MONITORING THE BIODIVERSITY AND ECOSYSTEM SERVICE IMPACTS OF RESTORATION OF DEGRADED BLANKET BOG SITES

CHAPTER 3: VEGETATION DIVERSITY

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Monitoring the biodiversity and ecosystem service impacts of restoration of degraded blanket bog sites

Chapter 3: Vegetation Diversity

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1. Summary

Vegetation diversity was monitored at sites across the Peak District National Park and South Pennines Moors Special Area of Conservation where restoration interventions were made. Sites which, pre-restoration, were dominated by bare peat, were monitored for up to 17 years. Sites which, pre-restoration, were dominated by single species (*Eriophorum vaginatum, Calluna vulgaris, Molinia caerulea*), were monitored for four years.

At the bare peat sites, vegetation cover returned to almost 100% within 5–7 years after initial revegetation work, with diversity continuing to increase over the following years. Blanket bog indicator species succeeded seeded and natural pioneer species, developing ~100% cover within 10 years. Invasive species (principally *Chamaenerion angustifolium*) and trees (principally *Salix* spp) were observed at most sites but did not develop significant cover within the monitoring areas. *Sphagnum* mosses (key blanket bog species and 'bog builders') did not recolonize naturally, but were observed to thrive when planted into revegetated areas once a comprehensive vegetation cover had been established. Where *Sphagnum* mosses were planted, favourable condition (JNCC guidelines for blanket bog – JNCC, 2009) was almost achieved; where no *Sphagnum* was planted, favourable condition was not achieved, with multiple attribute targets being failed by significant margins. Where *Sphagnum* mosses were planted, they achieved ~25% cover within six years on undulating ground, and were approaching 100% cover in some flow pathways. This highlights the need – and importance – of planting *Sphagnum* as part of restoration packages for areas of bare peat.

At the species dominated sites, *Sphagnum* was successfully introduced into all the dominant vegetation types: *Eriophorum vaginatum, Calluna vulgaris and Molinia caerulea.* This resulted in a statistically significant difference in cover of *Sphagnum* compared to the untreated control sites, in all cases. Over the four years of the monitoring, there was little clear change observed in the cover of any of the dominant vegetation types. However, the *Sphagnum* introduction successfully increased the number of indicator species on all sites. Where *Sphagnum* plugs were introduced at a high density into 50% *Calluna vulgaris* cover, all criteria for achieving favourable condition were met.

2. Introduction

The long history of degradation of peatland landscapes within the areas now designated as the Peak District National Park and South Pennines Moors Special Area of Conservation (SAC) is outlined in the introductory chapter of this report.

Exploitation for agriculture and forestry, together with deposition of atmospheric pollution and outbreaks of wildfire have been severely detrimental to the peatland habitats within this area. Such processes had led to the loss of *Sphagnum* mosses in almost all locations, a reduction in the diversity within remaining vegetation communities (leaving some peatlands dominated by a single species), and extensive areas without any vegetation cover, leaving an exposed and fragile bare peat surface.
This degradation has important implications for the provision of peatland ecosystem services. This investigation, commissioned through the MoorLIFE2020 project, sets out to build on the work of Moors for the Future Partnership's Making Space for Water project, through which the initial effects of revegetation of bare peat surfaces were monitored from 2011–2014.

As described in Pilkington *et al* (2015), the original notification of the Dark Peak SSSI (Site of Special Scientific Interest) was primarily as result of its upland breeding bird interest, with the result that much of the site includes a variety of degraded forms of blanket bog and dry heathland. The later SAC moderation of the notification recognised this area as containing rare upland habitats typical of northern England, even though these habitats were highly degraded.

In addition to the dearth of indicator species in degraded areas such as these, there have also been severe erosional processes and gullying causing changes to hydrological regimes, in particular the lowering of water tables.

Similar problems of diversity (if not hydrology) may be experienced in blanket bog-designated areas that have become dominated by *Calluna vulgaris, Eriophorum spp.*, *Molinia caerulea,* or other species. Thus the achievement of "favourable condition" status on these sites may require extreme management intervention, including a complete exclusion of grazing and burning pressure coupled with a prolonged period of intense stabilisation, re-vegetation and gully-blocking measures.

In theory for general upland areas, a site was designated as a blanket bog due to (i) a dominance of indicator species (including *Sphagnum* bog mosses, other bryophytes, cotton-grasses, dwarf shrubs, and occasionally lichens) and (ii) a depth of more than half a metre of peat. However, many sites that fulfil only one of these requirements may still have been designated as blanket bog. The assumption here is that a more complete expression of this feature occurred on the site in the past and that all attributes on the site would once have satisfied the target compliance for favourable condition.

A further assumption is that, in the expert opinion of the surveyor, the site has the potential to return to this state again in the future. Indeed, under the revised CSM guidance (JNCC 2009) there is clear instruction that degraded mire communities or those areas of deep peat currently vegetated by dry heath or acid grassland communities should only be assessed against the blanket bog criteria if restoration back to blanket bog communities is considered feasible. However, it is unclear how this assessment can be made in the absence of supporting evidence.

PAA (2005) commented on problems associated with choosing the appropriate habitat feature for assessing condition using the CSM methodology. This is because highly degraded habitats often bear little floristic resemblance to their former and thus potential future habitat type. For example, *Molinia* swards are commonly assessed as either Wet heath or blanket bog, although it could also be assessed as "purple moor-grass-tormentil mire community". The precise choice that is made can influence the CSM status that is eventually awarded to the site. JNCC guidance for designation as blanket bog habitats is the average depth of peat (generally being >0.5m), but PAA (2005) suggested that areas exist with sufficient depth for designation as blanket bog but which also have a strong Dwarf shrub community. In such cases perhaps these areas should be treated as transitional between blanket bog and Dwarf shrub heath. This may be particularly relevant for upland habitats in the Peak District and South Pennines, especially on their eastern side, because these areas are amongst the driest regions in Britain where blanket bog still survives but may not have the correct conditions to become active bogs in the future. The opposite case also was found, such as Heptonstall Moor, with insufficient depth of peat but some characteristic blanket bog vegetation. In both cases, English Nature (now Natural England) suggested that where the blanket peat had been so badly eroded that its hydrological integrity cannot be effectively restored, then restoration from bare peat to a degraded blanket bog habitat should be the aim (PAA, 2005).

For many degraded areas with extensive bare peat and gullying, PAA (2003) suggested extensive grazing exclusion together with brashing, or cover with geojute on steeper parts, and then re-vegetation using seed, lime and fertilising. Gully blocking was also recommended. For surrounding areas there could be general specifications for stocking levels but a suspension of all burning.

There are 168 SSSI units lying within or below the Upper Derwent Catchment area. Natural England's long-term objective for many degraded upland SSSIs of the South Pennines is for their restoration specifically towards either blanket bog or Dwarf shrub habitats that are rich in *Sphagnum* and dwarf shrubs but poor in graminoids (PAA, 2003). This objective then gained impetus from "Biodiversity 2020", a government strategy that aimed to increase the proportion of SSSIs that are in favourable condition to at least 50% by 2020 (Natural England, 2015).

However, current assessment for condition status is not of a sufficient detail or temporal resolution to show the effect of management in making progress towards favourable condition.

The aim of this investigation is therefore not only to show the development of this artificially re-vegetated plant community in terms of its general cover characteristics, but also to record the development of sites dominated by a single species, once restoration interventions are made. In both cases this is an opportunity to build on the work of the Making Space for Water project of 2015, and to further detail the trajectory of these sites towards blanket bog favourable condition.

As such, vegetation biodiversity on sites with varying starting states have been monitored as restoration processes have been implemented. Recording changes in vegetation cover and community composition over time provides vital context to other processes being monitored including water table, surface water runoff, catchment discharge, sediment generation and water chemistry.

Vegetation diversity was monitored at two different sets of sites:

1. Those with a bare peat starting state (including field labs on Kinder Scout; and wider context sites in the South Pennines) many of which have undergone restoration
2. Those dominated by a single species (referred to as species dominated sites)

Table 1. Sites at which vegetation diversity was monitored

Bare peat starting state		**Species dominated starting state**
Kinder Scout field labs	**Wider context sites**	
N	Joseph Patch (Bleaklow)	Heather (*Calluna*) – Derwent and Howden
O	Shelf Moor (Bleaklow)	Cottongrass (*Eriophorum*) – Birchinlee
F (bare peat control)	Shining Clough (Bleaklow)	Purple moor-grass (*Molinia*) – Moss Moor
	Woodhead (Bleaklow)	
	Skyes Moor (Bleaklow)	
	T (Bleaklow bare peat control)	
	Black Hill	
	Rishworth	
	Turley Holes Seal Edge (Kinder Scout)	

2.1. Treatment regimes

2.1.1. Bare peat sites

The bare peat restoration process carried out on the Kinder field lab sites is described in detail the introductory chapter of this report.

Under the Making Space for Water project in 2011–2013, grazing was excluded from the Kinder plateau, peat was stabilised using heather brash and geo-jute and the bare peat areas were then revegetated with applications of lime, mixed grass seed and fertilizer. Moorland species were then added as plug plants, and in 2015–2018 *Sphagnum* mosses were reintroduced to some areas in the form of mixed species plug plants. In addition, erosion gullies were blocked with both stone and timber dams. The treatments applied, and dates of application for each of the main field lab sites are summarised in Table 2 below.

2.1.2. Species dominated sites

The species dominated sites were treated by introducing mixed species *Sphagnum* moss plug plants at a density of 1 plug per m^2, aside from several higher-density areas as follows:

The 30 x 30 metre area containing a cluster of dipwells had plugs introduced at a density of 4 per m^2 – planted at 50 cm spacing regardless of micro-topography or vegetation. Flow pathways were also planted at 4 plugs per m^2, while the intensively planted run-off plots were planted at the highest density of 100 plugs per m^2; in order to attempt to simulate the potential future condition of the wider catchment during a shorter time span. In addition, wooden gully blocks were also added to a further treatment catchment on the *Calluna* dominated site. Treatments applied and the dates of application are summarised in Table 2 below.

Table 2. Summary of treatments applied to field lab monitoring sites

Restoration process	Bare Peat sites				*Calluna* site			*Eriophorum* site		*Molinia* site	
	F	P	O	N	Cal. con	Cal. sph	Cal. sph.gb	Eri. con	Eri. sph	Mol. con	Mol. sph
Grazing exclusion	2013	-	2013	2013	-	-	-	-	-	-	-
Gully blocking	-	-	-	2011	-	-	2019	-	-	-	-
Heather brash	-	-	2011	2011	-	-	-	-	-	-	-
Geo-jute	-	-	2011	2011	-	-	-	-	-	-	-
Seeding: amenity grasses and moorland species	-	-	2011	2011	-	-	-	-	-	-	-
Lime + fertiliser	-	-	2011, 2012, 2013	2011, 2012, 2013	-	-	-	-	-	-	-
Sphagnum planting	-	-	-	2015, 2018	-	2019	2019	-	2019	-	2019

2.2. Common Standards Monitoring

Monitoring changes in the vegetation communities on these sites will allow their condition to be measured, and their progress towards achieving favourable condition status to be tracked.

Favourable condition is the objective for all SSSIs and one of the habitat condition statuses determined by using Natural England habitat assessment criteria.

The possible condition outcomes of this assessment are:

- Favourable
- Unfavourable (recovering condition)
- Unfavourable (no change)
- Unfavourable (declining)
- Part destroyed
- Destroyed

Sites in favourable condition are defined by Natural England as those where "habitats and features are in a healthy state and are being conserved by appropriate management" (Natural England, 2020).

Condition assessments are made using a range of sources, including CSM (Common Standards Monitoring) guidance. CSM criteria for Upland Habitats (blanket bog communities) were applied to the data collected from these sites. This was carried out to chart progress toward achieving favourable condition status, and highlight which areas or species are reducing the chances of that status being achieved.

3. Methodology

3.1. Experimental design

3.1.1. Bare Peat

Vegetation diversity was monitored following revegetation of bare peat at degraded and eroding sites across the South Pennines. The monitoring design also included areas from which treatment had been excluded, as bare peat control sites. Initially, bare peat control areas were monitored at almost all sites. Due to the importance of revegetating bare peat areas, however, only two of these areas were left as long-term control sites; the rest were subsequently revegetated. Results from the early years of these short-term control sites, and those from the remaining long-term ones, show minimal change in vegetation cover in bare peat areas where no revegetation work has been undertaken. Therefore, it is considered appropriate to present raw data from the sites with no control as evidence of trajectories of change as a result of revegetation work.

The sites are grouped into two sets: field labs (on Kinder Scout), and wider context sites (across the South Pennines). The field lab sites received more intensive monitoring of a wider range of variables; the wider context sites add extensive replication as well as a longer timescale of monitoring. All sites were monitored before the start of MoorLIFE 2020, under a range of different projects. Results from these sites have previously been reported in project-specific reports and also in Alderson *et al* (2019).

3.1.2. Species Dominated

Vegetation diversity was monitored before and after the planting of *Sphagnum* mosses at three sites dominated by different individual vegetation species: *Calluna vulgaris, Eriophorum vaginatum* and *Molinia caerulea*. At each site, vegetation diversity was monitored in both treated and untreated (control) mini-catchments. Treatment consisted of the planting of *Sphagnum* mosses and, in the case of one mini-catchment at the *Calluna* site, gully blocking. Within each treatment catchment, monitoring included areas that had received medium density *Sphagnum* planting (4 plugs per m^2) and a set of three 3 m x 1 m 'intensive plots' where *Sphagnum* was planted at a very high density. Details of planting densities and timings can be found in the introduction section of this chapter.

3.2. Monitoring vegetation in the field

3.2.1. Locating quadrats

Sets of quadrats measuring 2 m x 2 m were established at monitoring sites across the South Pennines using a stratified randomised sampling approach. Avoiding areas of bare mineral, gully floors, gully sides or hag tops, quadrats were set up on undulating ground representing the surrounding area; precise locations were selected at random. These locations were marked by wooden stakes, enabling portable quadrats to be placed in exactly the same position on each repeat of the surveys. At each site, a minimum of ten quadrats were installed and monitored.

On species dominated sites, ten 2 m x 2 m quadrats were placed in the dipwell cluster area of each mini-catchment – areas with a higher *Sphagnum* planting density than the broader site. In addition, three 1 m x 3 m intensively planted plots (intensive plots) in each mini-catchment were treated as quadrats and monitored concurrently.

3.2.2. Frequency of surveys

Surveys were conducted annually in July–September. Table 3 shows which sites were surveyed in each year from 2003–2021.

Table 3. Record of sites surveyed 2003–2020.
***Calluna, Eriophorum* and *Molinia* are the species dominated starting-state sites; all others are bare peat starting-state sites.**

Site	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Bare peat (Kinder Scout) field labs																			
O								■	■	■	■	■	■	■	■	■	■	■	■
N								■	■	■	■	■	■	■	■	■	■	■	■
F (bare peat control)								■	■	■	■	■	■	■	■	■	■	■	■
Species dominated																			
Calluna (Derwent and Howden)																■	■	■	■
Eriophorum (Birchinlee)																■	■	■	■
Molinia (Moss Moor)																■	■	■	■
Bare peat (Bleaklow) – wider context sites																			
Joseph Patch	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	
Shelf Moor		■	■	■		■	■	■	■		■	■			■	■	■		
Shining Clough		■	■	■	■	■	■	■	■		■	■			■	■	■		
Woodhead								■	■	■	■	■	■	■	■	■	■	■	
Sykes Moor		■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	
T (bare peat control)					■	■	■	■	■	■	■	■			■	■	■	■	
Bare peat (other) – wider context sites																			
Black Hill				■	■	■	■	■	■	■	■	■	■			■	■		
Rishworth									■		■	■				■	■		
Turley Holes								■	■		■	■				■	■		
Seal Edge (Kinder Scout)											■	■				■	■		

3.2.3. Calculating percentage cover of species

Within each quadrat, all vegetation species present were recorded as an estimated percentage cover of the 2 m x 2 m area. Where multiple layers of vegetation were present, total percentage cover was allowed to run over 100%. For example, in some quadrats, there may have been a near-complete understorey of bryophytes overlain by canopies of ericoids (dwarf shrubs), graminoids (grasses) and/or tree saplings.

3.2.4. *Sphagnum*

Identifying *Sphagna* to individual species level is difficult in the field, especially in the initial years following planting as small plug plants. For this reason, any species of *Sphagnum* observed during the general surveys were recorded simply as *Sphagnum*. While this didn't affect results in terms of *Sphagnum* coverage, it resulted in a lower number of different *Sphagnum* species counted. Individual *Sphagnum* species each count as separate indicator species when conducting a Common Standards Monitoring assessment of overall condition. One requirement for blanket bog 'favourable condition' status is that there must be at least six indicator species present. In order to gain a more complete understanding of how the *Sphagnum* community was developing, additional surveys were conducted in 2018 and 2020, in locations with established *Sphagnum* populations (Kinder Scout only) which included identification of all individual *Sphagnum* species.

In order to gain an understanding of how *Sphagnum* cover was developing in streamflow pathways at field lab N on Kinder Scout (important for understanding changes in stormflow behaviour), rough walkover surveys were conducted. All flow pathways in the field lab N mini-catchment were mapped and divided into stretches. These were then surveyed in the field by measuring the width and length of the flow pathway (width estimated based on likely width of flow in high-flow conditions) and estimating the *Sphagnum* percentage cover within that area. These data were then used to estimate the total area of the flow pathways within the mini-catchment, and the proportion of this area covered by *Sphagnum*. This survey was completed in February/March in 2018, 2020, 2021 and 2022. While this survey method provides an approximate estimate only, it gives a valuable indication of the development of *Sphagnum* within flow pathways, with important implications for hydrological processes affecting storm flow behaviour.

3.2.5. Trees

No trees were planted on any sites, but it was anticipated that some might establish, either from windblown seed, or introduced in the heather brash. Tree heights were recorded in addition to percentage cover, to monitor the growth characteristics of trees following the revegetation work. For each quadrat, the height of the tallest tree present in each quarter of the quadrat was recorded. These were then converted into a maximum and mean of the height values.

3.3. Data processing

All species data were processed into time series of percentage cover and presence/absence so that change over the years following treatment could be assessed. Results were summarised into categories of vegetation species: bare peat, indicator species, ericoids, graminoids (including sedges and rushes), bryophytes, invasive species and trees. Individual species of particular interest were highlighted. In order to assess whether conditions were met for sites to be defined as being in ‘favourable condition’ according to Common Standards Monitoring (CSM), results were processed to show whether individual attribute targets for favourable condition were being met on each site. For attribute targets to be met at site-level, 90% of quadrats should achieve the target; for a site to be classed as in favourable condition, all attribute targets should be met. Lists of indicator species and attribute targets for favourable condition were taken from CSM guides produced by the JNCC (JNCC, 2009) for assessment of blanket bogs and are summarised in Table 4 and Table 5. For the species dominated sites, CSM criteria were examined by processing results for intensively treated plots, rather than the wider catchment area. This was done since the intensive plots are intended to give an accelerated view of how the wider catchment may develop over a longer time period.

Table 4. List of indicator species relevant to blanket bogs taken from JNCC (2009). The full list is more extensive; the species listed here are those which were observed during surveys

Blanket bog indicator species
Calluna vulgaris
Erica spp.
Empetrum nigrum
Eriophorum angustifolium
Eriophorum vaginatum
Non-crustose lichens
Pleurocarpous mosses
Sphagnum spp.
Trichophorum germanicum
Vaccinium spp.

Table 5. Attribute targets for favourable condition assessment (blanket bog), taken from JNCC (2009). For each target to be met, at least 90% of quadrats should satisfy the criteria. All targets should be met for a site to achieve favourable condition.

Attribute	Targets
Frequency of indicator species	At least six indicator species should be present - Score each *Sphagnum* species separately - *Sphagnum fallax* only counts as an indicator species if other *Sphagnum* spp are also present
Cover of indicator species	At least 50% of vegetation cover should consist of at least three indicator species *Sphagnum* cover should not consist only of *Sphagnum fallax* Any one of *Eriophorum vaginatum*, ericaceous species collectively, *Trichophorum* should not individually exceed 75% of the vegetation cover
Cover of other species	Less than 1% should be made up of non-native (invasive) species Less than 10% of vegetation cover should be made up of scattered native trees and scrub Less than 1% of vegetation cover should consist of, collectively, *Agrostis capillaris, Holcus lanatus, Phragmites australis, Pteridium aquilinum, Ranunculus repens*
Physical structure	Less than 10% of the feature area should be disturbed bare ground

3.3.1. Bare Peat

17 years of post-treatment data were available from bare peat starting-states monitoring sites. Both raw data and relative data (treatment-control) are of interest when monitoring vegetation following revegetation of bare peat. To assess the overall condition of the sites, raw data are appropriate; to assess the difference that revegetation work has made as compared to leaving the sites untreated, relative data are appropriate. In practice, there is very little difference between these two methods, as very little change was observed at the bare peat control sites.

3.3.1.1. Data from treatment sites

For each metric of interest (percentage cover of individual species, percentage cover of species categories, number of indicator species present), data from the revegetated bare peat starting-state sites are presented as mean values of all quadrats within each site for each growing season (year) since the first application of lime, seed and fertiliser. For the Kinder Scout field lab sites (O and N) these mean values are presented individually; for the wider context sites these mean values were then compiled into a single median per year since treatment. Revegetation work occurred in different years on different sites meaning that Year Zero (the growing season prior to treatment) occurred in a range of years. While this is not expected to affect results, it does mean that more years of data are available for some sites than others (see Table 3). For growing seasons 0–11, n = ~13; for growing seasons 12–17, n gradually reduces from 6 to 1. Therefore, while the median values of yearly means from all sites in the first 11 years may be a good representation of the heterogeneity of sites in a range of locations with varying characteristics (wetness, aspect, topography, severity of erosion), these median values become more focussed on individual sites towards the end of the trajectory.

3.3.1.2. Data from control sites

Data from the two bare peat control sites are presented as comparisons for the revegetated sites, and were also used to normalise treatment data (treatment-control) to assess the impacts of treatment. 14 years of data were available from T (Bleaklow); 12 years of data were available from F (Kinder Scout). As with the treatment data, a mean value was calculated for each site for each year and then a median of these values was calculated for each year. For years 13–14, data become focussed on site T; while this effect is small, it is observable. For years 15–17, no control data were available. In order to normalise treatment data for these years, control data were estimated by extrapolating data from years 1–14 using the Forecast function within Excel. While these data are only an estimate and should be treated with caution, the changes in the recorded control data are sufficiently small that this process is considered appropriate.

3.3.1.3. Normalised data (treatment-control)

In order to assess the impacts of treatment on vegetation diversity and cover, data from the treatment sites with a corresponding bare peat control site were normalised. For each metric of interest, data were normalised by subtracting the mean control value from the mean value of each corresponding treatment site (all treatment sites on Bleaklow used T as control; all treatment sites on Kinder Scout used F as control; all other sites had no control so normalised data were not calculated). Median values of these normalised means for each year were calculated (Bleaklow and Kinder Scout combined) to create one trajectory of change as a result of treatment for each metric of interest.

