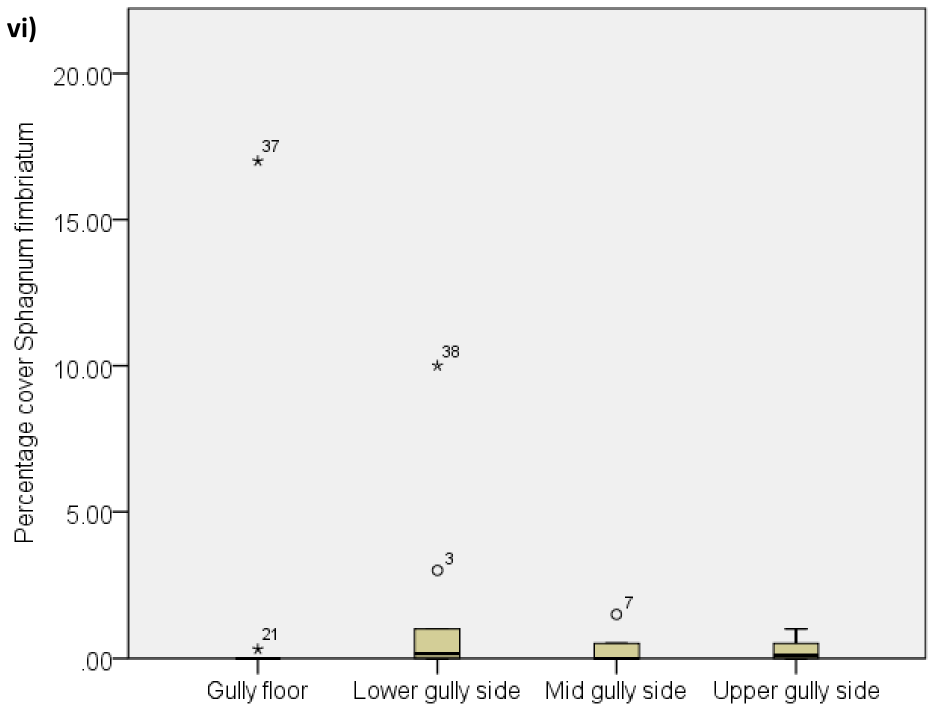




**Figure 14. Percentage cover of four plug-derived species split by topographical situation 68 months after planting the 'moorland mix' plugs* (n = 10) *Species varied in their proportions in the plug mix according to Table 1.**

## 5. Discussion

### *Sphagnum* Propagule Trial

The success of *Sphagnum* plugs and clumps relative to the beads and gel may have been due to the larger plant mass being better able to withstand extreme fluctuations in environmental conditions, for example desiccation and waterlogging, and crowding by other vegetation (Caporn *et al*. 2018). The size of *Sphagnum* plants in micro-propagated material varied widely, from 1-5 mm moss fragments within beads to the fully developed (20–40 mm) plants in the gel and plugs. The larger and faster growing *Sphagnum* plugs can establish more quickly and cover ground sooner than the juvenile plants within beads and gel (Caporn *et al.* 2018). It is thought that the aggregate size of reintroduced *Sphagnum* is important for performance (Robroek *et al.* 2009), with larger patches better able to supply the capitula with water (Robroek *et al.* 2007). A MFFP study of single-species plug-derived *Sphagnum* growth on blanket bog areas showed that on average single-species samples increased in size by about eight times their original area over 16 months when 6 x 6 plugs were planted closely packed together in areas with some vegetation cover (Benson *et al.* 2021).

As far as was practically possible, the same amount of plugs and clumps were applied to quadrats. Despite this, the initial mean percentage cover of translocated clumps (7.9%) was higher than that for plugs (2%), which should be noted for the propagule comparison due to the potential head start for clumps. Clump and plug quadrats were re-surveyed four months after planting, and while the percentage cover of plugs had increased (2.6%), clumps had decreased (5.7%). As plugs were smaller, nine plugs were planted per quadrat, compared to four clumps per quadrat, providing more sources for *Sphagnum* to spread out from (lateral growth) in the case of plugs. Thus, when one clump did not survive, the amount of *Sphagnum* remaining decreased by a greater proportion than when a plug was lost. Nonetheless, *Sphagnum* derived from plugs and the translocated clumps continued to grow well over time and there was no difference between the cover of Sphagnum from the two propagule types 68 months after planting by this planting design. The initial decline in cover of clumps between 0-4 months may suggest that more stress is caused to *Sphagnum* propagules that are harvested and transplanted than to *Sphagnum* propagules that are transferred from greenhouse to field sites.