3.3.1.4. Trendlines

Trends with a range of characteristics were observed in the data from sites following treatment. Some species/categories followed a dose response (a rapid increase in cover followed by a stabilisation, best represented by a logistic curve); some followed a steady increase, best represented by a linear trendline; some followed a single peak response (an increase followed by a decrease, best represented by an exponentially modified Gaussian peak curve); others had multiple distinct phases of increase/decrease at different rates and were best represented by multiple order polynomial curves. Where appropriate, the same curves have been used as in Alderson *et al* (2019). It should be noted that in all cases, the most appropriate curves/lines have been used to describe the overall trends observable in the data but, in some cases, it may not be appropriate to draw robust conclusions about future trajectories from these apparent trends.

3.3.2. Species Dominated

Data from the sites which, pre-treatment, were dominated by single species, are presented both as mean values of all quadrats within each site and as mean values of difference between treatment and control. As these sites already have a vegetation community, monitoring of untreated control sites is required to understand whether any changes to the vegetation community are occurring 'naturally', separately to the *Sphagnum* planting. Presentation of the absolute (raw) data allows an assessment of the overall condition of each site; processing data as treatment-control enables the isolation and assessment of the effects on diversity specifically of the treatment.

3.3.2.1. Data from treatment sites

For each metric of interest (percentage cover of individual species, percentage cover of species categories, number of indicator species present), data from the sites planted with *Sphagnum* (and in one case gully-blocked) are presented as mean values of all quadrats within each site for each growing season (year) since the treatment. These mean values were then compiled into a single median per year since treatment in 2019. It should be noted that treatment of the intensive plots occurred in late summer 2019, after that year's vegetation survey had taken place.

3.3.2.2. Data from control sites

Data from the control sites are presented as comparisons for the treatment sites, and were also used to normalise treatment data (treatment-control) to assess the impacts of treatment. Four years of data were available (2018–2021) for all species dominated sites.

3.3.2.3. Normalised data (treatment – control)

In order to assess the impacts of treatment on vegetation diversity and cover, data from the treatment sites with a corresponding control site were normalised. For each metric of interest, data were normalised by subtracting the mean control value from the mean value of each corresponding treatment site. Median values of these normalised means for each year were calculated to create one trajectory of change as a result of treatment for each metric of interest.

3.3.2.4. Trendlines

Due to the nature of the interventions, significant trends of change were not anticipated for most metrics in the timescale of monitoring (two years after planting of *Sphagnum*). Linear trendlines best characterised most observed changes, although it should be noted that in many cases these were indicative only, with variability between years more significant than overall directional change. In the case of *Sphagnum* percentage cover at the *Eriophorum* and *Calluna* sites, change followed a dose response (a rapid increase in cover followed by a stabilisation, best represented by a logistic curve).

4. Results

Results presented in this section are raw (not normalised by subtracting control from treatment data) unless otherwise stated, to allow a description of the changing condition of each site. Where appropriate, normalised data are presented to highlight the specific impact of treatment compared to control.

4.1. Bare peat

Data from the bare peat sites have previously been presented in Maskill *et al* (2015), Pilkington *et al* (2015) and Alderson *et al* (2019). The data presented below include and extend these datasets, providing a more long-term understanding of the evolution of vegetation communities following revegetation work.

4.1.1. Control data

All quadrats across both control sites (T and F) were 100% bare peat at the start of monitoring. By 2020, 90% of quadrats remained >95% bare peat; one quadrat at T had 10% *Calluna vulgaris* cover; one quadrat at F had 80% *Eriophorum angustifolium* cover (see Figure 1). Both of these species are indicator species. Both of these species were present within the control area (but not within the quadrats) at the start of monitoring and have become abundant in the areas surrounding the untreated control sites due to revegetation work.

Ingress of these species into these two quadrats could be from either of these sources. If from windblown seed from surrounding revegetated areas, this should be considered as contamination of the control site (these quadrats should be removed from analyses); if it is from extant vegetation within the control sites, this should be considered as ‘natural’ recolonisation within the control (these quadrats should be included in analyses), although it is possible that this recolonisation was accelerated by the grazing exclusion fences which were installed around both plateaux as part of the restoration process.

In this report this ingress is considered as natural recolonisation (although the true source is not known); all control data are included. When considered in this way, the assumption is that a comparable rate of recolonisation would occur at the treatment sites even if no revegetation work took place. Therefore, when treatment data are normalised (treatment-control), the amount of change attributed to the revegetation work is reduced. Given that the ingress may well be a result of treatment in the area surrounding the control sites, these normalised data may be viewed as conservative estimates. This effect is small and only applies to metrics where presence or percentage cover of *Calluna vulgaris* or *Eriophorum angustifolium* are relevant (number of indicator species present; percentage cover of bare peat, total vegetation, indicator species, ericoids, graminoids).

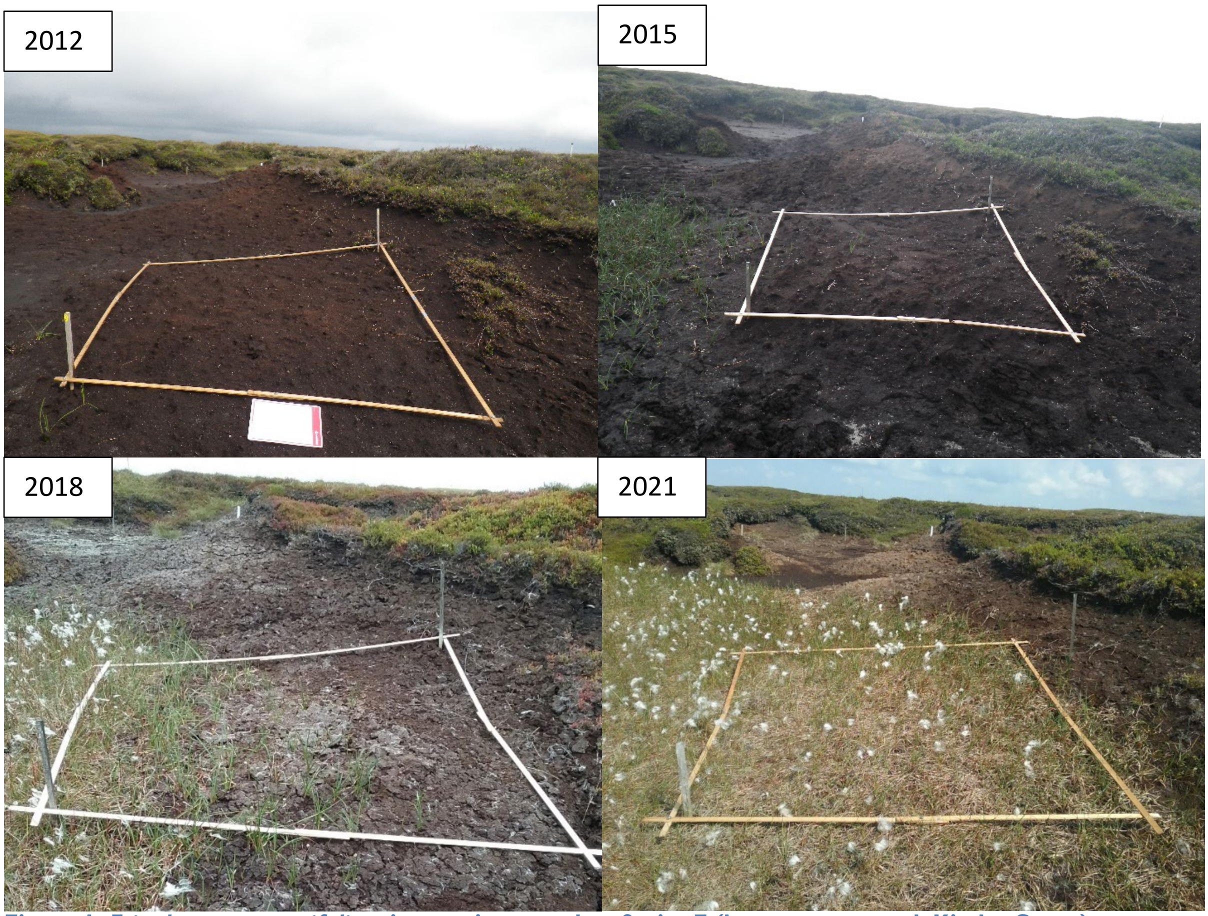


Figure 1: *Eriophorum angustifolium* ingress into quadrat 9, site F (bare peat control, Kinder Scout)

4.1.2. Treatment data

Overview metrics are presented with the field labs and wider context sites on the same graph to enable to comparison across sites. These metrics include bare peat cover, total vegetation cover, indicator species cover and number of indicator species present. Data relating to the composition of vegetation species are then presented for each field lab individually, and for the wider context sites combined

4.1.3. Overview species cover data

4.1.3.1. Bare peat

Median bare peat cover reduced to less than 5% at treatment sites in the 5th growing season after treatment. Over the following years, bare peat cover fluctuated slightly (fluctuations in the median value due largely to different sites being monitored in different years) but remained around 5%. There was a slight ingress of vegetation at the bare peat control sites, as discussed in 4.1.1. The reduction in bare peat at treated sites was best characterized by a dose response logistic curve; the reduction in bare peat at the bare peat control sites was best characterized by a linear trendline. See Figure 2.

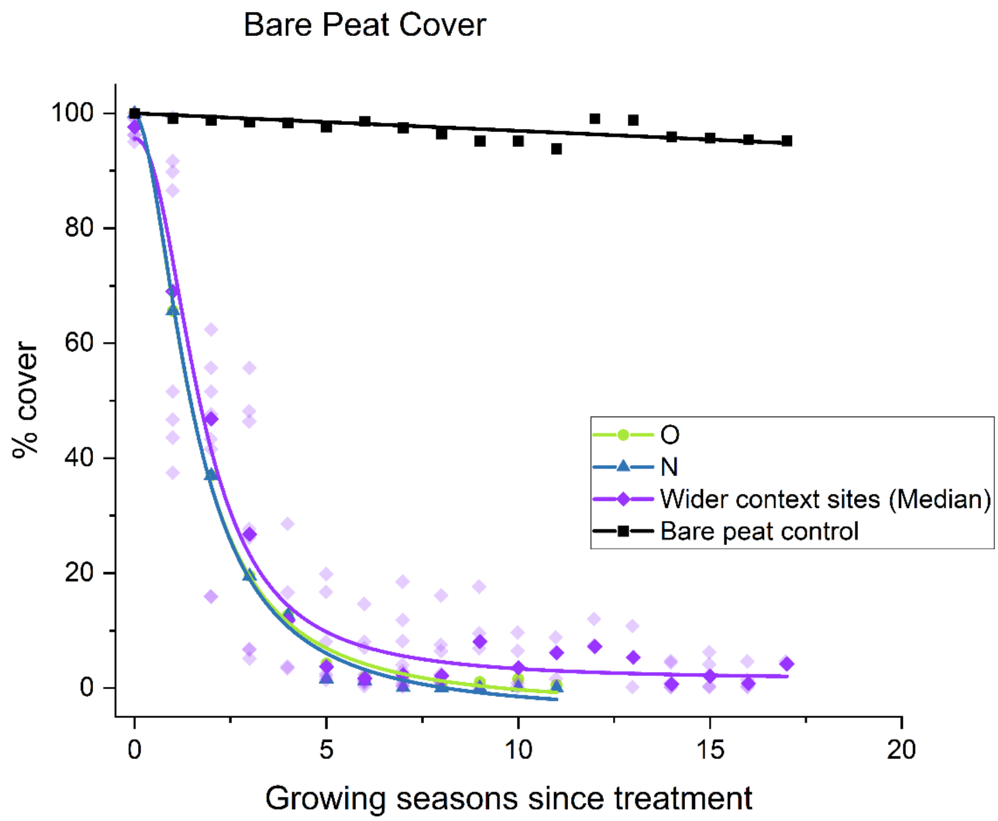


Figure 2: Bare peat cover at bare peat sites, expressed as mean cover for quadrats within each study site Data from wider context sites are presented as the median of the mean values from each wider context site

4.1.3.2. Total vegetation

Total vegetation cover increased rapidly over the first ~6 years, followed by plateau at around 160%. It was still increasing at N at the end of monitoring (~200% after 11 years). Total vegetation cover may exceed 100% due to layering: total vegetation cover is calculated as the sum of the ericoid, graminoid, bryophyte, tree and invasive species layers. It is possible to have an extensive bryophyte cover overlaid with other species; this was observed in many quadrats. A slight, gradual increase in total vegetation was observed at the bare peat control quadrats due to ingress of species from the surrounding areas (~5% after 17 years). The increase in total vegetation cover at treated sites was best characterized by a dose response logistic curve; the increase in total vegetation cover at the bare peat control sites was best characterized by a linear trendline. See Figure 3.

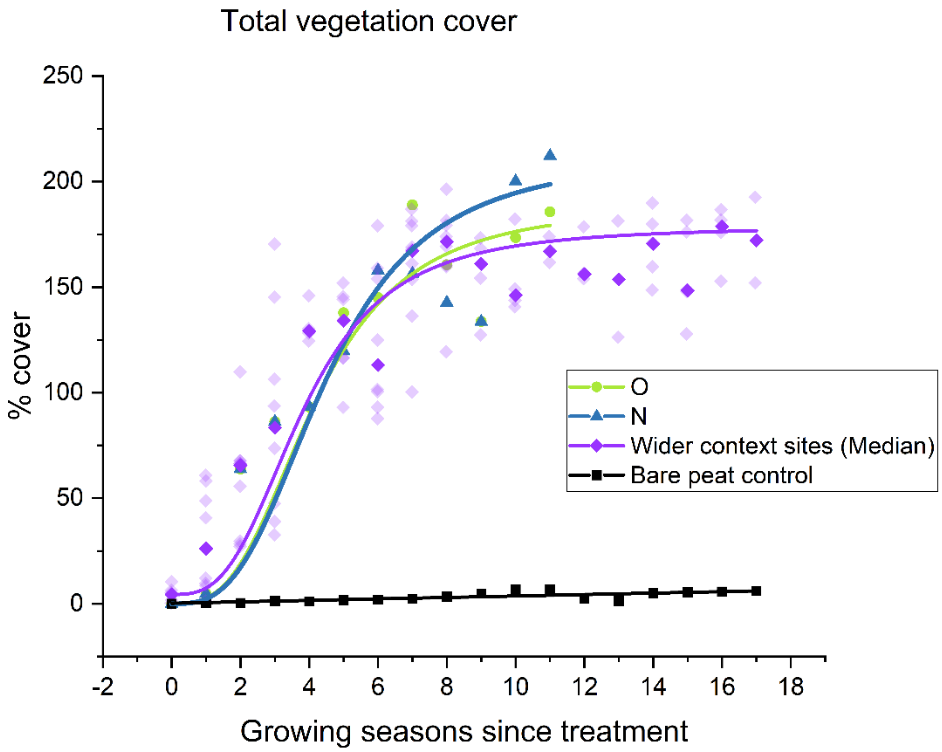


Figure 3: Total vegetation cover at bare peat sites, expressed as mean cover for quadrats within each study site.
Data from wider context sites are presented as the median of the mean values from each wider context site.

4.1.3.3. Indicator species

The Joint Nature Conservation Committee published a list of indicator species (see Table 4), any six of which should be present in at least 90% of quadrats in order for a site to be classified as in 'favourable condition' (JNCC, 2009). These species include: *Calluna vulgaris, Erica* spp, *Empetrum nigrum, Eriophorum angustifolium, Eriophorum vaginatum*, *Pleurocarpous* mosses, *Sphagnum* spp (each individual species counted separately), *Trichophorum germanicum* and *Vaccinium* spp.

Total cover of indicator species increased rapidly (but slightly slower than total vegetation) from years three to seven (to around 80–100%) at all sites (Figure 4). It slowed slightly in the following years but was still increasing at N and wider context sites to the end of monitoring; it declined slightly at O in the last three years.

As shown in Figure 5 the number of indicator species present increased rapidly from years two to five/six at all sites, followed by a plateau at 4–5 species at O and the wider context sites. Indicator species count stabilised at around seven species at N. *Sphagnum* spp were only recorded as a single species (not surveyed to species level), despite multiple species being present; indicator species count at N was therefore underestimated. In 2018 and 2020, *Sphagna* were surveyed to species level; if individual *Sphagnum* species were included, indicator species count was ~10 in both years. This was not relevant to O or the wider context sites as no *Sphagna* were present (or only in negligible quantities so the presence of multiple species was unlikely).

Indicator species cover and count increased at bare peat controls due to the ingress of *Eriophorum angustifolium*, *Eriophorum vaginatum* and *Calluna vulgaris*. Even in only very small amounts, the presence of these species increases the number of indicator species present. By the end of monitoring there was ~1 indicator species present per quadrat.

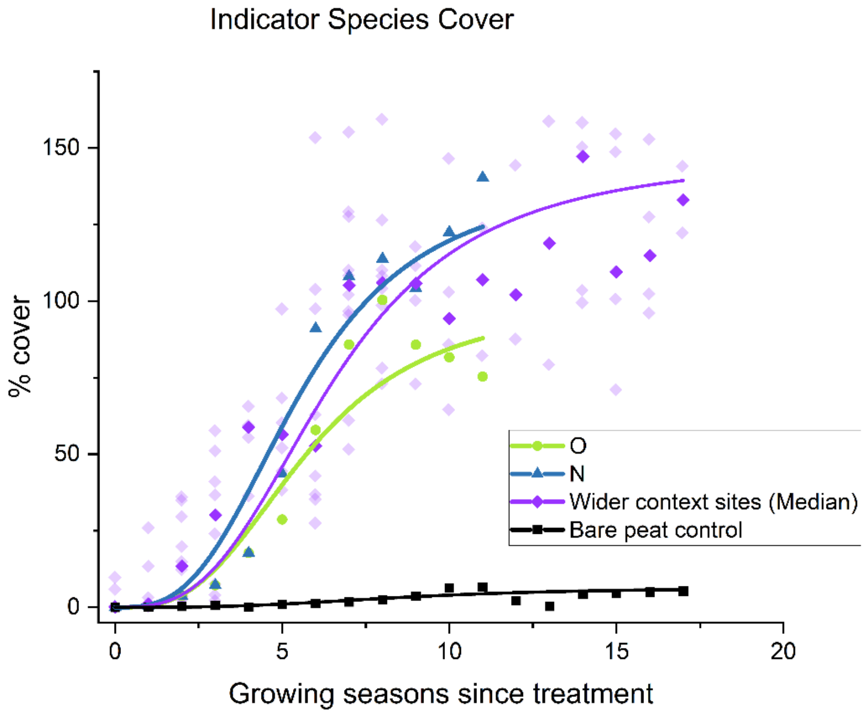


Figure 4: Total cover of all indicator species at bare peat sites, expressed as mean cover for quadrats within each study site.
Data from wider context sites are presented as the median of the mean values from each wider context site

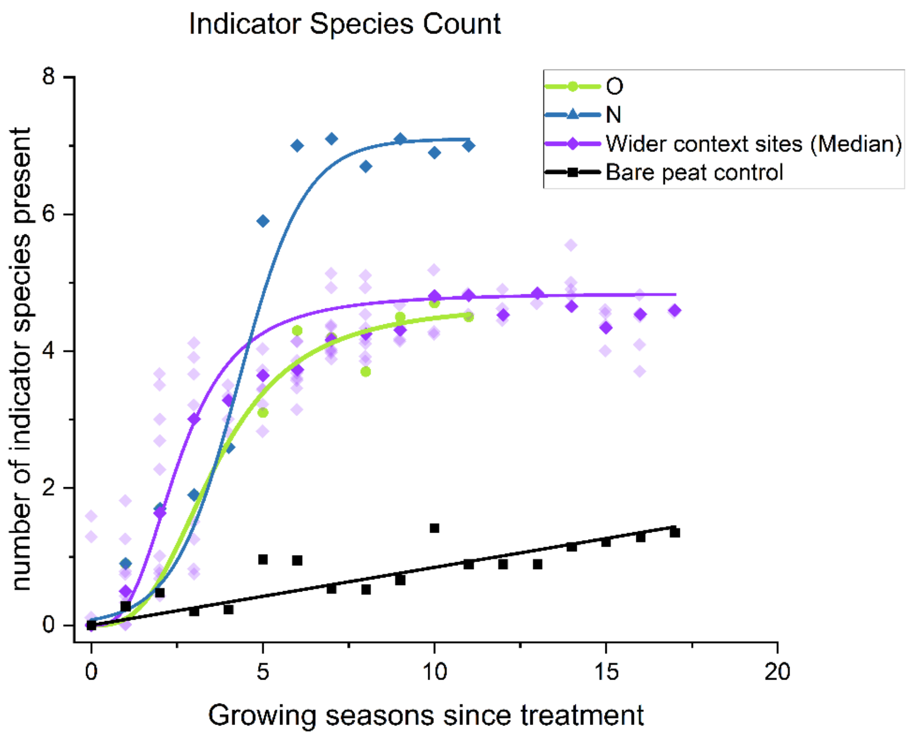


Figure 5: Number of indicator species present at bare peat sites, expressed as the mean count of indicator species in quadrats within each study site.
Data from wider context sites are presented as the median of the mean values from each wider context site

4.1.4. Vegetation composition at field labs O and N
For the first five years of monitoring a single set of 10 quadrats (located within field lab O, immediately adjacent to N) were used to monitor vegetation composition across both field labs O and N. In 2015 (5^{th} year after revegetation), 10 new quadrats were installed within field lab N; the original quadrats were continued as the quadrats for field lab O. The results presented here use the data from the original quadrats for the first five years for both field labs; for field lab N these initial years are illustrative only (although it is likely that the trends were similar in these years).

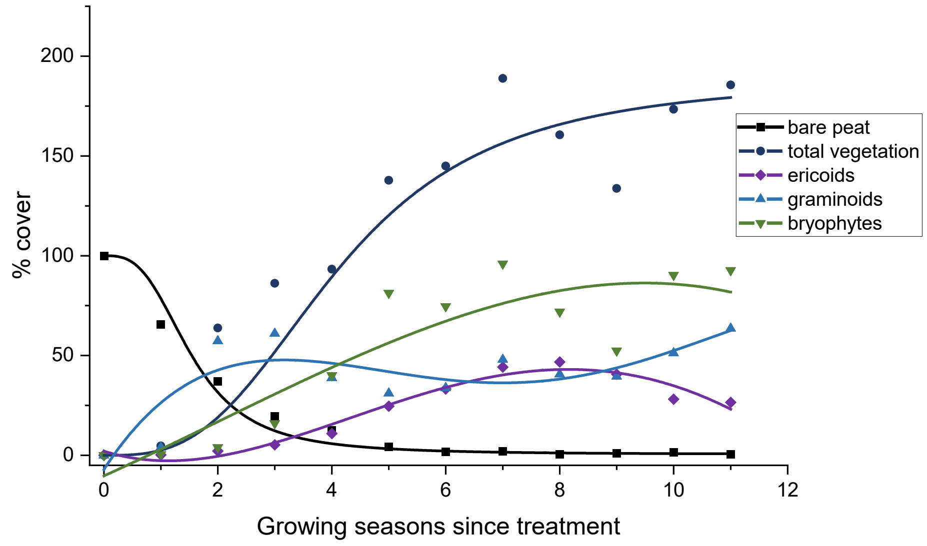
At O and N, the initial increase in vegetation following treatment was dominated by graminoids, peaking at ~50% in the second and third growing seasons after initial treatment (Figure 6).

At O, these were then succeeded by bryophytes and ericoids, which peaked at around 90% and 50% respectively, around 8 growing seasons after initial treatment. In the subsequent years, bryophytes stabilised and ericoids appeared to decline while graminoids appeared to increase again. By the end of monitoring, the vegetation community was dominated by bryophytes (~90%) and graminoids (~60%), with ericoids covering ~25%.

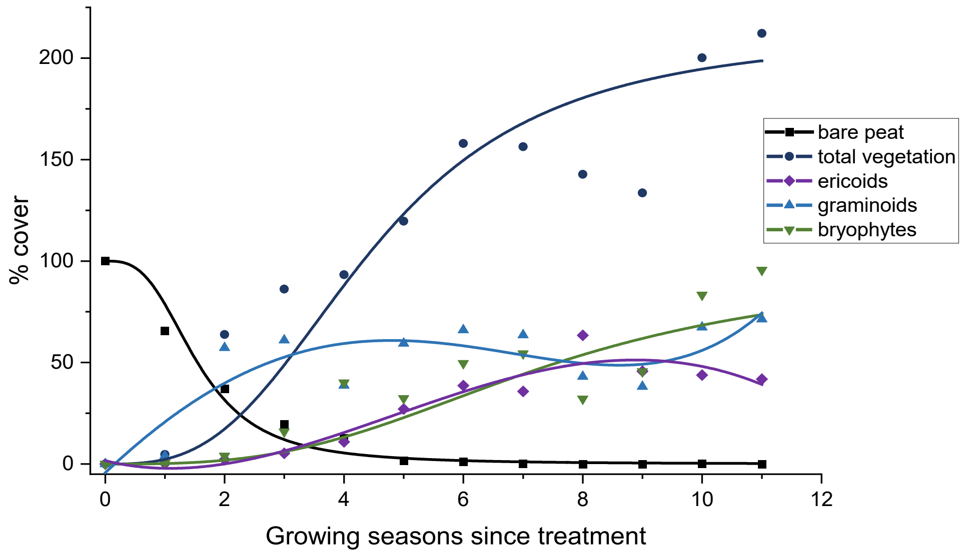
At N, the initial increase in graminoids cover stabilised at around 55%, with ericoids and bryophytes building more slowly. From years 6–8, ericoids, graminoids and bryophytes had similar % cover at around 50% each. By the end of monitoring, the vegetation community was dominated by bryophytes (~90%) and graminoids (~75%), with ericoids appearing to decline slightly to ~45%.

At the wider context sites the initial increase in vegetation following treatment was dominated by graminoids, peaking at ~60% in the fourth and fifth growing seasons after initial treatment (Figure 6). These then stabilised slightly below this level, before declining gradually to ~30% 17 years after initial treatment. Bryophytes succeeded graminoids around year 6 and remained the most extensive category to the end of monitoring, at around 90%. Ericoids increased gradually before stabilising at ~50% from years 13–17.

Vegetation categories at O



Vegetation categories at N



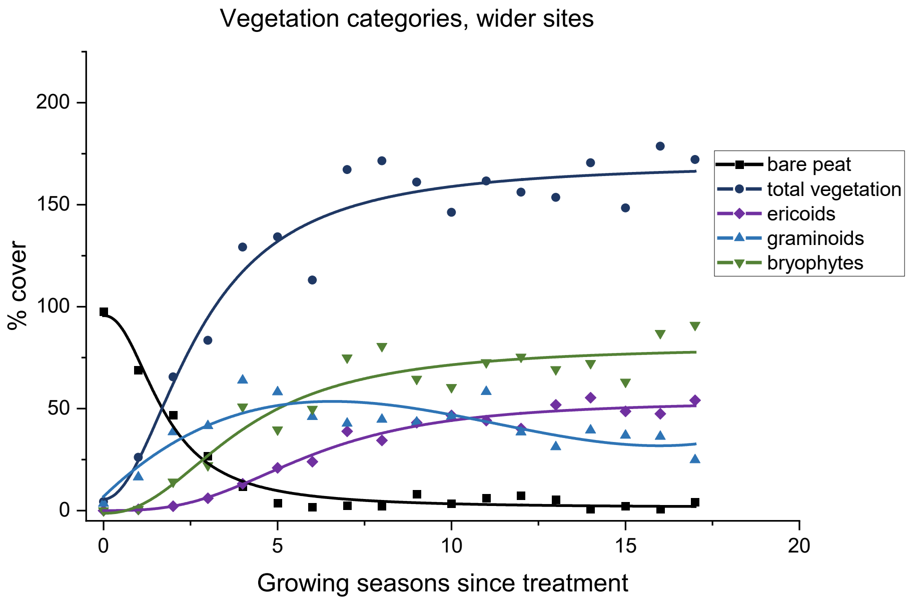


Figure 6: Vegetation community composition at bare peat study sites.
Total vegetation cover may >100% due to layering of different categories' canopies

4.1.4.1. Ericoids

As shown in Figure 7, at field lab O, almost all of the ericoid cover was *Calluna vulgaris* throughout the monitoring period. There was an apparent decline from years 8–11. In year 11, 57% of the *Calluna vulgaris* present was recorded as appearing to be dead.

At N, the ericoid cover comprised a relatively even mix of *Calluna vulgaris* and *Vaccinium myrtillus*. In years 8–11, *Calluna vulgaris* appeared to decline slightly; *Vaccinium myrtillus* stabilised. In year 11, 32% of all *Calluna vulgaris* present was recorded as appearing to be dead.

At the wider context sites *Calluna vulgaris* was the main ericoid present, stabilising at ~40% cover. *Vaccinium myrtillus* cover increased gradually throughout the monitoring period, reaching ~10% by the end of monitoring (17 years).

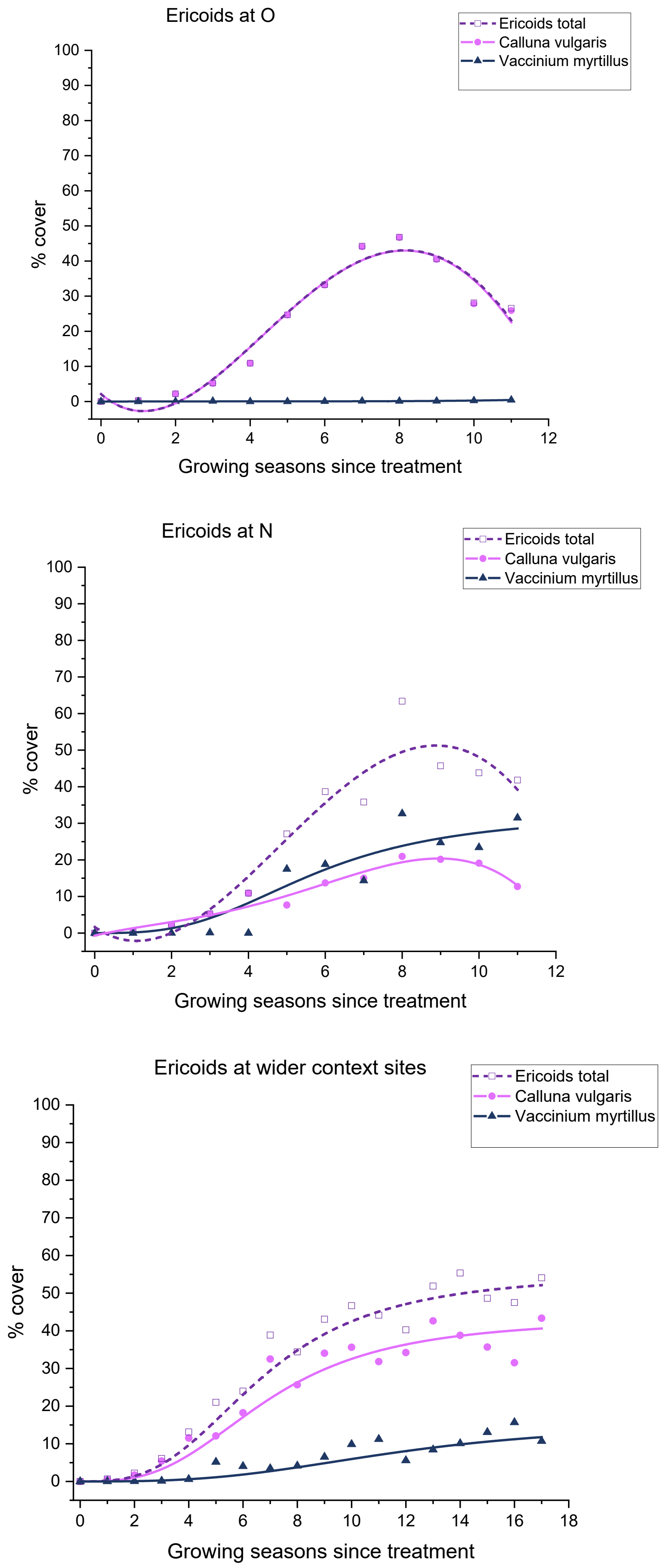


Figure 7: Ericoids cover at bare peat study sites showing total cover and cover of dominant individual species. The apparent decline at the start of some of the curves is an artefact of the logistic curve algorithm.

4.1.4.2. Graminoids

At field labs O and N, pioneer graminoids were dominated in years 1–5 by *Agrostis spp* (*Agrostis castellana* was included in the nurse crop seed mix) and *Deschampsia flexuosa. Festuca* spp developed some cover in these years (*Festuca ovina* was included in the nurse crop seed mix) before declining to ~1% in years 6–11 (Figure 8).

At field lab O, these were succeeded by *Eriophorum angustifolium* in years 6–10, but this appeared to decline in years 9–11, re-succeeded by *Deschampsia flexuosa* with the latter becoming the dominant species by year 11.

At N, *Agrostis spp* declined to ~3% in years 6–11; *Deschampsia flexuosa* was variable but declined in years 2–8 before increasing rapidly in years 9–11, becoming the strongly dominant species by the end of monitoring (~65%). *Eriophorum angustifolium* increased to ~25% in year 7 but then declined to ~3% by the end of monitoring.

Agrostis spp were not surveyed to species level. It was therefore not possible to determine whether the *Agrostis* recorded in the later years were *Agrostis castellana* (as introduced in the nurse crop seed mix) or *Agrostis capillaris* (a common generalist grass commonly found in moist grasslands, meadows and disturbed areas).

At the wider context sites, the initial increase in graminoid cover was dominated by *Agrostis* spp, *Festuca* spp (both included in the nurse crop seed mix) and *Deschampsia flexuosa* (included in the nurse crop seed mix at low rates at some but not all sites). *Agrostis* spp and *Festuca* spp cover declined to ~1% in years 6–17. *Deschampsia flexuosa* cover was variable in years 4–17, fluctuating around 10–35%. *Eriophorum angustifolium* and *Eriophorum vaginatum* each increased to ~8% in years 7–13 but then declined to ~2% by the end of monitoring.

Lolium perenne (another species included in the nurse crop seed mix) and *Molinia caerulea* (a potential species of concern due to its tendency to dominate at the expense of other species) did not establish in any quadrats at O, N or the wider context sites.

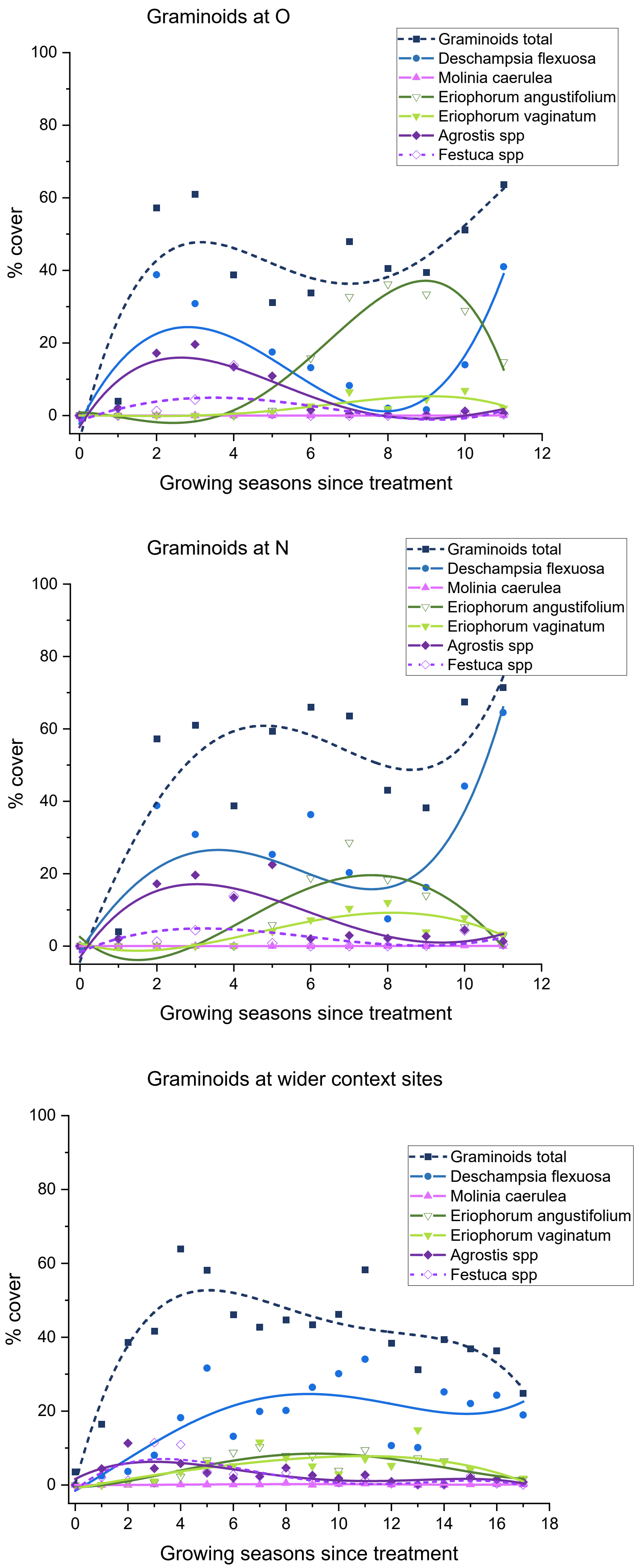


Figure 8: Graminoids cover at bare peat study sites showing total cover and cover of dominant individual species. The apparent decline at the start of some of the curves is an artefact of the logistic curve algorithm.

4.1.4.3. Bryophytes

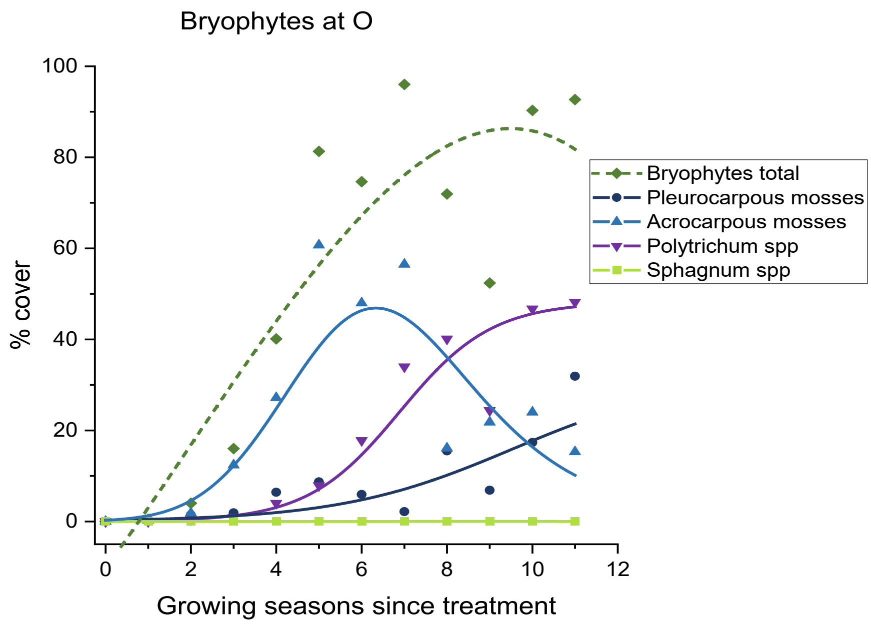
At field lab O, bryophyte cover was dominated by acrocarpous mosses for the first seven growing seasons. These then declined – succeeded by *Polytrichum* spp. Pleurocarpous mosses started to increase towards the end of the monitoring period. *Sphagnum* spp remained below 1% throughout the monitoring period (Figure 9).

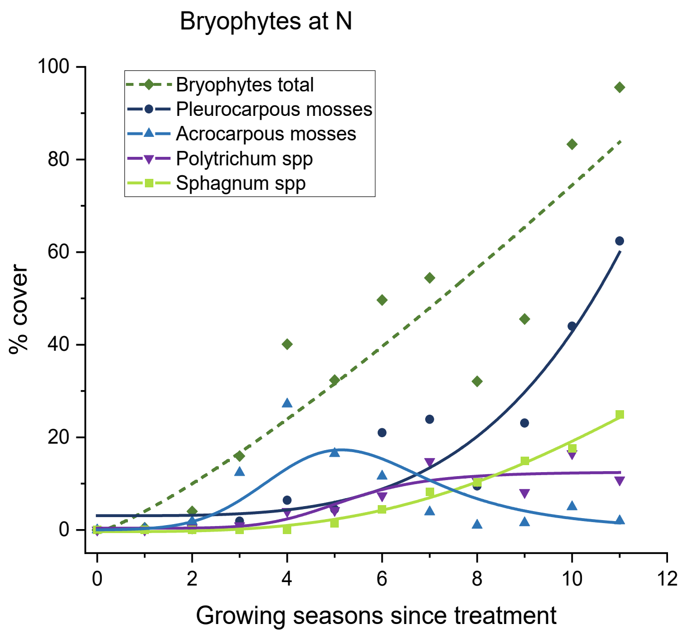
At N, bryophyte cover was dominated by acrocarpous mosses for the first five growing seasons. These then declined – succeeded by pleurocarpous mosses. *Polytrichum* spp increased in years 4–7 before stabilizing at ~10% cover. *Sphagnum* spp were introduced in year 5 and increased steadily to the end of the monitoring period. By the end of monitoring, pleurocarpous mosses were dominant (~60), followed by *Sphagnum* spp (~25% and *Polytrichum* spp (~10%).

At the wider context sites bryophyte cover was dominated by acrocarpous mosses for the first four growing seasons. Acrocarpous mosses cover stabilised at around 20% and then gradually declined – succeeded by pleurocarpous mosses. *Polytrichum spp* increased gradually in years 4–17. By the end of monitoring, pleurocarpous mosses were dominant (~60), followed by polytrichum spp and acrocarpous mosses (both ~10%). *Sphagnum* spp remained below 1% throughout the monitoring period.

Additional monitoring of *Sphagnum* spp on the Kinder plateau, as reported in Benson *et al* (2022), show that *Sphagnum* growth rates on undulating ground were approximately four times faster than those on hag tops. The data displayed in Figure 9 are from a range of topographic positions including undulating ground and hag tops, with the intention of representing the mini-catchment as a whole. In some areas – most notably within flow pathways – *Sphagnum* spp cover may be significantly higher than reported here.

Sphagnum spp cover was comprehensive in the wetter areas of mini-catchment N by the end of monitoring, with cover approaching 100% in some areas of low-lying undulating ground and flow pathways (see Figure 10, Figure 11). These areas were not included in the 10 quadrats installed for use in the monitoring reported here. They were included to some extent in Benson *et al* (2022), and may be important when considering impacts on functioning of the mini-catchment in terms of water table depth, soil moisture, overland flow generation, streamflow and water chemistry.





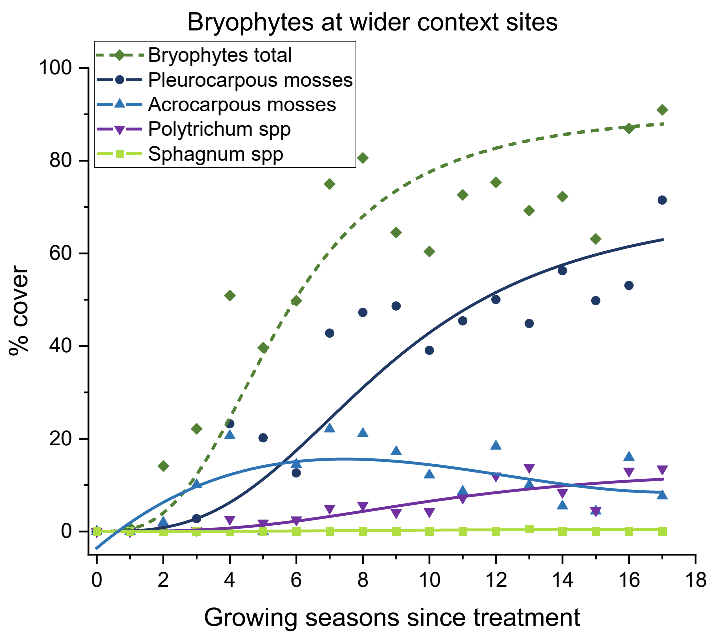


Figure 9: Bryophytes cover at bare peat study sites showing total cover and cover of dominant species group

Figure 10: Fixed point photography showing growth of *Sphagnum* plugs from 2018 (on the left) to 2021 (on the right)

Figure 11: *Sphagnum* mosses were planted as mixed-species plugs at mini-catchment N and have grown to cover large areas of undulating ground and streams, approaching 100% cover in some places

Further information is available in Benson *et al* (2022) regarding the relative success of the 11 different *Sphagnum* species planted at field lab N, including detail of which species grew best in which micro-topographic positions. In summary, *Sphagnum fallax* and *Sphagnum palustre* were the dominant species in terms of mean cover overall; *Sphagnum cuspidatum* grew well on the gully floors and *Sphagnum subnitens, Sphagnum papillosum* and *Sphagnum fimbriatum* were more successful in the slightly drier topographic positions.

Within field lab N, all *Sphagnum* was planted as plug plants; a range of different propagation methods were used in the surrounding areas (beads, gel and transplanted clumps) – the relative success of each method is also detailed in Benson *et al* (2022). In summary, all four application methods were successful in that *Sphagnum* survived and grew; mean cover in 2020 was greatest from plugs, but plugs were the most expensive method so the most cost-effective method appeared to be gel (further monitoring required to confirm this finding).

Results from the rough walkover survey of *Sphagnum* in the flow pathways (see Figure 12, Figure 13, Table 6) showed that *Sphagnum* cover increased from 16% in February 2018 to 85% in March 2022 (~18 percentage points per year). Total flow pathway area within the catchment was estimated as 598 m^2. *Sphagnum* covered 96m^2 within this area in 2018, increasing to 506 m^2 by 2022 – an increase of 410 m^2 (305% increase) over four years. Median % *Sphagnum* cover at all flow pathways was 5% in 2018, increasing to 98% in 2022, reflecting the anecdotal observation that the majority of stretches were approaching 100% *Sphagnum* cover by 2022. These data are estimates only and are not as reliable as those from quadrat surveys.