### Cost-benefit considerations

Whilst clumps and plugs were the most successful in terms of mean percentage cover, plugs were the most expensive, followed by clumps and then beads and gel. When both of these measures of success are taken into account together, the most successful propagule type was gel, followed by clumps, plugs and beads. It should be noted that as percentage cover of *Sphagnum* continues to increase over time, the cost per one percent cover will decrease disproportionately for all propagule types.

Whilst there was no difference in mean percentage cover of *Sphagnum* established from plugs and clumps 68 months after planting, the cost to achieve the same coverage was almost three times more than with clumps. Consequently, where there is a source of *Sphagnum* from which to harvest and transplant, this option may be preferred. However, despite plugs being more expensive than clumps they do offer a number of benefits, for example, only a small amount of donor *Sphagnum* material is required; a 'clean' *Sphagnum* culture, free of potential disease can be propagated; the species composition can be adjusted; and they are potentially available in large quantities. These benefits also apply to other forms of micro-propagated *Sphagnum* (i.e. beads and gel).

If gel is to be used, based on initial cost, careful consideration must be given to the method of application to ensure that it allows the gel to make contact with the peat and that it is practical over a large area. Gel, which was much more successful than beads, was applied using a syringe to ensure that it made contact with the peat and did not get caught on the vegetation where it would have been prone to drying out. This application method was very time consuming and would not be appropriate for application over a large area. A prototype planting machine has been produced for applying BeadaGel™. The machine cuts grooves into the surface vegetation to ensure that *Sphagnum* gel makes contact with the peat surface (Caporn *et al.* 2018).

**Dense Plug Plant Trial**

68 months was almost double the original target time for achieving comprehensive *Sphagnum* cover in re-vegetated areas at the set density. The mean sampled area was also twice as dense as the planting in the Nogson catchment area. This outcome can be used to inform best practice for planting *Sphagnum* plugs at an optimal planting density.

Nine *Sphagnum* species were identified from plugs in the Dense Plug Plant Trial. There had been some concerns at MFFP that due to the high proportion of *S. fallax* contained within the plug (30–50 %), this species would dominate at the expense of other more favoured species. Bogs dominated by *S. fallax* are less favoured in conservation terms in the UK (JNCC 2009, cited in Caporn *et al.* 2018); however *fallax* has been demonstrated to be a potential pioneer species (Grosvernier *et al*. 1997). Whilst *S. fallax* was the dominant species on undulating ground, *S. palustre* was the second most dominant species, and on areas less favourable for *S. fallax* a number of species have established. Pilkington & Walker's 2020 study of *Sphagnum* planted in *Molinia*-dominated peatlands identified eleven species in total that had established from the mix.

Research on *Sphagnum* restoration of lowland raised bogs suggests that a high water table and some form of protection against desiccation (e.g. straw mulch or nurse crop) is required for successful *Sphagnum* establishment (Quinty & Rochefort 2003, Groeneveld *et al.* 2007 cited in Caporn *et al.* 2018). According to Caporn (2018), it is less certain whether a high water table is essential on blanket bog. This is because blanket bog occurs in areas of high precipitation and cloud cover (Rydin & Jeglum 2013, cited in Caporn *et al.* 2018); therefore, moisture arriving from above may compensate for a poor supply of water from below (Caporn *et al.* 2018). In the area of dense plug planting, *Sphagnum* survived on hag tops but the growth had been much slower than where it had survived on lower, undulating ground. Hag tops are likely to have a lower water table than the surrounding undulating ground and also offer less protection from desiccation. This suggests that moisture from precipitation and cloud cover was sufficient for *Sphagnum* to survive and grow slowly, whilst much faster growth was observed when *Sphagnum* was located in areas likely to have a higher water table.

The decrease in the percentage cover of *Sphagnum* established on hag tops over the drought period in summer 2018 highlighted some desiccation; a sign that the *Sphagnum* plant ceased to conduct water as a result of capillary film breakage (Hayward & Clymo, 1981). The Met Office reported that 2018 was provisionally the equal warmest on record for the UK. The autumn 2020 survey data showed recovery and expansion in the cover of the *Sphagnum* in both topographical areas and confirmed that this was likely a seasonal fluctuation in percentage cover that had disproportionately affected the *Sphagnum* in depressions/hollows on hag tops relative to *Sphagnum* on undulating ground.