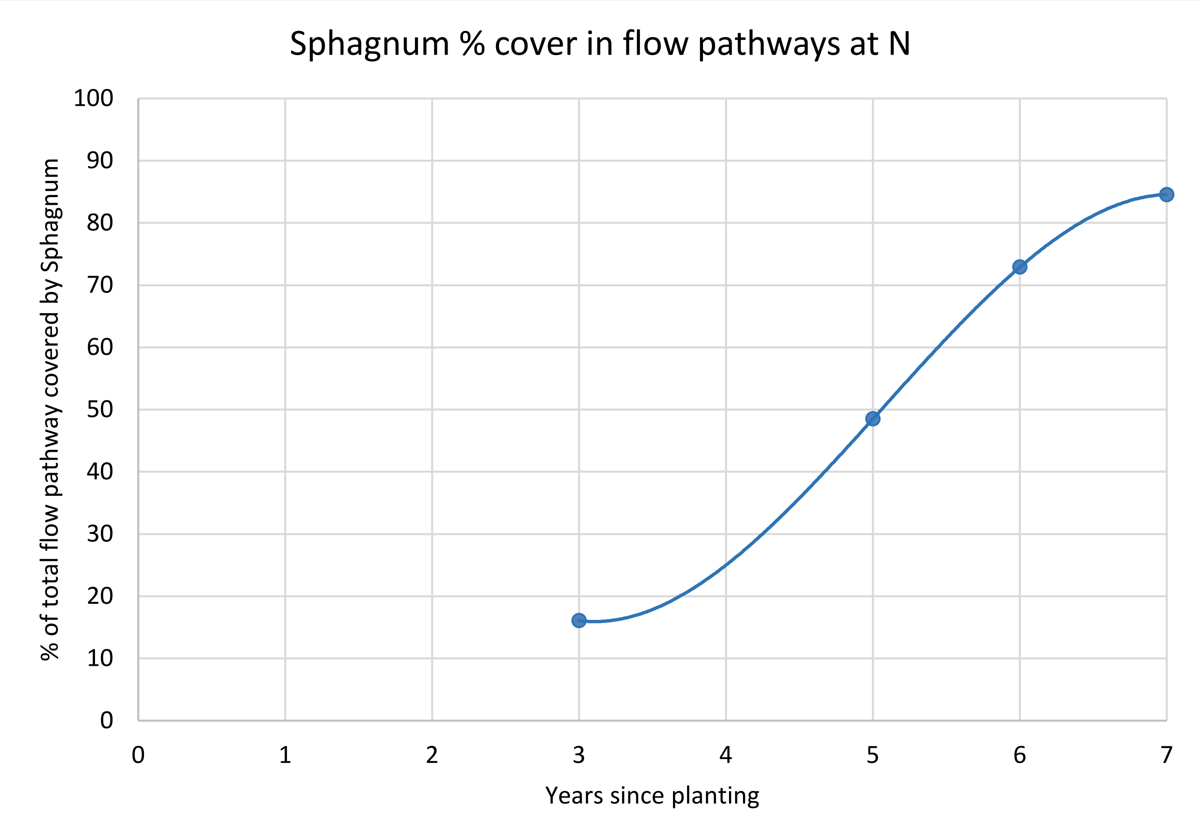


Figure 12: Development of *Sphagnum* cover within the flow pathways at field lab N on Kinder Scout. *Sphagnum* plugs were planted generally in the catchment in 2015 and then at high density in the flow pathways in 2018. The 2018 datapoint in this graph is from a survey prior to the 2018 planting

Table 6: Development of *Sphagnum* cover within the flow pathways at field lab N on Kinder Scout Sphagnum plugs were planted generally in the catchment in 2015 and then at high density in the flow pathways in 2018

Year	Total flow pathway area (m^2)	*Sphagnum* area (m^2)	*Sphagnum* % cover
2018	598	96	16
2020	598	289	52
2021	598	435	76
2022	598	506	85

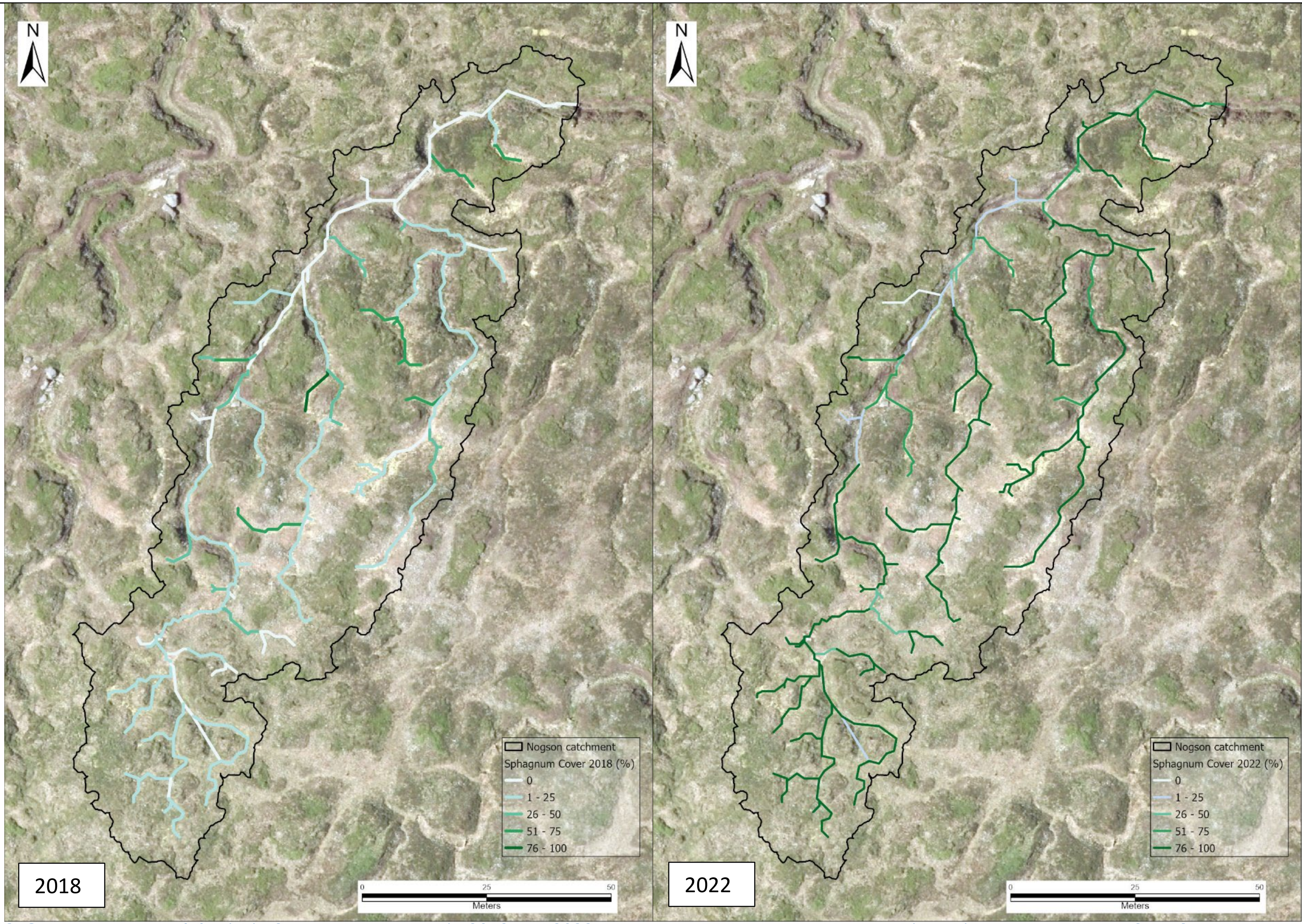


Figure 13: Sphagnum cover (%) within flow pathways at N in 2018 and 2022. More than 75% cover had been achieved in most stretches of the flow pathway network by 2022

4.1.4.4. Invasive species

At both field labs O and N and the wider context sites, invasive species presence in quadrat data was negligible throughout monitoring, at around 1.5–3% at O/N and 0.5–1.5% at the wider context sites (predominantly *Chamaenerion angustifolium* at all sites). Areas of extensive *Chamaenerion angustifolium* were observed in both field lab site mini-catchments outside of the quadrats, generally on hag tops (see photo in Figure 14).

Figure 14: Top: an area of extensive *Chamaenerion angustifolium* within the N mini-catchment but not captured within quadrat data.
Bottom: *Picea* trees are starting to establish within the monitoring area. Unlike *Salix* and *Betula*, which remain stunted, the *Picea* appear to continue growing

4.1.4.5. Trees

At both field labs O and N, tree species presence in the quadrat data was negligible throughout monitoring at around 1–2.5% (predominantly *Salix* spp). Areas of extensive *Salix* spp were observed in both mini-catchments outside of the quadrats.

Within the quadrats at O, the maximum height of tree species recorded peaked at ~450 mm in year 8 and then declined to ~300 m in year 11. The mean of tree heights recorded stabilised at ~200 mm in year 8 and did not increase further (Table 7).

Within the quadrats at N, the maximum height of tree species recorded peaked at ~750 mm in year 9 and then declined to ~600 mm in year 11. The mean of tree heights recorded stabilised at ~300 mm in year 9 and did not increase further.

These tree height data were consistent with anecdotal observations from across the mini-catchment outside of the quadrats.

Table 7: Tree heights at sites O and N on Kinder Scout
Observed tree heights appeared to reach a 'natural' maximum around 9 years after initial treatment before then stabilising or starting to decline

Years since treatment	O		N	
	Max. tree height (mm)	Mean (of 4 max.) tree height (mm)	Max. tree height (mm)	Mean (of 4 max.) tree height (mm)
0	NR	NR	NR	NR
5	170	75	200	104
8	460	194	180	716
9	400	191	760	318
10	370	173	620	304
11	300	167	600	316

No conifers were recorded within the quadrats. Several *Picea* spp (Sitka spruce) were observed within both mini-catchments, some of which were in excess of 1.5m in height by year 11 (see Figure 14). Most of these were subsequently removed by the National Trust.

At the wider context sites tree species presence in quadrat data was negligible throughout monitoring the monitoring period, remaining less than 0.5%.

4.1.5. Common Standards Monitoring at O

Of the primary 3 criteria for a site achieving favourable condition (bare peat cover should be less than 10%; at least 50% of the vegetation present should be comprised of at least 3 indicator species; there should be at least 6 indicator species present), only the bare peat criterion was met at at least 90% of quadrats (from year 7 onwards); the other 2 were not met at any point during the monitoring period (Figure 15). Although there were at least 6 indicator species present at only ~10% of quadrats in year 11, there were at least 5 indicator species present at 90% of quadrats in year 11. While this is not an official criterion, it may be seen as progression towards achieving the official criterion.

Most other criteria were met throughout the monitoring period, although the criterion that ericoids should not exceed 75% total cover was only just above the 90%-of-quadrats threshold. The criterion that *Holcus lanatus* + *Agrostis capillaris* should be less than 1% cover was uncertain. *Agrostis* spp were not surveyed to species level and were simply recorded as *Agrostis* spp. It is likely that the *Agrostis* recorded in the first five years was *Agrostis castellana* (included in the nurse crop seed mix); this may have continued to be present at low levels throughout or may have been replaced by *Agrostis capillaris* (a common generalist grass commonly found in moist grasslands, meadows and disturbed areas). In the results presented, all *Agrostis* was assumed to be *Agrostis capillaris*), even in the early years when it was most likely *Agrostis castellana*. In terms of favourable condition assessment, this therefore produces conservative estimates. Using this method, the criterion that *Holcus lanatus* + *Agrostis capillaris* should be less than 1% cover was not met while the nurse crop species were dominant. Once these had declined, the criterion was met in years 7–9, but in years 10–11 it was not met due to small increases in both species. If *Agrostis* was excluded from this target, the target would have been met from year 4 onwards.

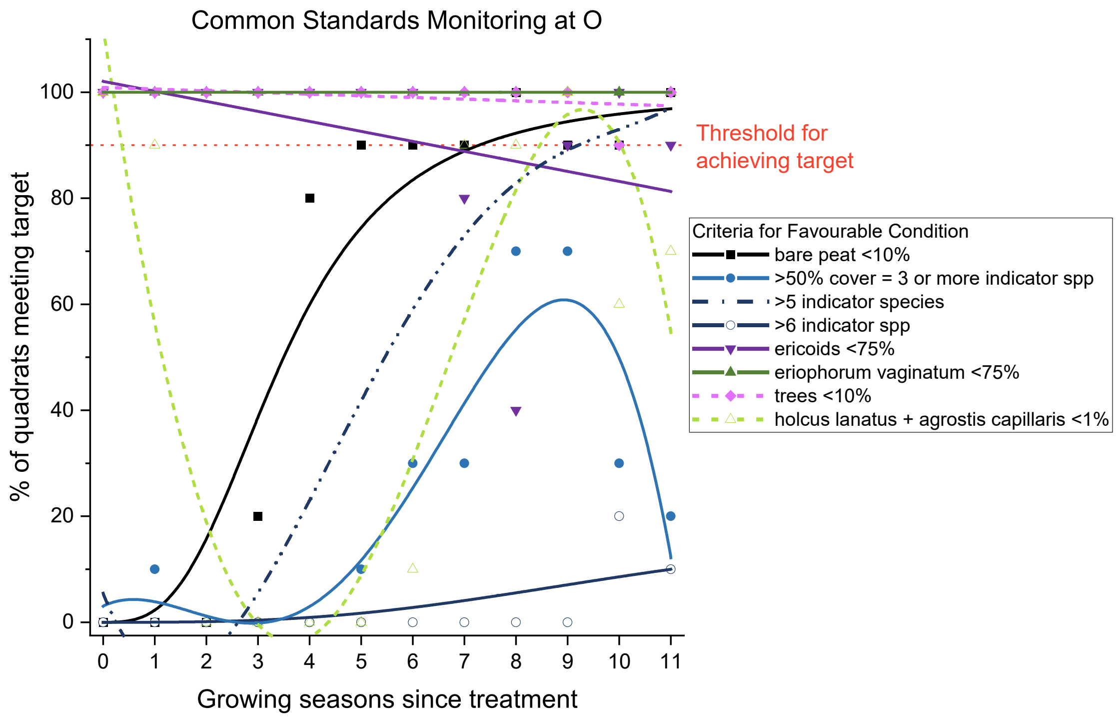


Figure 15: Common Standards Monitoring at study site O
Data points represent the percentage of quadrats meeting the criteria for achieving favourable condition in the years following treatment.

4.1.6. Common Standards Monitoring at N

Following revegetation and subsequent planting of *Sphagnum* mosses, the three principle criteria for favourable condition (bare peat cover should be less than 10%; at least 50% of the vegetation present should be comprised of at least 3 indicator species; there should be at least 6 indicator species present) were achieved for some/all of years 7–11 (Figure 16). Ericoids increased in cover beyond the 75% threshold in year 8 but, following their subsequent slight decline, this criterion was achieved in years 9–11. All other criteria were achieved, with the exception of *Holcus lanatus* + *Agrostis capillaris* covering less than 1% per quadrat. As described above, *Agrostis* was not surveyed to individual species level; all *Agrostis* recorded was assumed to be *Agrostis capillaris* (although it was likely *Agrostis castellana* in the initial years after treatment). As a result, less than 20% of quadrats met this target in most years following the application of nurse crop grass seeds as part of the initial treatment. It should be noted, however, that if *Agrostis* was excluded from the criterion, ~80% of quadrats would achieve this target in years 10–11.

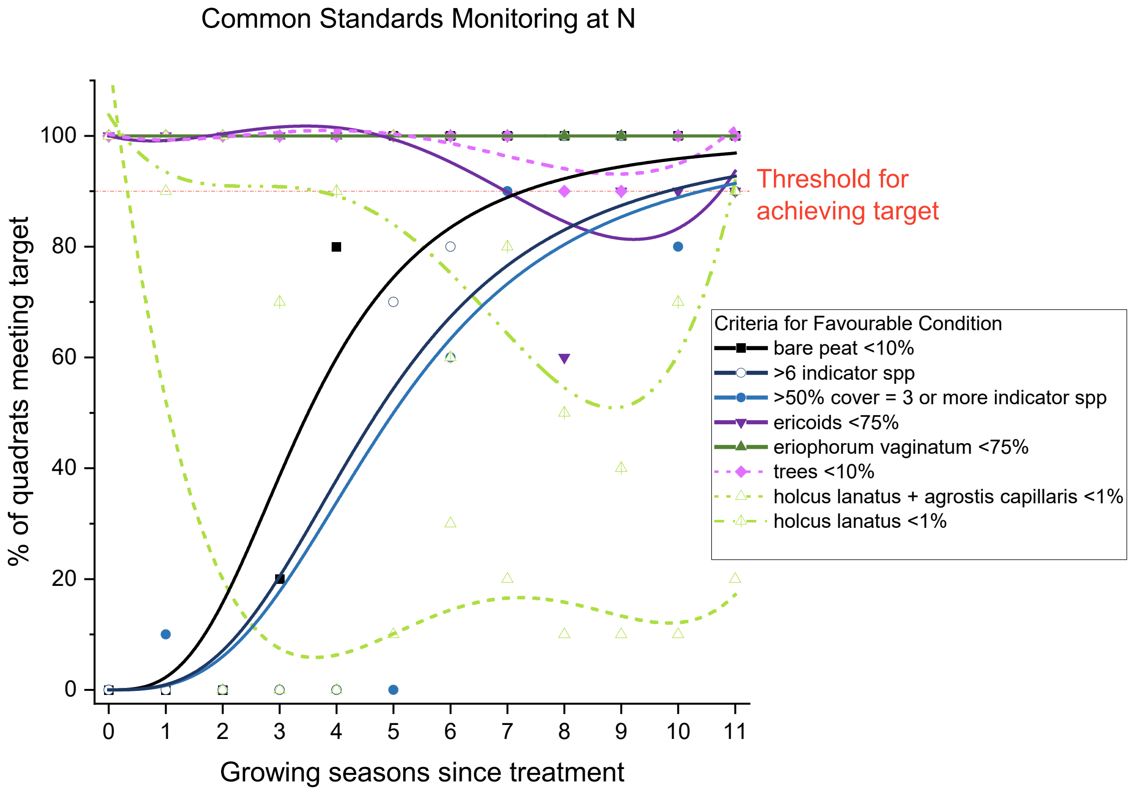


Figure 16: Common Standards Monitoring at study site N.
Data points represent the percentage of quadrats meeting the criteria for achieving favourable condition in the years following treatment.

4.1.7. Common Standards Monitoring at the wider context sites

The criterion of bare peat covering less than 10% was achieved at ~90% of quadrats from year 5 to the end of monitoring (Figure 17). The criteria that at least 6 indicator species should be present and at least 50% of the vegetation present should comprise at least 3 indicator species did not reach the threshold of 90% of quadrats at any point during the 17 years of monitoring. If the target for minimum number of indicator species present was reduced to from six to four, the 90% threshold would have been met from year 10 onwards.

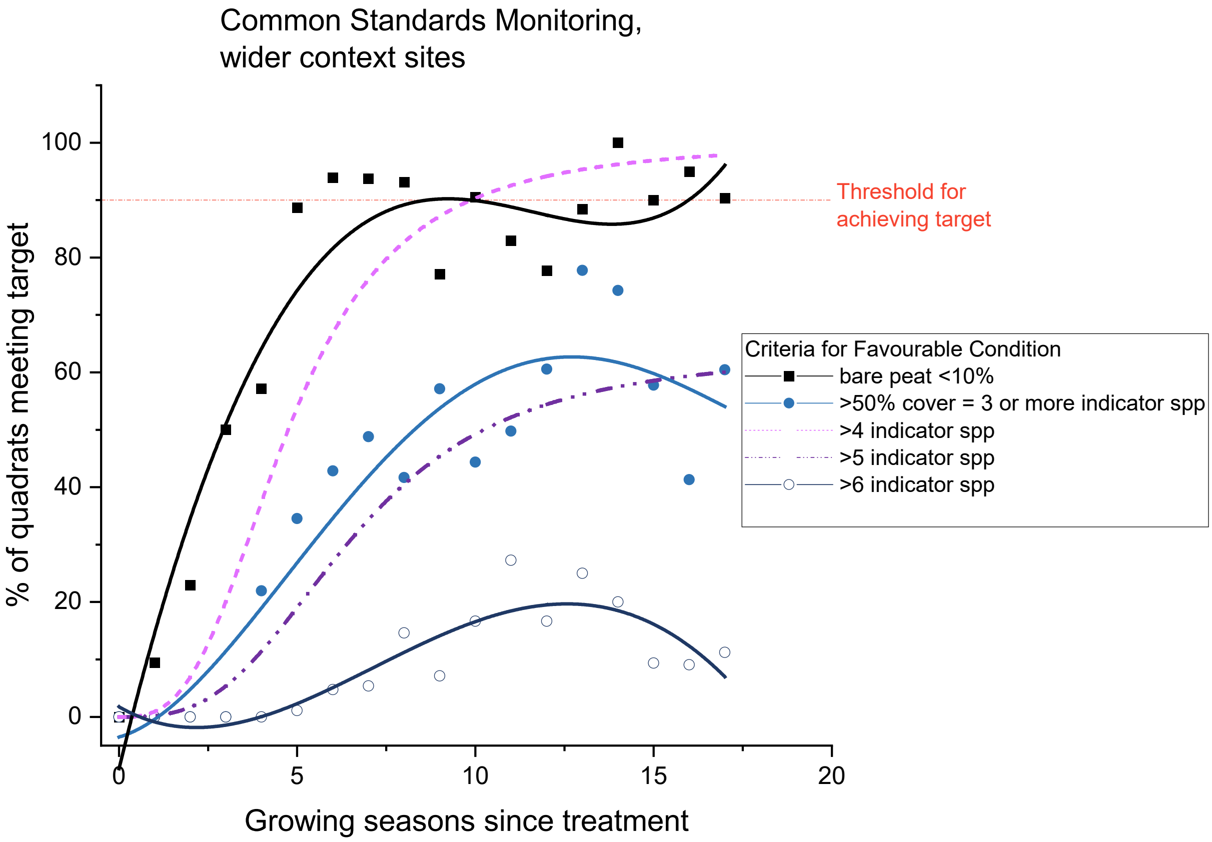


Figure 17: Common Standards Monitoring at the wider context sites.
Data points represent the percentage of quadrats meeting the criteria for achieving favourable condition in the years following treatment

4.2. Species dominated

4.2.1. *Calluna* dominated site

4.2.1.1. Vegetation composition

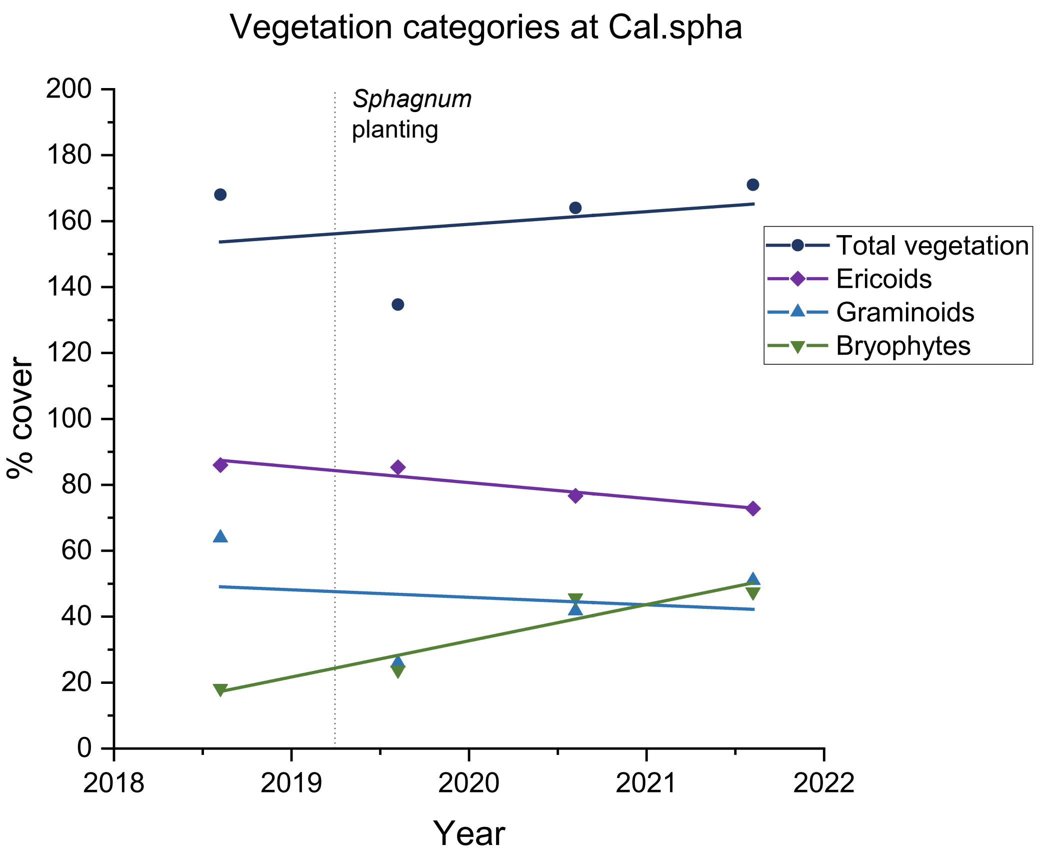


Figure 18. Vegetation category cover at Cal.Spha.
Expressed as mean cover of quadrats in 'cluster area' before treatment (2018) and after (2019–2021). Data points represent the mean of n = 10 in each case.