A similar trial compared the growth of different forms of *Sphagnum* (beads, gel and plugs) on a low-land cut-over peatland (Caporn *et al.* 2018). This trial applied approximately the same density of beads (400 $m^2$) as the current trial, a higher density of gel (3 L $m^2$) and a higher density of plugs (30 $m^2$). *Sphagnum* was applied into a low-density sward of naturally regenerating *Eriophorum angustifolium*. *Sphagnum* growth was assessed by recording percentage cover of gel and area cover of plugs. *Sphagnum* cover from gel reached 56 % just 16 weeks after application, increasing to 95 % cover after two years. *Sphagnum* plugs increased in area cover by 750 % in two years. This was consistent with results from the Dense Plug Plant Trial in which percentage cover of plugs located on undulating ground increased by 637 % in 2 years. Caporn *et al.* (2018) did not present the results for beads; the authors reported that the increase in cover for beads was slower than for gel or plugs.

In another trial, Rosenburgh (2015, cited in Caporn *et al.* 2018), investigated the growth of different species of *Sphagnum* beads associated with different peatland substrates and times of year. The *Sphagnum* species used in this trial were *S. capillifolium*, *S. cuspidatum*, *S. fallax*, *S. fimbriatum*, *S. palustre* and *S. papillosum*. Despite poor establishment of beads overall, *S. fallax* was the most successful species, followed by *S. cuspidatum*, *S. papillosum*, *S. palustre*, *S. fimbriatum*. *S. capillifolium* failed to grow.

### Effect of topography on plug-derived *Sphagnum* species in revegetated erosional gullies

Deep, active gullies on Kinder Scout have developed through natural erosion processes and are typical of the degraded blanket bogs of the Peak District and South Pennines SAC. Conditions in the gully systems are dryer where the water table has been drawn down for an extended period of time than the surrounding blanket peat areas and these local water table drawdown effects are observed immediately adjacent to erosion gullies (Allott *et al.* 2009).

As well as the successful establishment of Moorland mix Sphagnum plugs at the hag top extremity, this study showed that Sphagnum plugs established successfully in each of the 4 topographic situations in the gully: gully floor, lower gully side, mid-gully side and upper gully side. Percentage cover Sphagnum on both of the lower situations: gully floor and lower gully side were the most comprehensive. The successful establishment and survival of six species derived from the plug mix in this study shows that erosion gullies are not unsuitable for *Sphagnum* reintroduction, as previously thought (*Caporn et al.* 2018).

The lower and more stable gully floor area where plug-derived *S. cuspidatum* was most frequently established was more likely to pool than the three other, gully side slope situations, where this species had limited or no success. Hayward & Clymo (1981) hypothesised that *S. cuspidatum* may be restricted to pools due to it not having pendent branches for capillary films that are required for water transportation.

Plug-derived *capillifolium* grew faster on the lower gully side situation than the upper gully side and gully floor, indicating that conditions were more favourable on the lower gully side. There is research to show that *capillifolium* is good at transporting water up its stem to keep moist, which is an adaptation to growing in these dryer areas than on the wet gully floor (Michael Pilkington, personal comms. 26/08/21). Hayward & Clymo (1981) found that whilst *S. capillifolium* (hummock species) is smaller in all its parts than *papillosum* (lawn species), it may be able to maintain water transportation to the capitula at a greater height above the water table at which the capillary films in the lawn species have broken.

Similarly, plug-derived *palustre* grew faster in the lower and mid-gully side situations than on the gully floor, where conditions were likely wetter, indicating a preference for the conditions in this drier zone.

The trend for plug-derived *fallax* to grow slower at each step change from gully floor up the gully side indicated that *fallax* preferred wetter conditions. Whilst this species is common in many habitats (FSC, 2012), it had greater success growing in the microclimate of the gully floor, which was also the flattest area. Rochefort (2000) concluded in a study of *Sphagnum* in habitat restoration that the more even the peat surface, the greater success with reintroduction of the plants.

Limitations of this study include that growth was measured in one plane, such that changes in growth in height were not investigated; other key variables such as soil moisture and water table were not measured and therefore conditions in the different zones of the gully could only be assumed to be different based on MFFP's on the ground experience.

## 6. Conclusion

A number of conclusions can be drawn from the trials:

**Sphagnum propagule trial**

- *Sphagnum* derived from plugs, translocated clumps, and gel, established and grew well over time. Mean percentage *Sphagnum* cover at 68 months was 24-fold for plugs than on day zero and 5-fold for clumps. The gel plants grew to almost 17 % mean area cover at 68 months, from 0 % on day zero (undetectable).
- The most successful propagule types in terms of area coverage were plugs and clumps: each covered over 40 % mean area of the quadrats by 68 months.
- Over the same time period beads showed limited success: *Sphagnum* derived from beads had a 2.4 % mean area cover at 68 months (undetectable upon application).

**Cost-benefit considerations**

- When both *Sphagnum* coverage and cost were taken into account the most successful propagule type was gel, followed by clumps, plugs and beads.
- As the percentage cover of *Sphagnum* continues to increase over time, the cost per one percent cover will decrease for all propagule types. This may justify the higher initial cost for plugs, as they expand to cover a larger area over time.
- Whilst the priority is rapid colonisation for Ecosystem Services benefits, however, plugs are MFFP's preferred option.

**Dense Plug Plant Trial**

- The study demonstrated that comprehensive *Sphagnum* cover (i.e. ~ 80 %) can be achieved in a minimum of 68 months when plug planting is delivered at a density of ~10 plugs per $m^2$* on undulating ground in revegetated areas.
- Much faster growth was observed when *Sphagnum* was located in lower areas with a higher water table and better protection from desiccation relative to the hag-top areas.
- The most dominant species derived from the moorland plug mix in terms of area coverage were *S. fallax* and *S. palustre* in both topographical situations: hag tops and lower undulating ground.
- The study suggests that that moisture from precipitation and cloud cover was sufficient for *Sphagnum* to survive and grow slowly on hag tops.

**Effect of topography on plug-derived *Sphagnum* species in revegetated erosional gullies**

- Comprehensive *Sphagnum* cover derived from plugs was achieved on the gully floor and lower gully sides, with additional establishment on the mid-gully side and upper gully side.
- The successful establishment and survival of six species derived from the plug mix in this study shows that revegetated erosional gullies are suitable for *Sphagnum* reintroduction.
- Six species were found to have established from plugs in all four situations in the erosional gullies: *S. capillifolium*, *fallax, fimbriatum*, *medium*, *pallustre* and *papillosum*.
- There were effects of topography on plug-derived *capillifolium*, *cuspidatum, fallax,* and *palustre*:
  - (i) Plug-derived *cuspidatum* was most frequently established on the gully floor;
  - (ii) Plug-derived *capillifolium* grew faster on the lower gully side situation than the upper gully side and gully floor, indicating that conditions were more favourable on the lower gully side;
  - (iii) Plug-derived *palustre* grew faster in the lower and mid-gully side situations than on the gully floor, where conditions were likely wetter, indicating a preference for the conditions in this drier zone;
  - (iv) The trend for plug-derived *fallax* to grow slower at each step change from gully floor up the gully side indicated that *fallax* preferred wetter conditions. Whilst this species is common in many habitats, it had greater success growing in the microclimate of the gully floor, which was also the flattest area.

* In the sampled area, mean plug density was 10 per $m^2$ following the general application of 5 plugs per $m^2$ to the Nogson catchment area

# 7. Recommendations

Where rapid colonisation is a priority, plugs are the recommended propagule. If gel is to be used, based on initial cost, then consideration must be given to the method of application to ensure that it allows the gel to make contact with the peat and that it is practical over a large area.

In addition to the Kinder Trials, MFFP *Sphagnum* reintroduction studies have shown that we can now be more optimistic about each of the species surviving and thus less reliant on *S. fallax* (Benson *et al.* 2021; Pilkington *et al.* 2021). Amongst the suite of *Sphagnum* mixes that MFFP use, MFFP will be trialling a new version of the Moorland Mix (mk 2) for enriched/flush/degraded locations from Autumn/ Winter 2021 with the aim of establishing a more favourable mix of *Sphagnum* species on these sites in future decades. The latest Moorland mix comprises an increased proportion of *denticulatum* (5 %), *medium* (10 %), *squarrosum* (5 %), *tenellum* (5 %), and reduced *cuspidatum* (5 %) and *fallax* (10 %); *russowii* is not included in the mix.

The effects of topography on plug-derived *capillifolium*, *cuspidatum, fallax,* and *palustre* planted in gullied areas suggests that some single-species *Sphagnum* planting could be feasible if we were to learn more about individual species niches to be able to further target the plug planting. MFFP are also trialling chunky and pool mixes for use in different geographic and topographical situations[1].

[1]The latest version of MFFP's *Sphagnum* Practitioner's Guide is available on the MFFP website

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# MoorLIFE2020

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