Figure 18 shows the categories of vegetation present in the *Calluna* site *Sphagnum* (Spha) treatment catchment since monitoring was started in 2018. The bryophytes category (which includes *Sphagnum* mosses) shows an increase of almost 30 percentage points cover over a four-year period. Graminoids and Ericoids show a small decline (13 percentage points; and 13 percentage points respectively). The total vegetation cover remained stable with a change of only 3 percentage points.

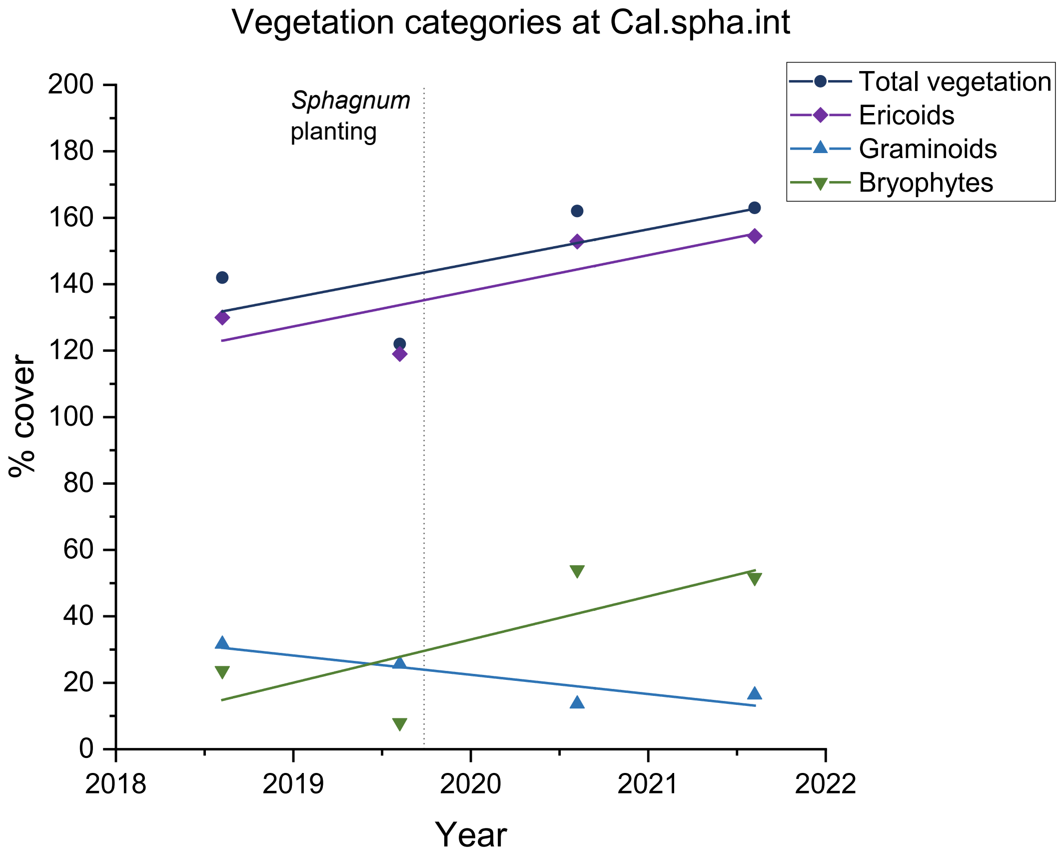


Figure 19. Vegetation category cover at Cal.Spha.Int
Expressed as mean cover of quadrats in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021). Data points represent the mean of n = 3 in each case.

Figure 19 shows the categories of vegetation present in the *Calluna* site *Sphagnum* treatment catchment intensive plot (Spha.int) since monitoring was started in 2018. The bryophytes category (which includes *Sphagnum* mosses) shows a similar increase of 28 percentage points cover over a four year period. Ericoids show an increase of 8 percentage points, while graminoids show a decrease of 16 percentage points. The total vegetation cover increased by 19 percentage points.

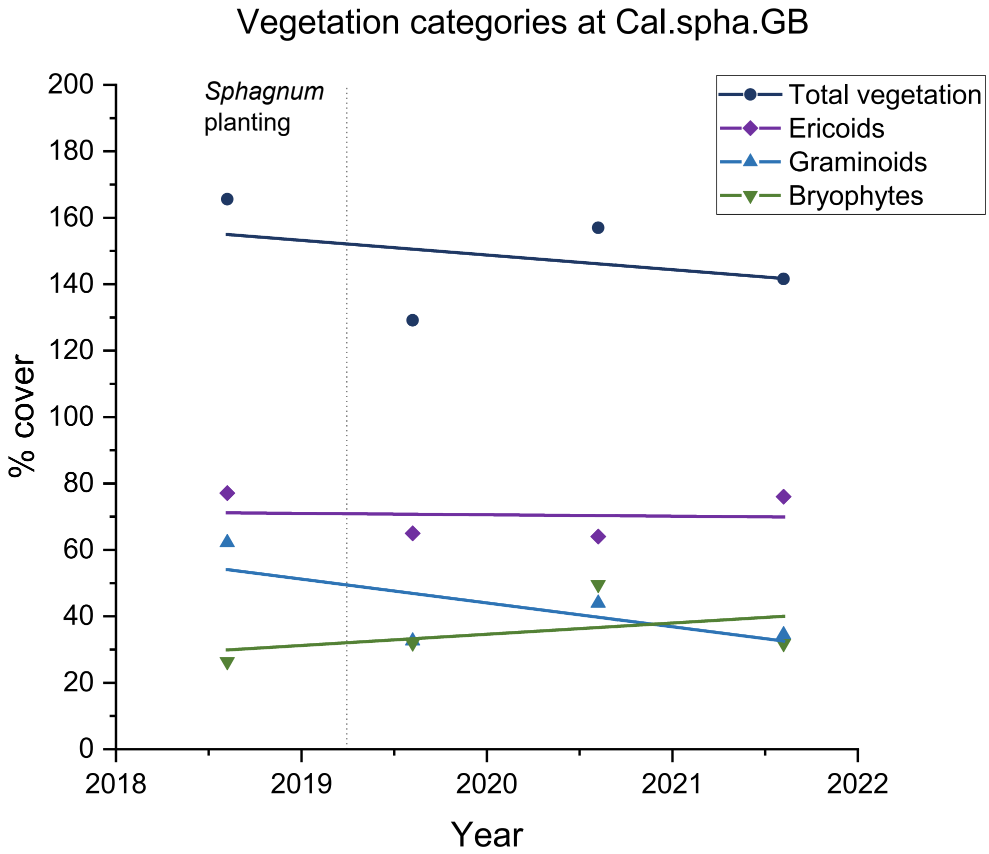


Figure 20. Vegetation category cover at Cal.SphaGB
Expressed as mean cover of quadrats in 'cluster area' before treatment (2018) and after (2019–2021). Data points represent the mean of n = 10 in each case.

Figure 20 shows the categories of vegetation present in the *Calluna* site *Sphagnum* and gully blocked (SphaGB) treatment catchment since monitoring was started in 2018. The bryophytes category (which includes *Sphagnum* mosses) shows an increase of 5 percentage points cover over a four year period. Graminoids and Ericoids show a decline (28 percentage points; and 2 percentage points respectively). The total vegetation cover showed a decline of 24 percentage points.

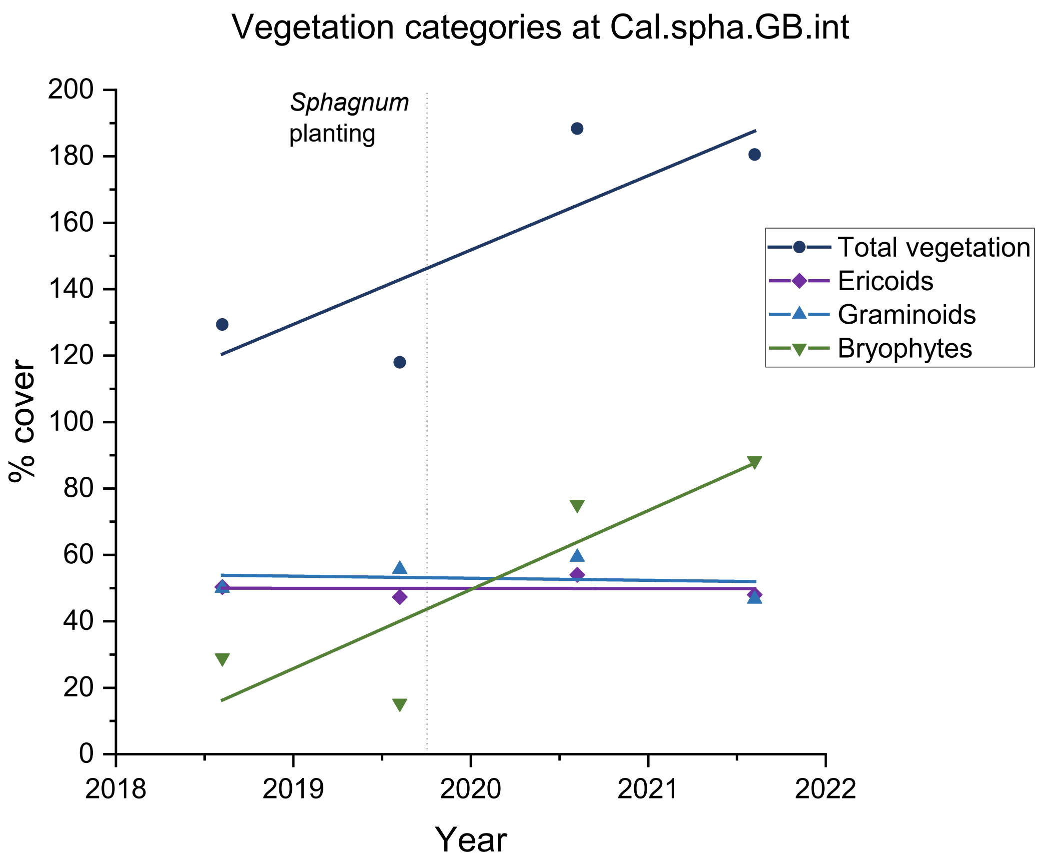


Figure 21. Vegetation category cover at Cal.SphaGB.Int
Expressed as mean cover of quadrats in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021). Data points represent the mean of n = 3 in each case.

Figure 21 shows the categories of vegetation present in the *Calluna* site *Sphagnum* and gully blocked treatment catchment intensive plot (SphaGB.int) since monitoring was started in 2018. The bryophytes category (which includes *Sphagnum* mosses) shows the greatest increase on the *Calluna* site of 59 percentage points cover over a four year period. Ericoids and graminoids remained stable, with only a very small decrease seen (5 percentage points and 4 percentage points respectively). The total vegetation cover increased by 51 percentage points.

4.2.1.2. *Calluna*

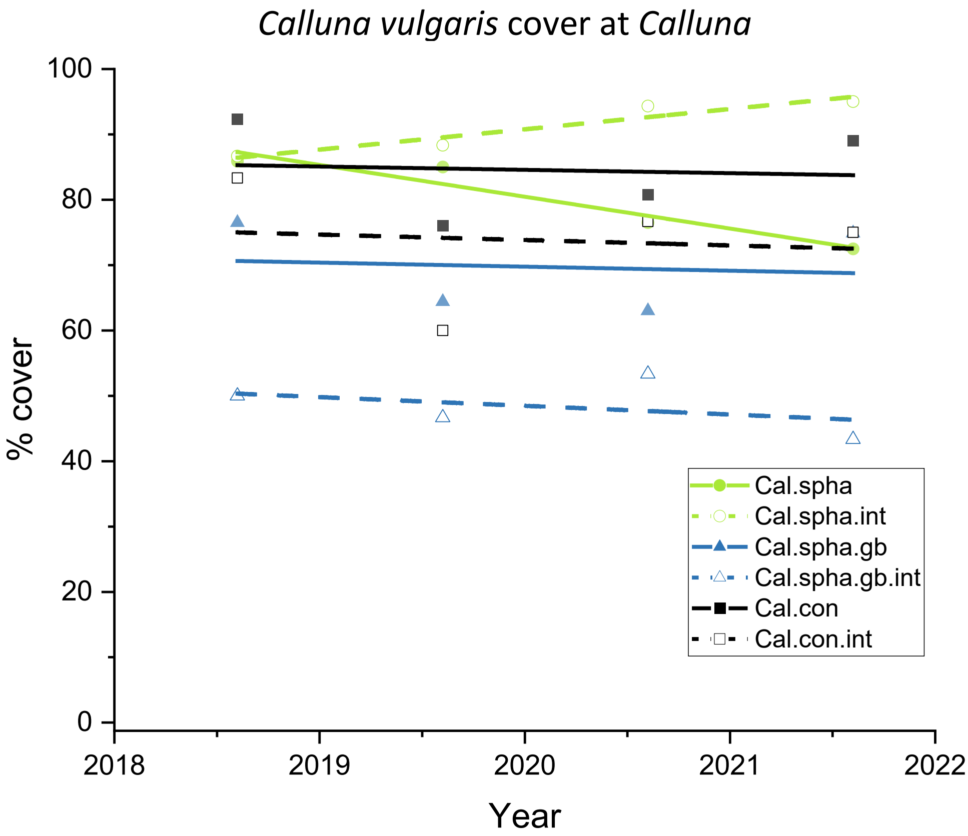


Figure 22. *Calluna* cover at *Calluna* sites.
Dominant species cover is expressed as mean cover in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 22 shows the raw data for *Calluna* cover across the monitored areas. Cover remained relatively stable in all locations, with the biggest change recorded being a decrease in cover by 14 percentage points in the Spha mini-catchment cluster areas. Conversely, an 8% point increase in *Calluna* cover was recorded in the intensive plots in that mini-catchment.

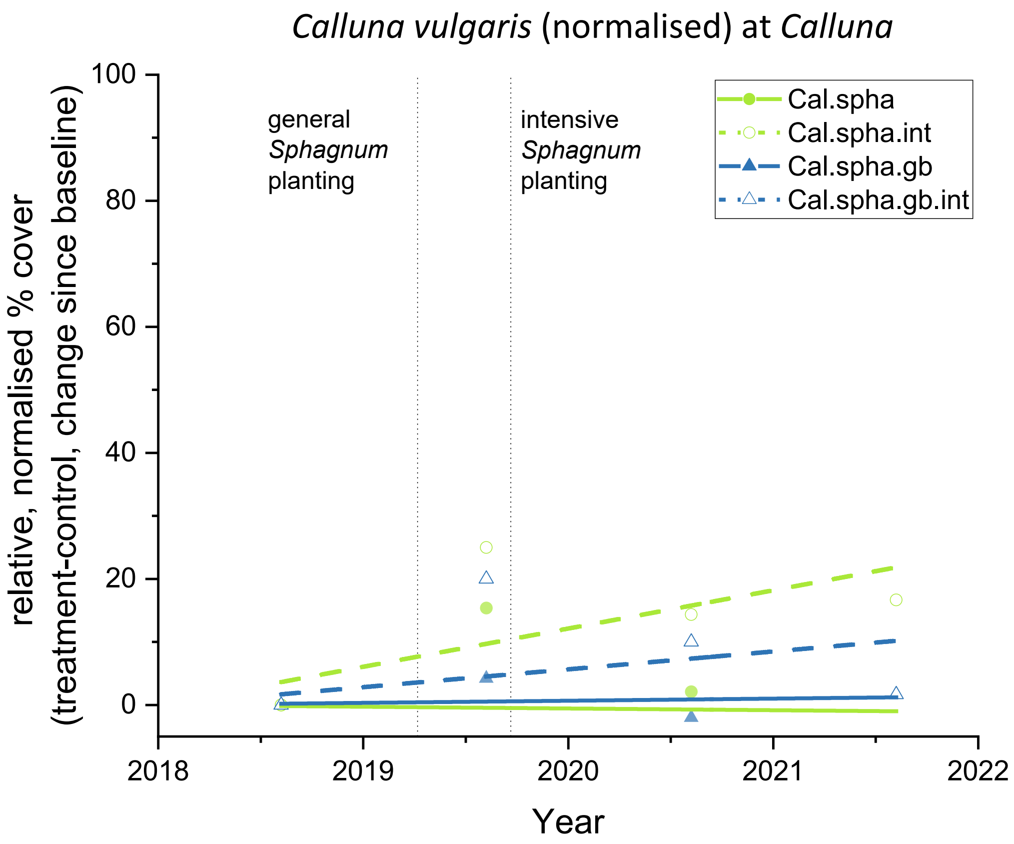


Figure 23. Relative *Calluna* cover at *Calluna* sites, normalised.
Normalised dominant species cover is expressed as mean cover in treatment areas minus mean cover in control areas for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 23 shows data relative to control (treatment-control) normalised to zero for the first year of monitoring in 2018. Only a small amount of change is seen, with an increase of cover in the intensive plots on the *Sphagnum* treated mini-catchment being most notable. However, for all sites the trend is unclear and fluctuation between surveys is more likely to be a result of recording error inherent in the survey method, than representative of a real change.

4.2.1.3. *Sphagnum*

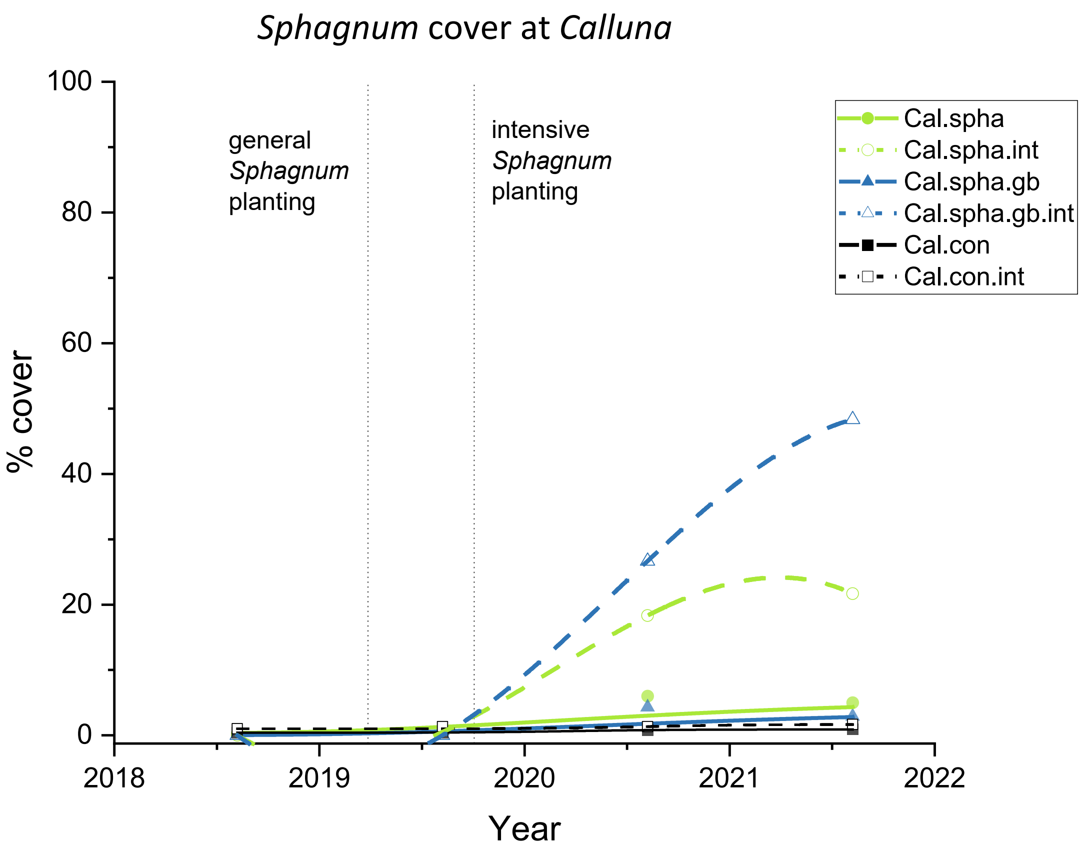


Figure 24. *Sphagnum* cover at *Calluna* sites.
Expressed as mean cover for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 24 shows raw data for *Sphagnum* cover across the monitored areas. Large increases in cover were recorded in intensive treatment sites in the years post-treatment. The SphaGB intensive plots showed an increase in *Sphagnum* cover from 0% in 2018 to ~48% by 2021 (see Figure 26 for example of plug growth in such a plot); whilst the Spha intensive plots showed an increase from 0% to 22% during the same period. The less intensively planted areas in the wider catchments by contrast showed a smaller increase from almost no *Sphagnum* present (0.3% cover in Spha catchment and 0% in all other areas), to around 5% cover. These figures fluctuated slightly throughout the recording period and this fluctuation may reflect recording error rather than real change.

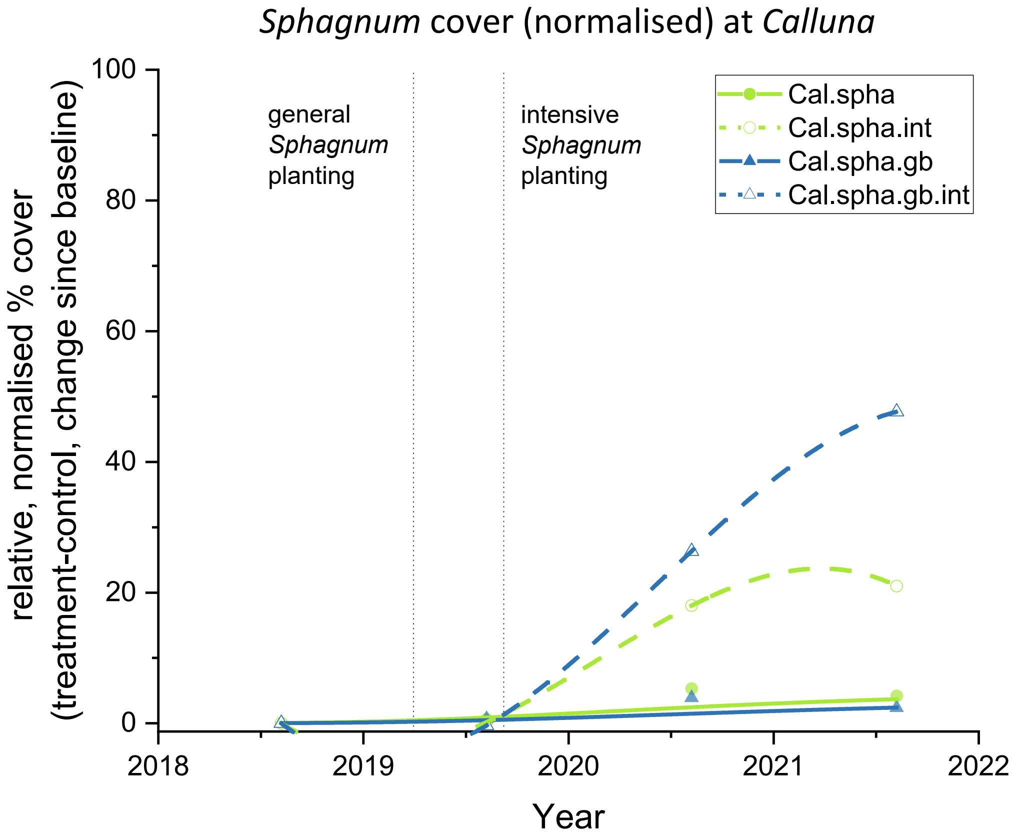


Figure 25. Relative *Sphagnum* cover at *Calluna* sites, normalised.
Expressed as mean cover in treatment areas minus mean cover in control areas for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 25 shows *Sphagnum* cover in the treated areas relative to the control site, normalised to zero for the first year of monitoring in 2018. The changes displayed are almost the same as the raw data, reflecting that the control areas contained very little *Sphagnum* at the start of monitoring, and this did not change by more than 0.7% cover during the four years of monitoring. Differences between the treatment areas (both Spha and SphaGB) and the control catchments were found to be statistically significant after the treatment had been applied, but not before (Table 8) reflecting that observed increase in *Sphagnum* cover in the treatment catchments. It was not possible to test for differences between the intensive plots due to the small sample size (n = 3), but the data show a clear difference (Figure 25).

Table 8. Statistical testing for *Sphagnum* cover at *Calluna* site
Values in the table are p-values resulting from the non-parametric Mann-Whitney U test for differences between the control and treatment areas. Significant differences at $p < 0.05$ are highlighted in grey; marginally significant values are lighter grey. Vertical line indicates time of treatment.

Cover type	Mini-catchment	2018	2019	2020	2021
Sphagnum	Cal.Spha	0.739	0.011	0.000	0.002
Sphagnum	Cal.SphaGB	0.280	0.015	0.002	0.009

Figure 26. *Sphagnum* plug growth in *Calluna* site intensive plot (SphaGB.Int.1) on 15/12/2021.

4.2.1.4. Bryophytes

Given the largest change in *Sphagnum* was observed in the intensive plots, the changes in other bryophytes in these areas should also be examined.

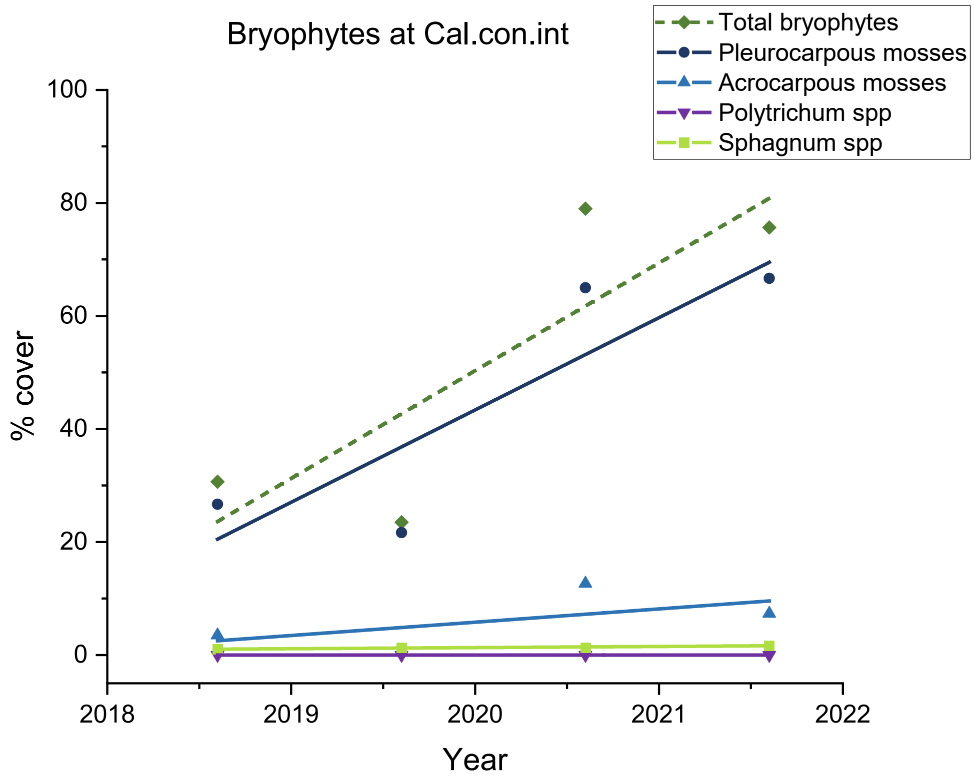


Figure 27. Bryophyte cover in *Calluna* site control catchment intensive plots.
Expressed as mean species cover in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 27 displays change at the control site intensive plot, and shows an increase in total bryophyte cover over the monitoring period; the majority of this accounted for by an observed increase in pleurocarpous (feather) mosses.

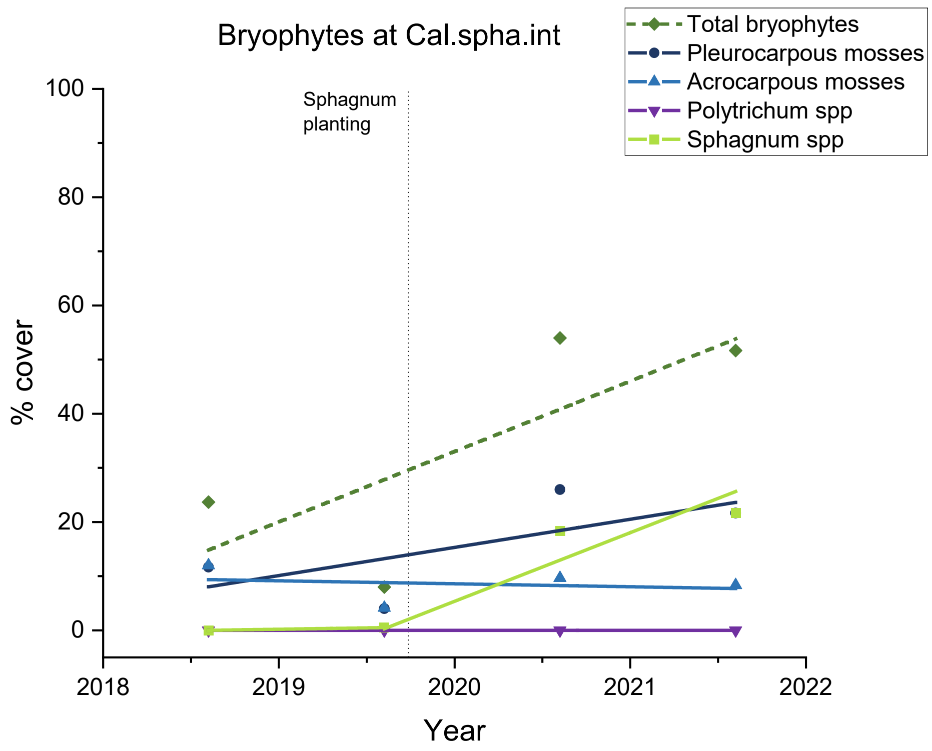


Figure 28. Bryophyte cover in *Calluna* site *Sphagnum* treatment catchment intensive plots. Expressed as mean species cover in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case

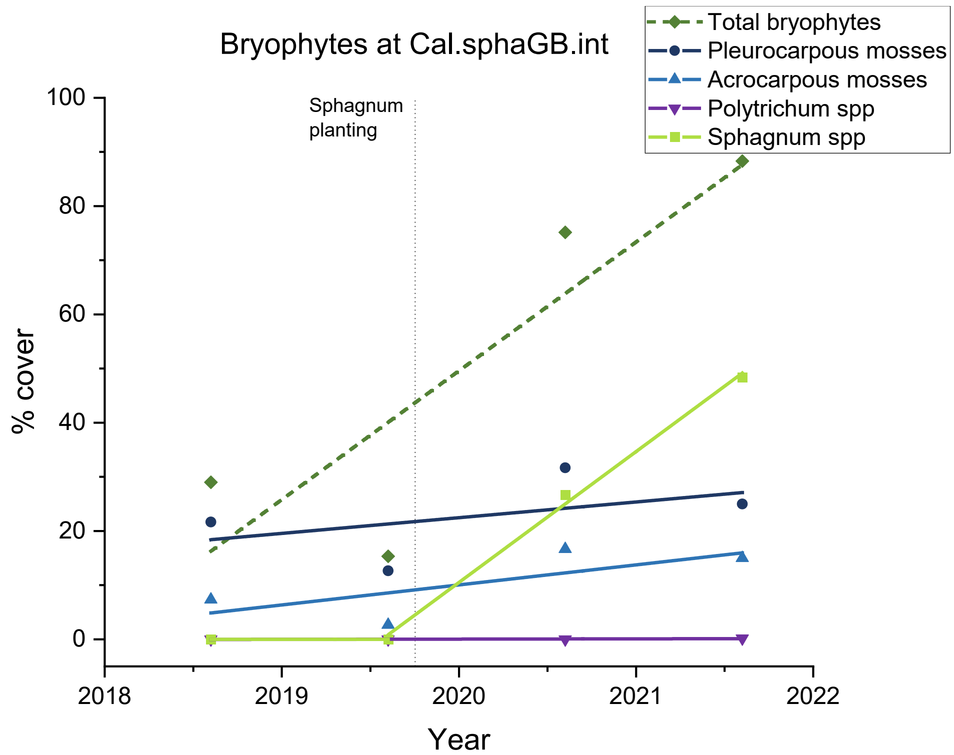


Figure 29. Bryophyte cover in *Calluna* site *Sphagnum* and gully blocked treatment catchment intensive plots.
Expressed as mean species cover in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

In contrast, Figure 28 shows that in the *Sphagnum* site intensive plots an increase in both *Sphagnum* and Pleurocarpous mosses accounted for the overall increase in bryophytes cover. Figure 29 displays changes at the *Sphagnum* and gully blocked site intensive plots; and shows the largest increase in bryophyte cover – in *Sphagnum* – accompanied by a slight increase in pleurocarpous and acrocarpous (cushion) mosses.

4.2.1.5. Indicator species

The percentage cover of indicator species, and indicator species count are presented for all mini-catchments and treatment types on the *Calluna* site. *Sphagnum* mosses were not recorded to species level, so it is known that the indicator species count for all sites where *Sphagnum* is present will be an underestimate. *Sphagnum* plugs introduced contained up to 11 species at the time of planting.

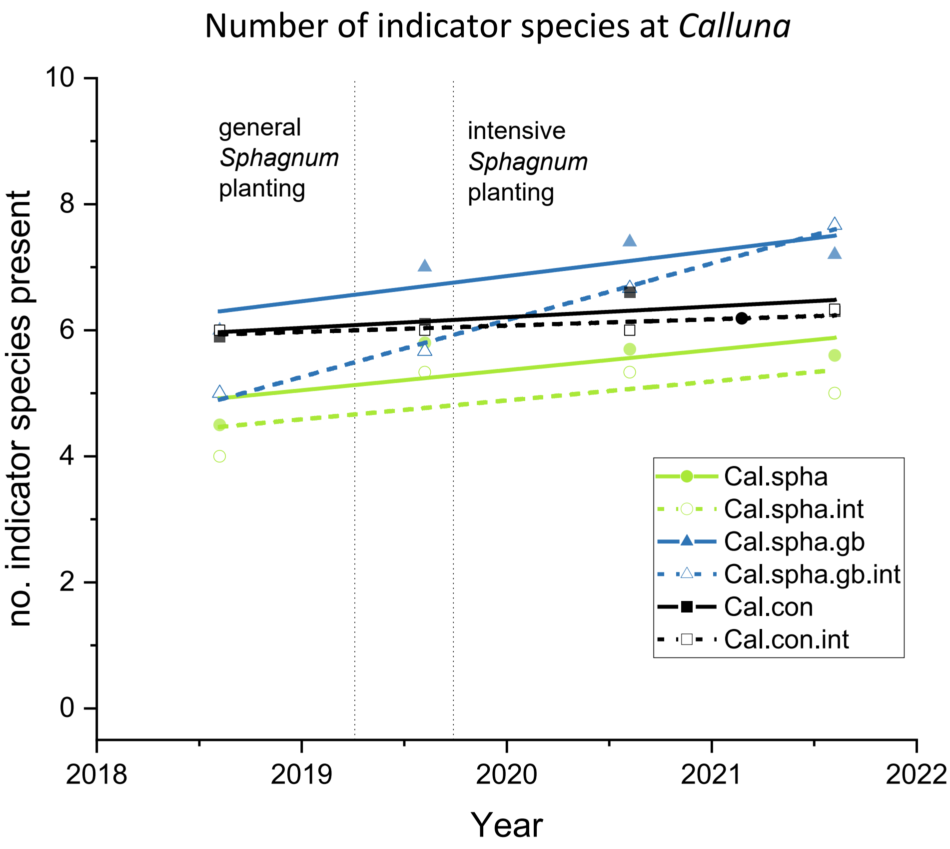


Figure 30. *Calluna* site indicator species count.
Expressed as mean species number in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 30 shows the mean number of indicator species recorded in each area throughout the four years monitored. The control catchment remains stable at ~6 indicator species during this time. The SphaGB intensive plots show the largest mean increase of 2.7 species, while the other treatment areas show a mean increase of ~1 species. It should be noted that since the only indicator species introduced was *Sphagnum* (counted here as one species), an increase of more than one indicator species in any given quadrat represents either a genuine increase caused by the colonisation of a new species, or an under-recording of those species already present in pre-treatment surveys.

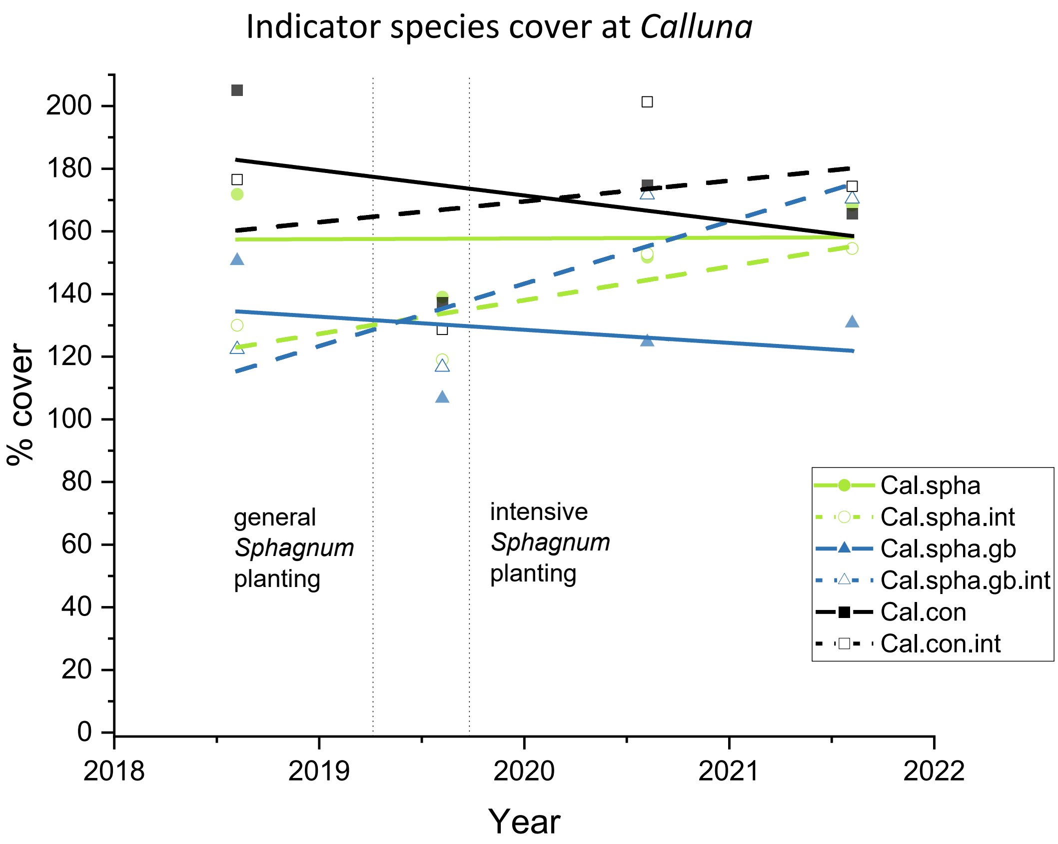


Figure 31. *Calluna* site indicator species cover.
Expressed as mean cover in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 31 shows mean indicator species cover. The intensive plots in both mini-catchments showed a slight upward trend in indicator species cover, whereas the control catchment showed a smaller upward trend, with the values for 2018 and 2021 being almost equal.
Little change was observed in the Spha cluster area; whereas the SphaGB and Con equivalents showed a slight decrease in mean indicator species cover over time. It should be noted that small changes in percentage cover over this short time period should be treated with caution due to the error inherent in the survey methodology.

4.2.1.6. Favourable condition at *Calluna* dominated site

Common Standards Monitoring criteria were applied to the intensive plots rather than the wider mini-catchment, to examine what factors are preventing them from reaching a condition that could be categorised as 'favourable', and progress towards this status made during the limited period of this experiment. Each figure features a threshold for the % of quadrats monitored that would need to meet each criterion in order for 'favourable' condition to be achieved.

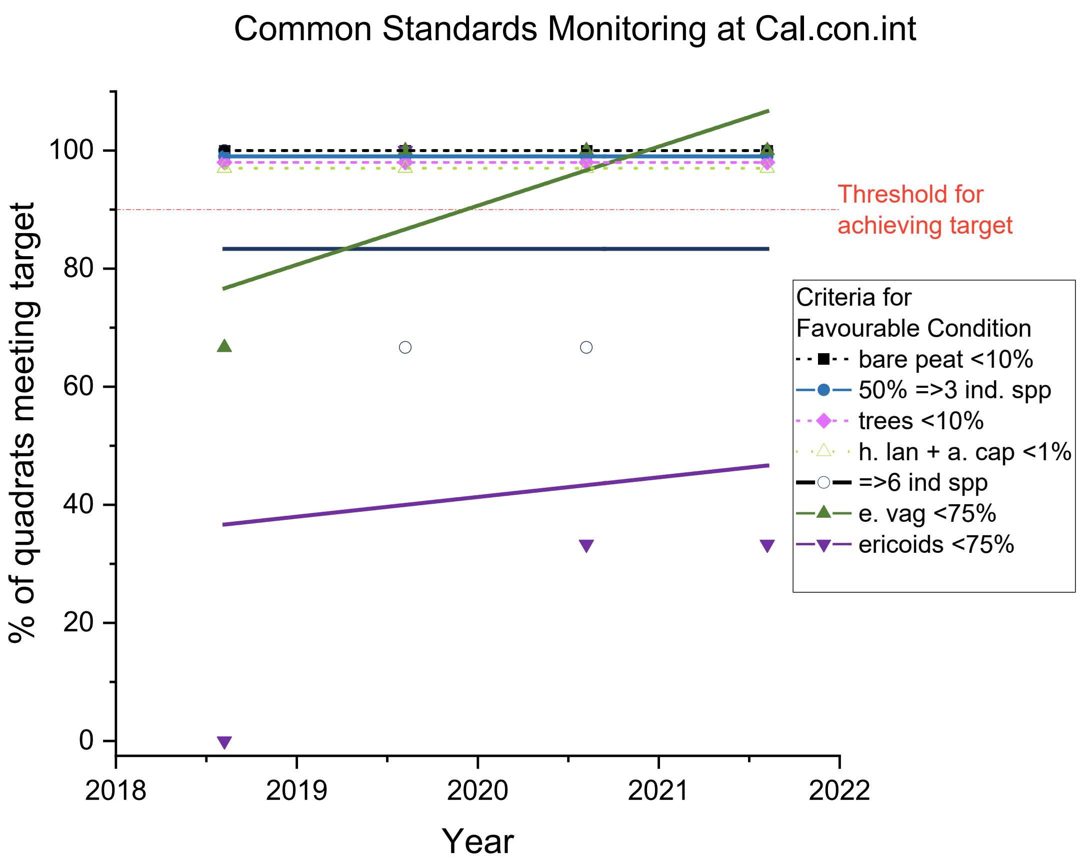


Figure 32. Common Standards Monitoring at *Calluna* control catchment intensive plots. Data points represent the percentage of quadrats in the catchment meeting the criteria for achieving favourable condition during survey period 2018–2021.

Figure 32 shows Common Standards Monitoring criteria for the control mini-catchment. It can be seen that the main factor preventing the site from being classed as favourable is the low proportion of quadrats containing less than 75% cover of ericoids. In addition, a higher proportion of quadrats would need to have more than 6 indicator species present. However, the levels of bare peat, trees and grasses would be considered acceptable.

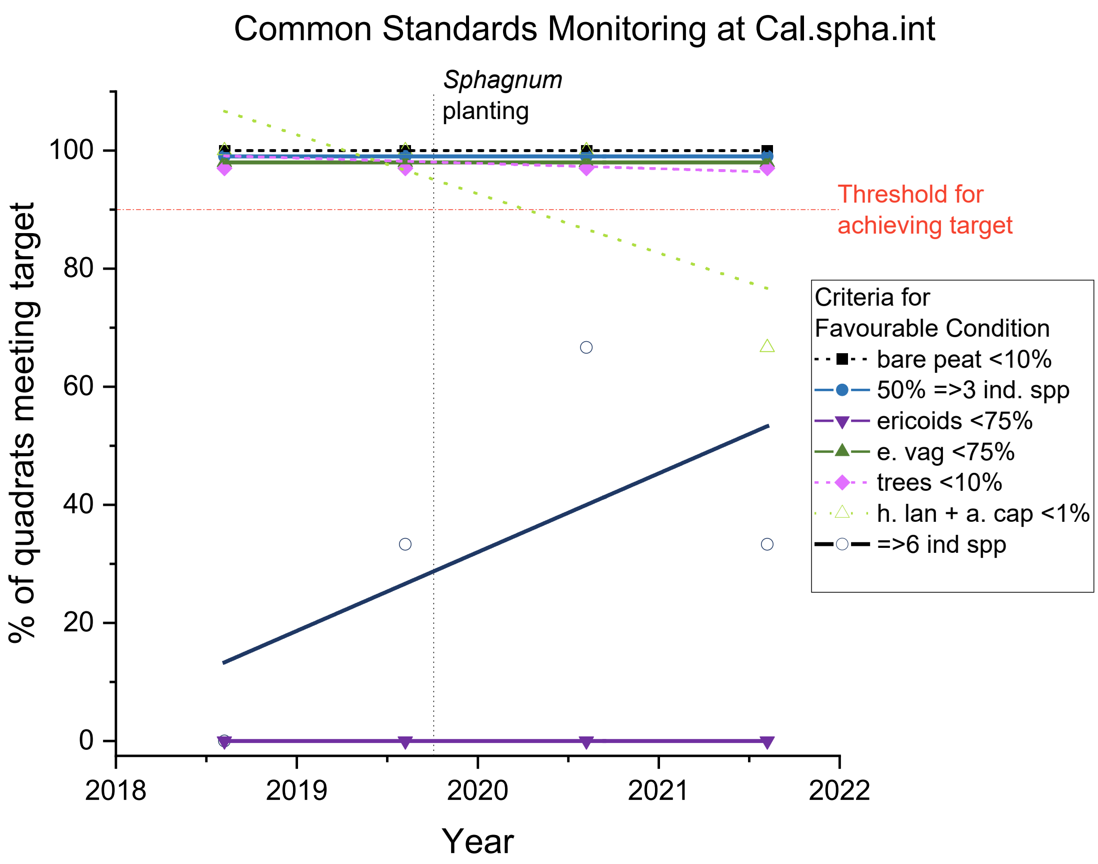


Figure 33. Common Standards Monitoring at *Calluna* treatment (*Sphagnum*) catchment intensive plots. Data points represent the percentage of quadrats in the catchment meeting the criteria for achieving favourable condition, before and after treatment in 2019.

Figure 33 shows Common Standards Monitoring criteria for the Spha mini-catchment. Similarly to the control, the dominance of ericoids is the main factor preventing the site from achieving favourable condition status. In contrast, the number of indicator species present is trending upward towards the threshold due to the introduction of *Sphagnum* plugs. However the, criterion for 90% of quadrats containing less than 1% of *Holcus lanatus* (yorkshire fog) and *Agrostis capillaris* (common bent) was no longer met in the 2021 survey. *Agrostis* spp were not surveyed to species level; for the purpose of CSM analyses any *Agrostis* spp observed were assumed to be *Agrostis capillaris,* whereas they may have been *Agrostis castellana* (a moorland species). These data therefore provide a conservative estimate of progress towards favourable condition. Further years of survey, and ideally a to-species survey of *Agrostis* would be required to more clarity on this criterion.

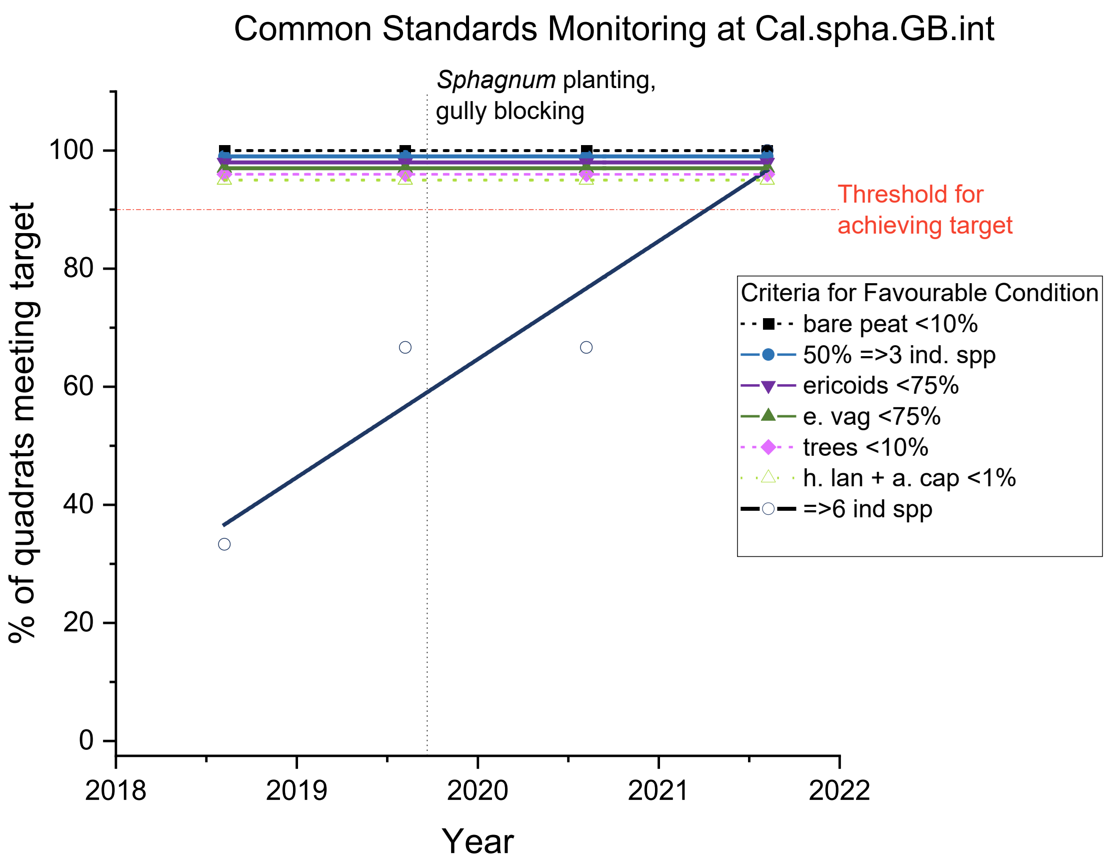


Figure 34. Common Standards Monitoring at *Calluna* treatment (*Sphagnum* and gully blocked) catchment intensive plots.
Data points represent the percentage of quadrats in the catchment meeting the criteria for achieving favourable condition, before and after treatment in 2019.

Figure 34 shows Common Standards Monitoring criteria for the SphaGB mini-catchment intensive plots. On this site, by the 2021 survey season all criteria tested for achieving favourable condition would be met, due to the increase in indicator species as a result of introducing *Sphagnum* plugs.

This area of the site already had a lower proportion cover of ericoids (a mean of ~50%) and met all other criteria before the treatment, so the introduction of *Sphagnum* plugs alone has allowed it to meet the target threshold.

4.2.2. *Eriophorum* dominated site

4.2.2.1. Vegetation composition

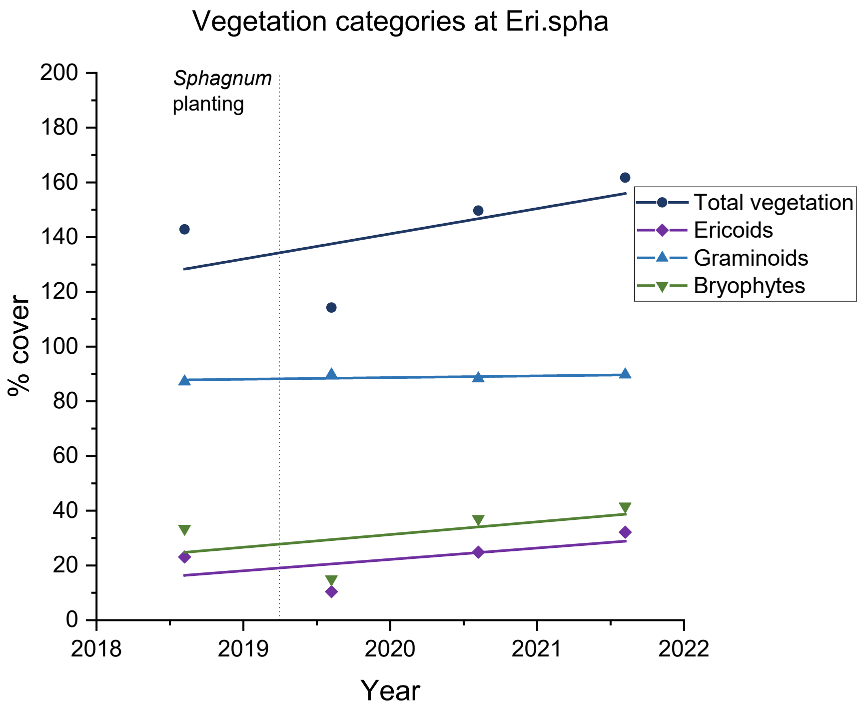


Figure 35. Vegetation category cover at Eri.Spha
Expressed as mean cover of quadrats in 'cluster area' before treatment (2018) and after (2019–2021). Data points represent the mean of n = 10 in each case.

Figure 35 shows the categories of vegetation present in the *Eriophorum* site *Sphagnum* (Spha) treatment catchment since monitoring began in 2018. The bryophytes (which includes *Sphagnum* mosses) and ericoid categories show a small increase (~9 %). Graminoid cover remained stable with no change larger than 2.5 percentage points. The total vegetation cover showed an increase of 19 percentage points over the four years of monitoring.

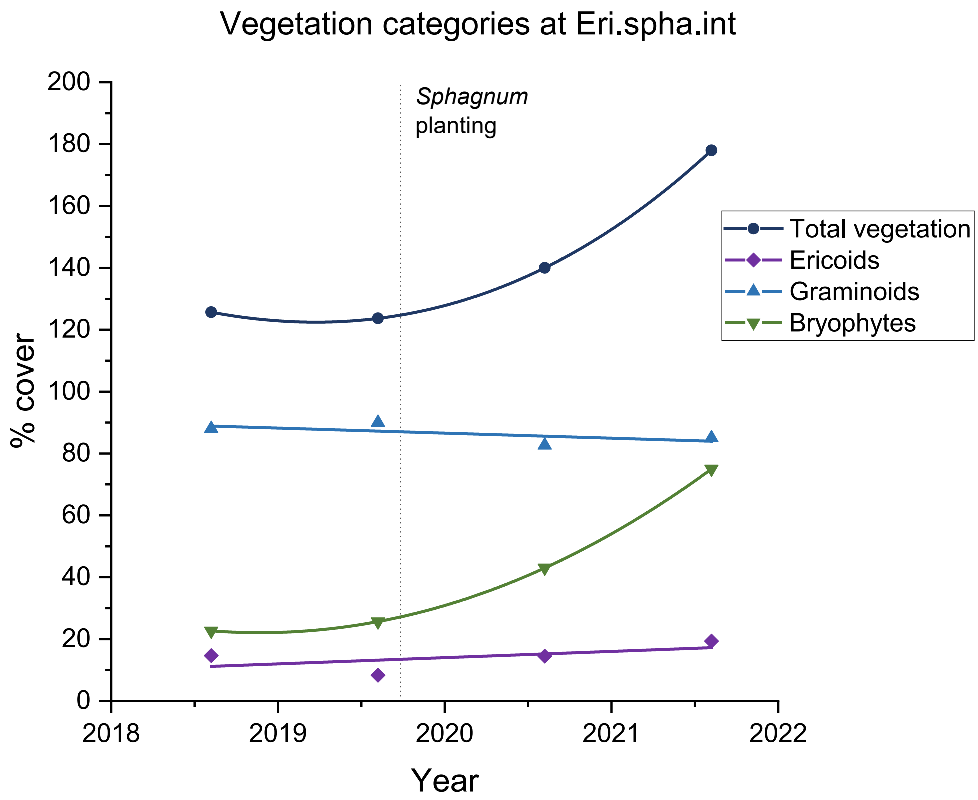


Figure 36. Vegetation category cover at Eri.Spha.Int
Expressed as mean cover of quadrats in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021). Data points represent the mean of n = 3 in each case.

Figure 36 shows the categories of vegetation present in the *Eriophorum* site *Sphagnum* treatment catchment intensive plot (Spha.int) since monitoring was started in 2018. The bryophytes category (which includes *Sphagnum* mosses) shows an increase of 52 percentage points cover over a four year period, beginning once the plugs were introduced in 2019. Ericoids remain relatively stable with a low level of cover, while graminoids remain stable at around 93% cover. The total vegetation cover increased by 52 percentage points – reflecting the introduction of the *Sphagnum* plugs.

4.2.2.2. *Eriophorum*

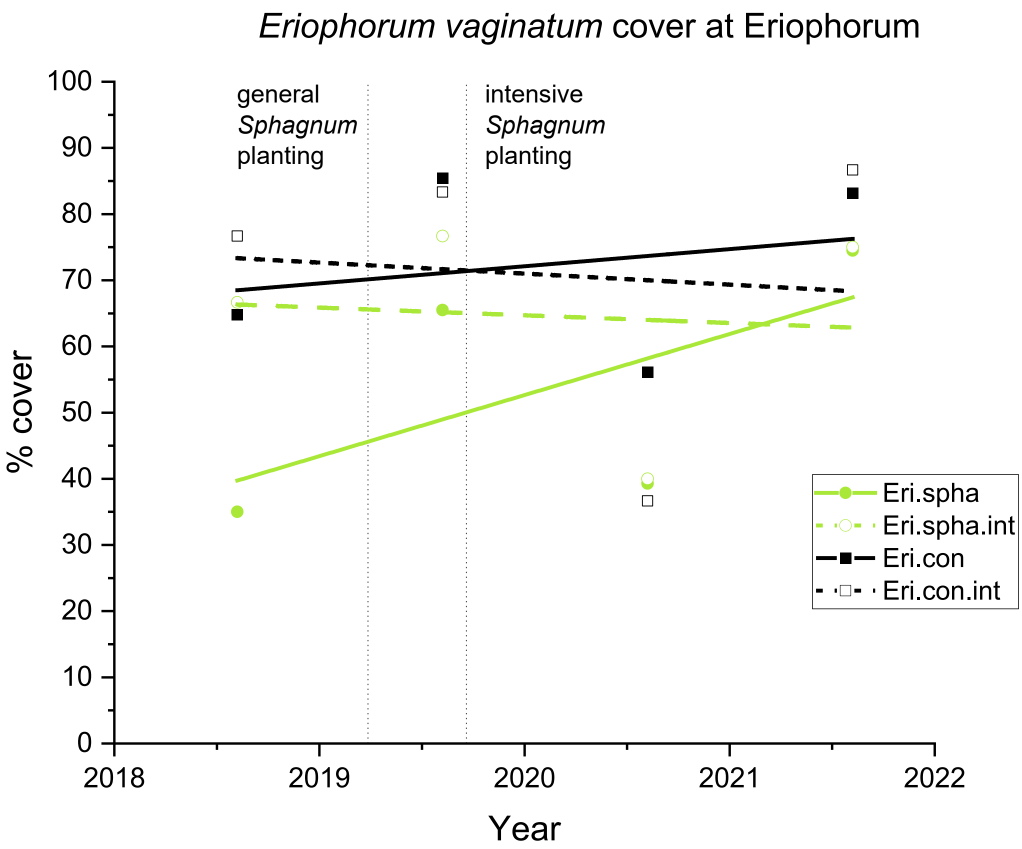


Figure 37. *Eriophorum* cover at *Eriophorum* sites.
Dominant species cover at the Eriophorum site is expressed as mean cover in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 37 shows the raw data for *Eriophorum vaginatum* cover across the monitored areas. Cover showed an increasing trend in the cluster quadrats, but conversely a weak decreasing trend in the intensive plots. These results should be treated with caution due to the error inherent in the survey method and the difficultly in estimating cover of this species. It appears that the species may have been under recorded in the 2020 survey, so further years will be required to establish whether a trend exists.

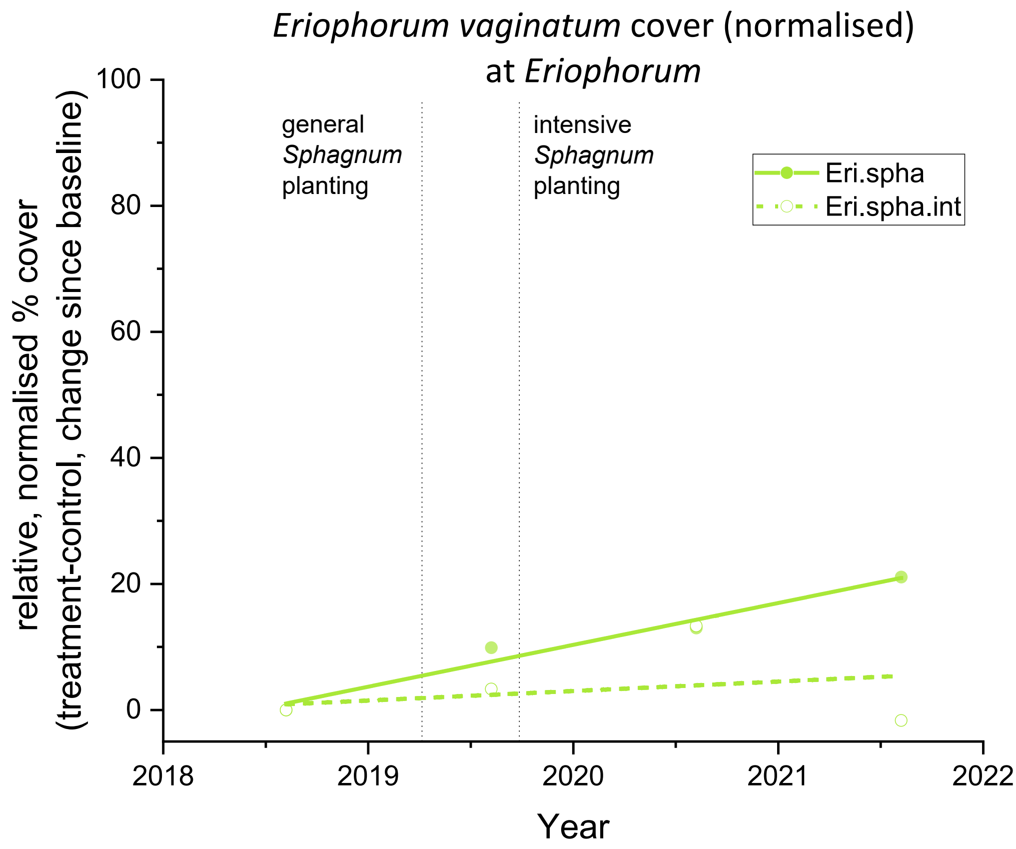


Figure 38. Relative *Eriophorum* cover at *Eriophorum* sites, normalised.
Normalised dominant species cover at the *Eriophorum* site is expressed as mean cover in treatment areas minus mean cover in control areas for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 38 shows data relative to control (treatment-control) normalised to zero for the first year of monitoring in 2018. Only a small amount of change is seen, with an increase of cover of 20 percentage points in the cluster quadrats being most notable. The trend in the intensive plots is less clear. Moreover, the fluctuation seen between survey years is more likely to be a result of recording error inherent in the survey method, than representative of a real change.

4.2.2.3. *Sphagnum*

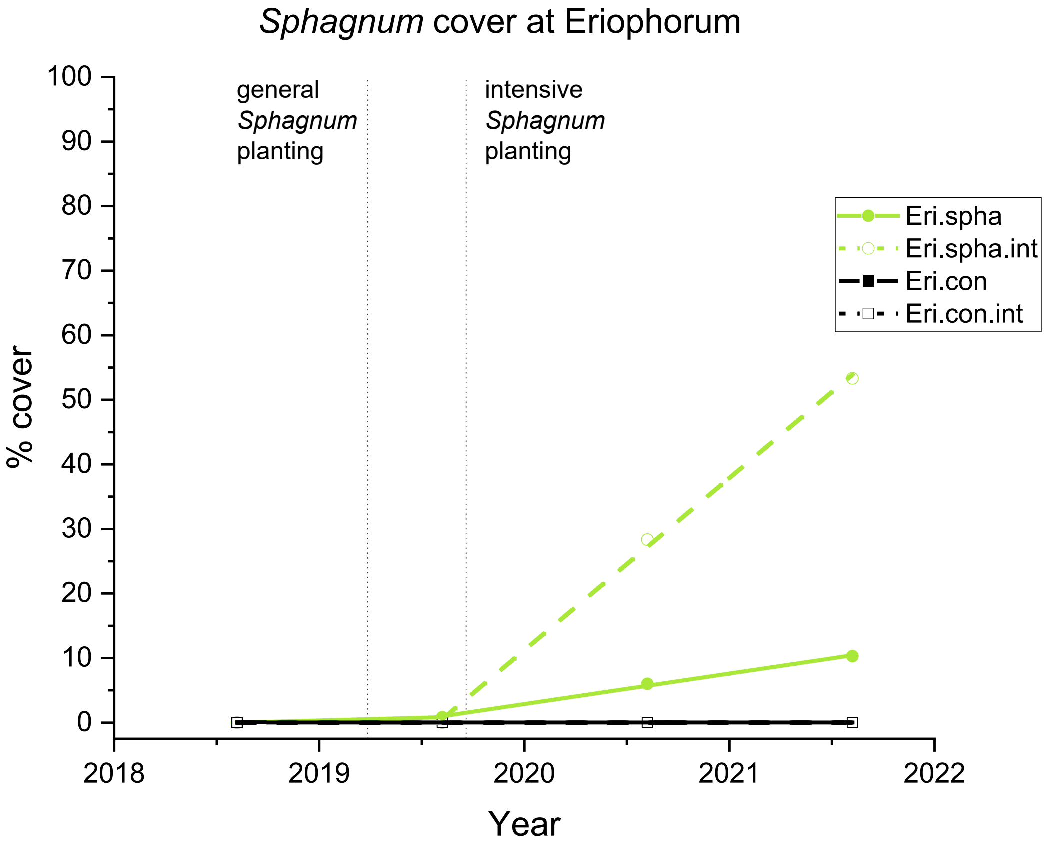


Figure 39. *Sphagnum* cover at *Eriophorum* sites.
Expressed as mean cover for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 39 shows raw data for *Sphagnum* cover across the monitored areas. A large increase in cover was recorded in intensive treatment sites in the years post-treatment. These showed a mean increase of 53 percentage points. An example of *Sphagnum* growing through *Eriophorum* in these plots is shown in Figure 41. The less intensively planted areas in the wider catchment by contrast showed a smaller increase from no *Sphagnum* present in 2018 to around 10% cover in 2021. The control catchment showed no significant change during the recording period.

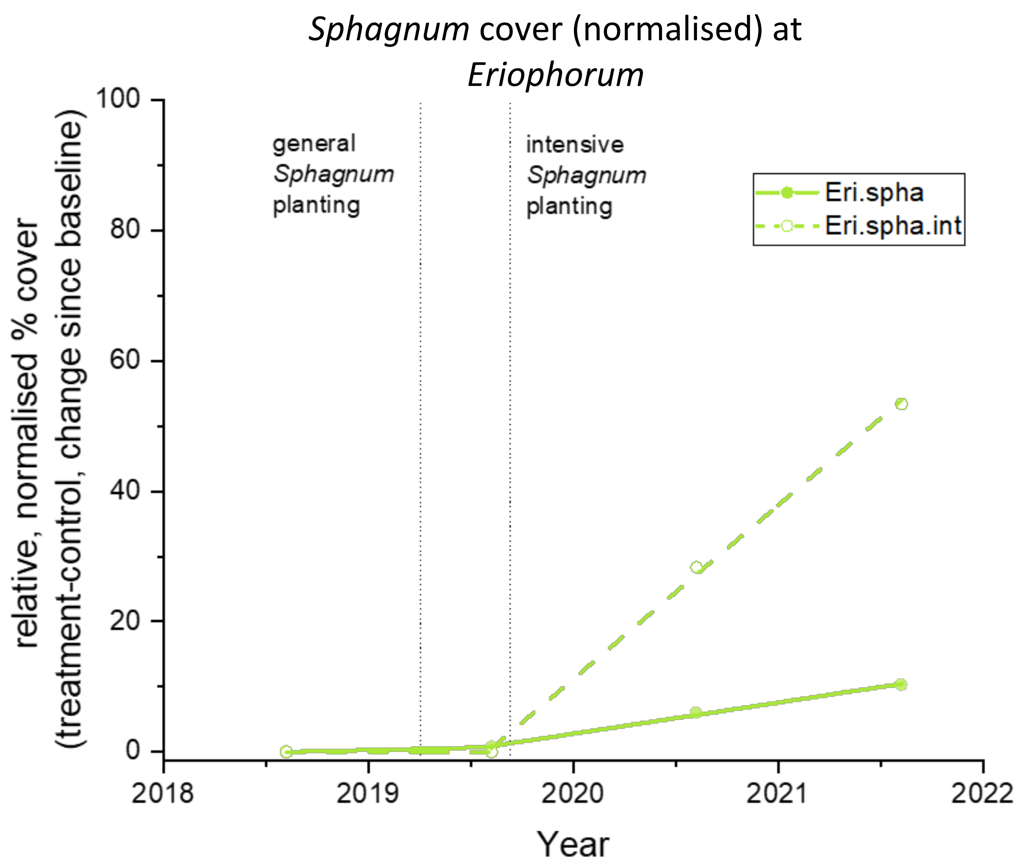


Figure 40. Relative *Sphagnum* cover at *Eriophorum* sites, normalised.
Normalised *Sphagnum* cover at the *Eriophorum* site is expressed as mean cover in treatment areas minus mean cover in control areas for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 40 shows *Sphagnum* cover in the treated areas relative to the control site, normalised to zero for the first year of monitoring in 2018. The changes displayed are almost the same as the raw data, reflecting that the control areas contained no *Sphagnum* at the start of monitoring, and this did not change more than 0.1% cover during the four years of monitoring.

Differences between treatment cluster *Sphagnum* cover and that in the control catchment were tested for statistical significance for each year of the study (Table 9). The increase in % cover in the treatment catchment in all years after planting (but not before) was found to be significant. It was not possible to test for differences between the intensive plots due to the small sample size (n = 3), but the increase in *Sphagnum* cover was clear.

Table 9. Statistical testing for *Sphagnum* cover at *Eriophorum* site
Values in the table are p-values resulting from the non-parametric Mann-Whitney U test for differences between the control and treatment areas. Significant differences at $p < 0.05$ are highlighted in grey; marginally significant values are lighter grey. Vertical lines indicate time of treatment.

Cover type	Mini-catchment	2018	2019	2020	2021
Sphagnum	Eri.Spha	1.000	0.000	0.000	0.000

Figure 41. ***Sphagnum*** **plug growth through** ***Eriophorum*** **in** ***Eriophorum*** **site intensive plot (Spha.Int.1) on 22/11/2021**

4.2.2.4. Bryophytes

Given the largest change in *Sphagnum* was observed in the intensive plots, the changes in other bryophytes in these areas should also be examined.

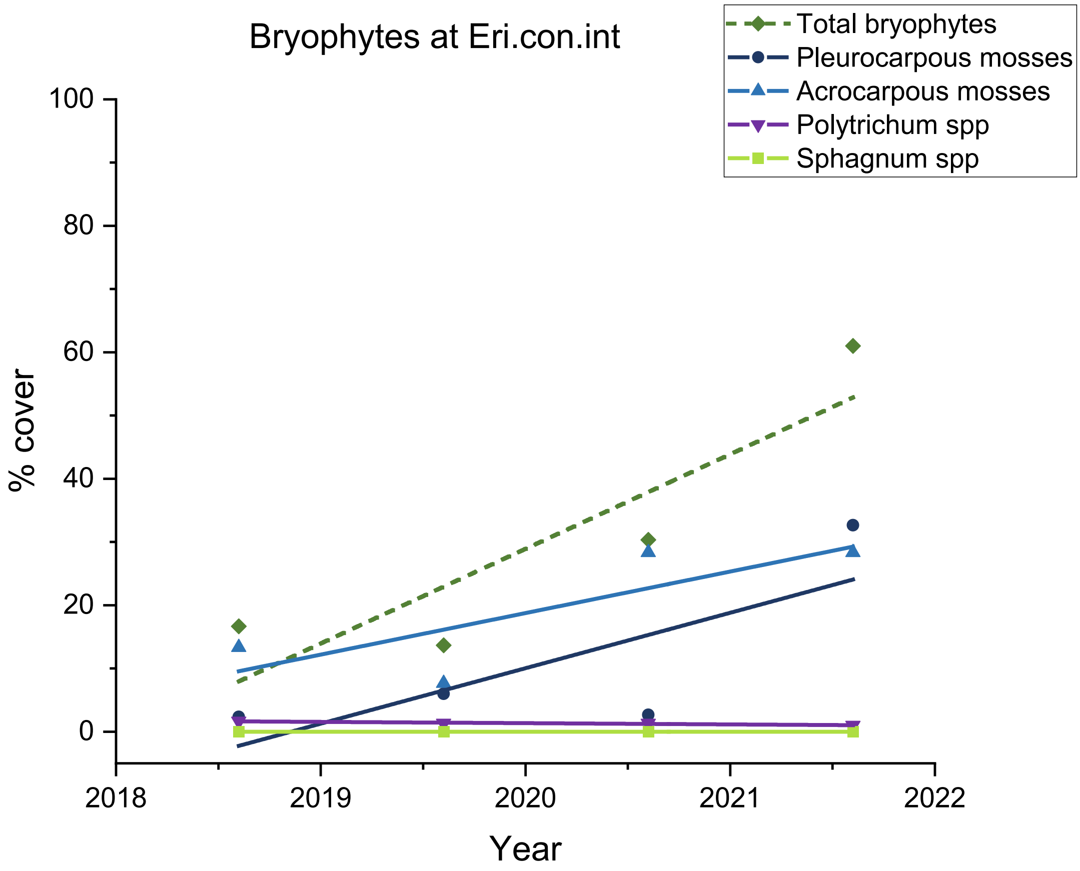


Figure 42. Bryophyte cover in the *Eriophorum* site control catchment intensive plots. Expressed as mean species cover in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 42 displays the control site intensive plot, and shows an increase in total bryophyte cover over the monitoring period; the majority of this accounted for by an observed increase in pleurocarpous (feather) and acrocarpous (cushion) mosses at around 30 and 15 percentage points respectively. *Polytrichum* remained stable throughout at ~1% cover, and there was no *Sphagnum* present during the monitoring period.

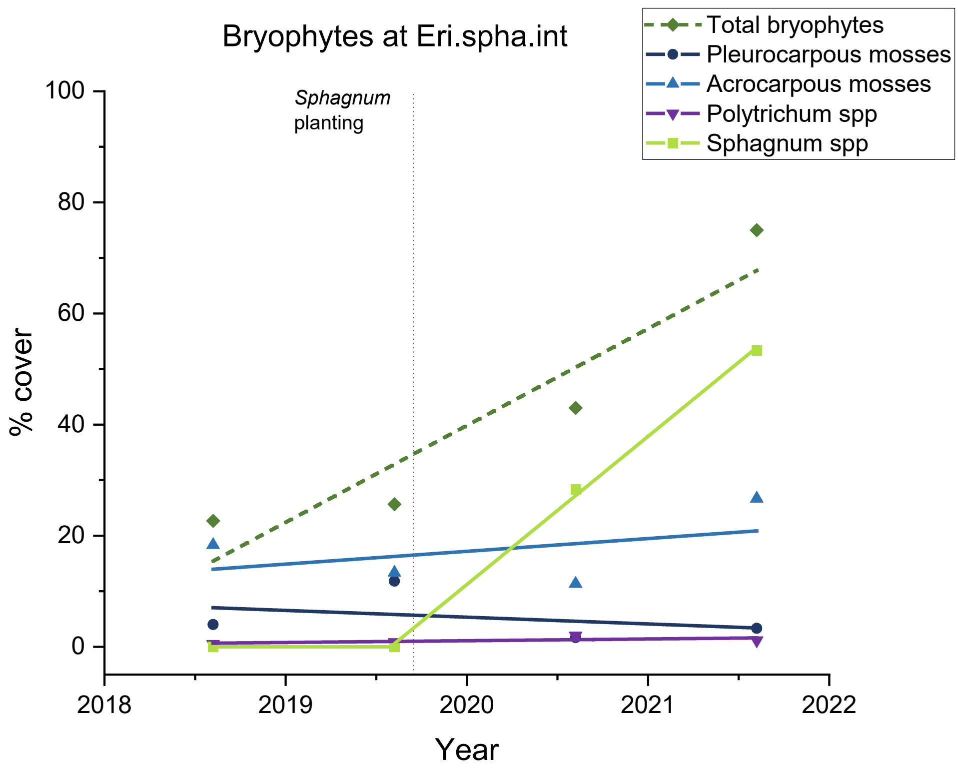


Figure 43. Bryophyte cover in the *Eriophorum* site *Sphagnum* treatment catchment intensive plots. Expressed as mean species cover in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

In contrast, Figure 43 shows that in the *Sphagnum* site intensive plots a 53% increase in *Sphagnum*, in addition to a small increase in acrocarpous mosses accounted for the overall increase in bryophyte cover.

4.2.2.5. Indicator species

The percentage cover of indicator species, and species count are presented for all mini-catchments and treatment types on the *Eriophorum* site. *Sphagnum* mosses were not recorded to species level, so it is known that the indicator species count for all sites where *Sphagnum* is present will be an underestimate. *Sphagnum* plugs introduced contained up to 11 species at the time of planting.

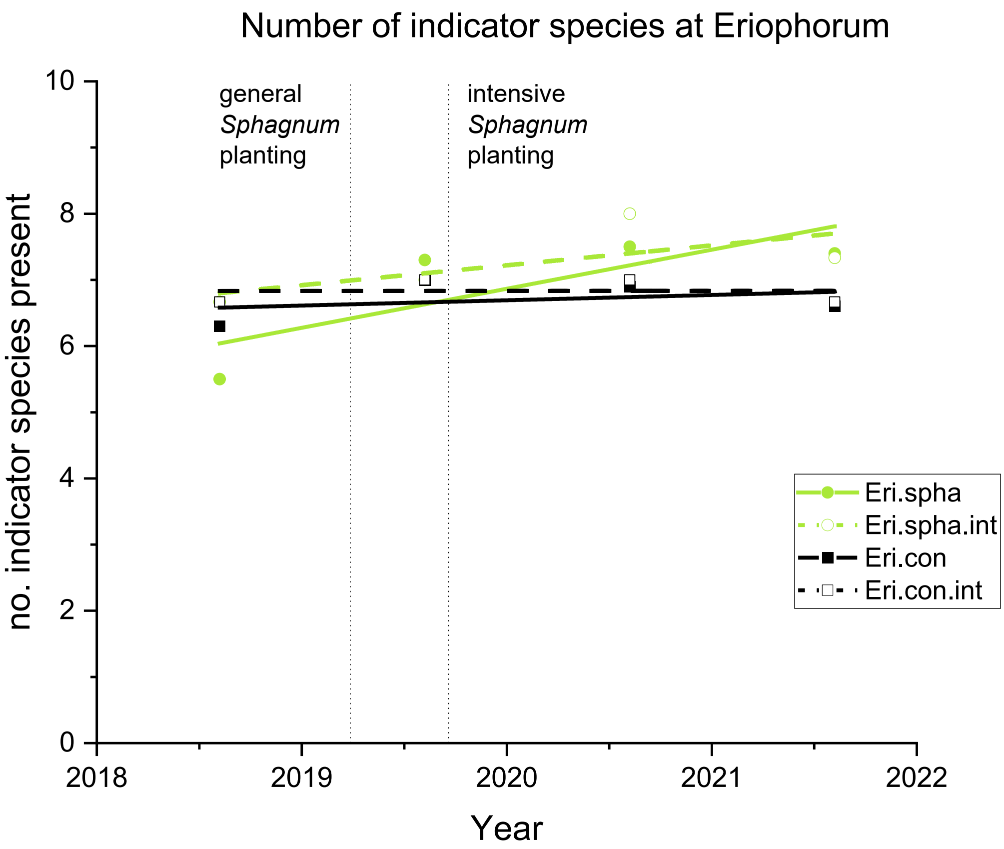


Figure 44. *Eriophorum* site indicator species count.
Indicator species count at the Eriophorum site is expressed as mean species number in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 44 shows the mean number of indicator species recorded in each area throughout the four years monitored. The control catchment remains stable at ~6.7 indicator species during this time. The Spha intensive plots show an increased mean of 0.7 species from baseline, while the other treatment areas show a mean increase of 1.9 species. This equates to mean totals of 7.3 and 7.4 species respectively. It should be noted that since the only indicator species introduced was *Sphagnum* (counted here as one species), an increase of more than one indicator species in any given quadrat represents either a genuine increase caused by the colonisation of a new species, or an under-recording of those species already present in pre-treatment surveys.

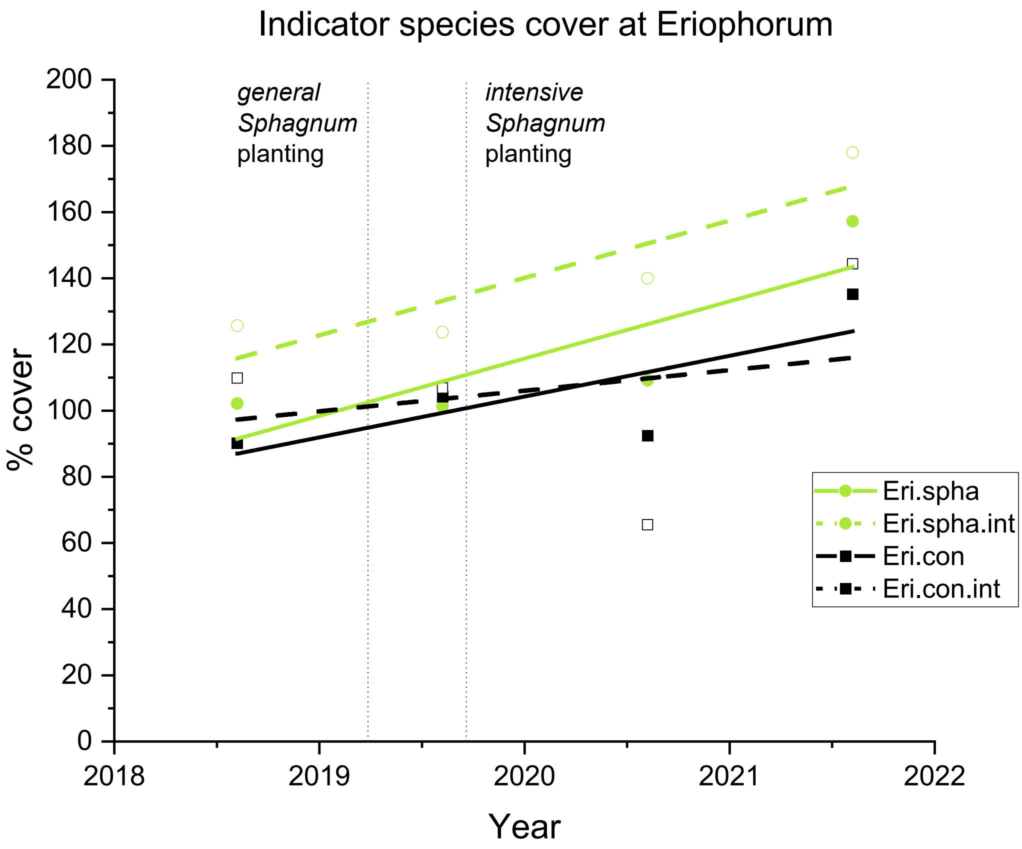


Figure 45. *Eriophorum* site indicator species cover.
Indicator species cover at the Eriophorum site is expressed as mean cover in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 45 shows mean indicator species cover. The intensive plots in both mini-catchments showed a slight upward trend in indicator species cover. An increase of 55% and 52 percentage points was observed in the Spha cluster area and intensive plots respectively. The control equivalents showed a slightly smaller increase in mean indicator species cover over time of 45% and 35 percentage points respectively. It should be noted that small changes in percentage cover over this short time period should be treated with caution due to the error inherent in the survey methodology.

4.2.2.6. Favourable condition at *Eriophorum* dominated site

Common Standards Monitoring criteria were applied to the intensive plots rather than the wider mini-catchment, to examine what factors are preventing them from reaching a condition that could be categorised as 'favourable', and progress towards this status made during the limited period of this experiment. Each figure features a threshold for the % of quadrats monitored that would need to meet each criterion in order for 'favourable' condition to be achieved.

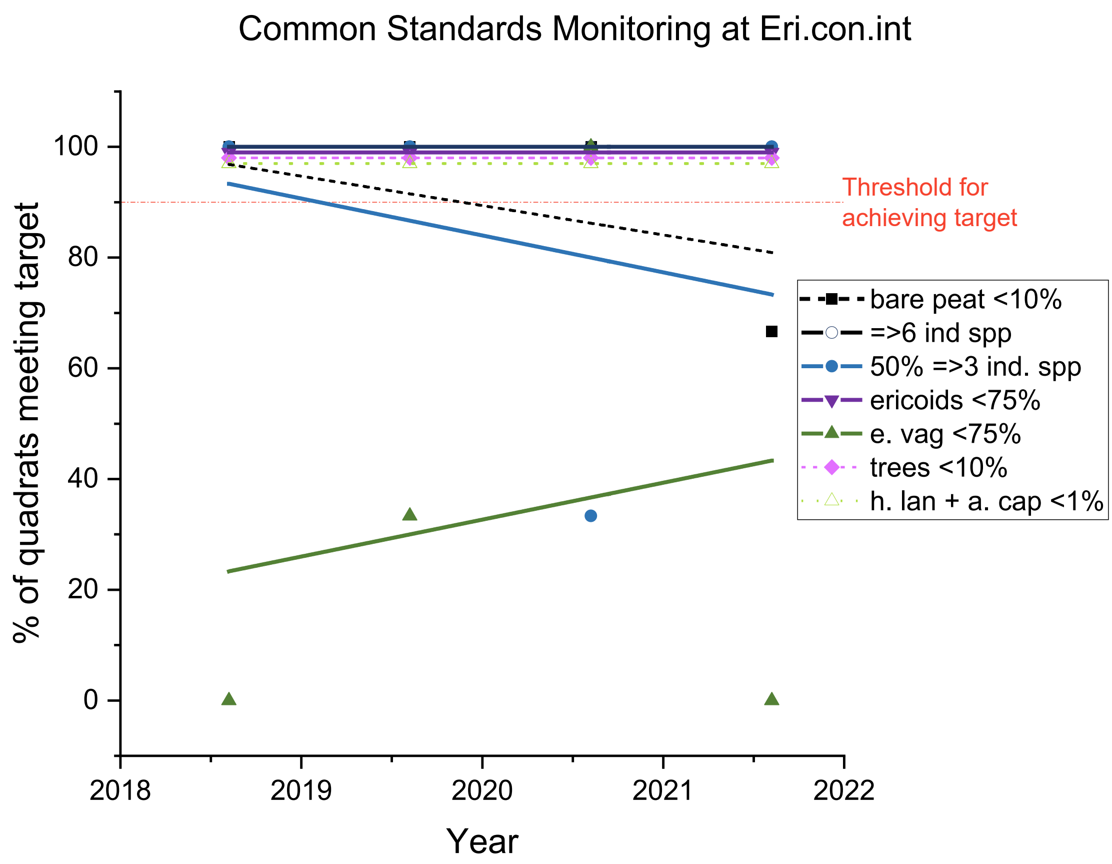


Figure 46. Common Standards Monitoring at *Eriophorum* control catchment intensive plots. Data points represent the percentage of quadrats in the catchment meeting the criteria for achieving favourable condition during survey period 2018–2021.

Figure 46 shows Common Standards Monitoring criteria for the control mini-catchment. It can be seen that the main factors preventing the site from being classed as favourable are the low proportion of quadrats containing less than 75% *Eriophorum vaginatum*. In addition, an increase in bare peat cover was noted in the 2021 survey – possibly as a result of disturbance caused by the monitoring. However, the levels of ericoids, trees and grasses and indicator species count would be considered acceptable.

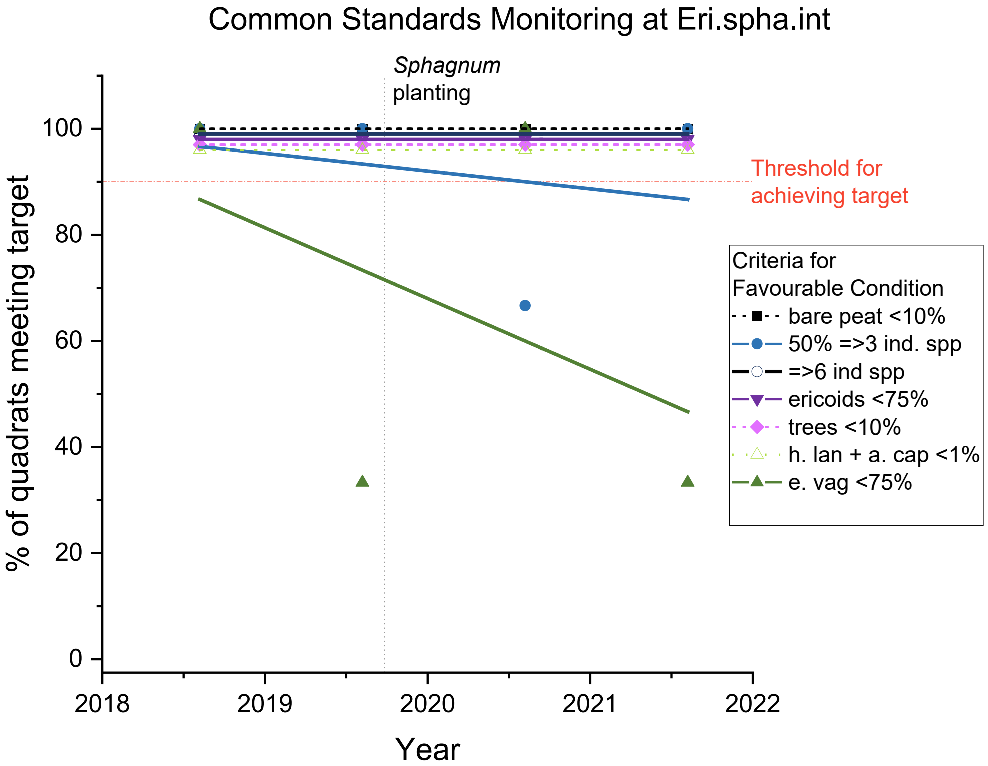


Figure 47. Common Standards Monitoring at the *Eriophorum* treatment (*Sphagnum*) catchment intensive plots.
Data points represent the percentage of quadrats in the catchment meeting the criteria for achieving favourable condition, before and after treatment in 2019.

Figure 47 shows Common Standards Monitoring criteria for the Spha mini-catchment. Similarly to the control, the dominance of *Eriophorum vaginatum* is the main factor preventing the site from achieving favourable condition status. The apparent trend in the *E. vaginatum* cover criterion should be treated with caution, see the discussion section of this annex for further detail.

4.2.3. *Molinia* dominated site

4.2.3.1. Vegetation composition

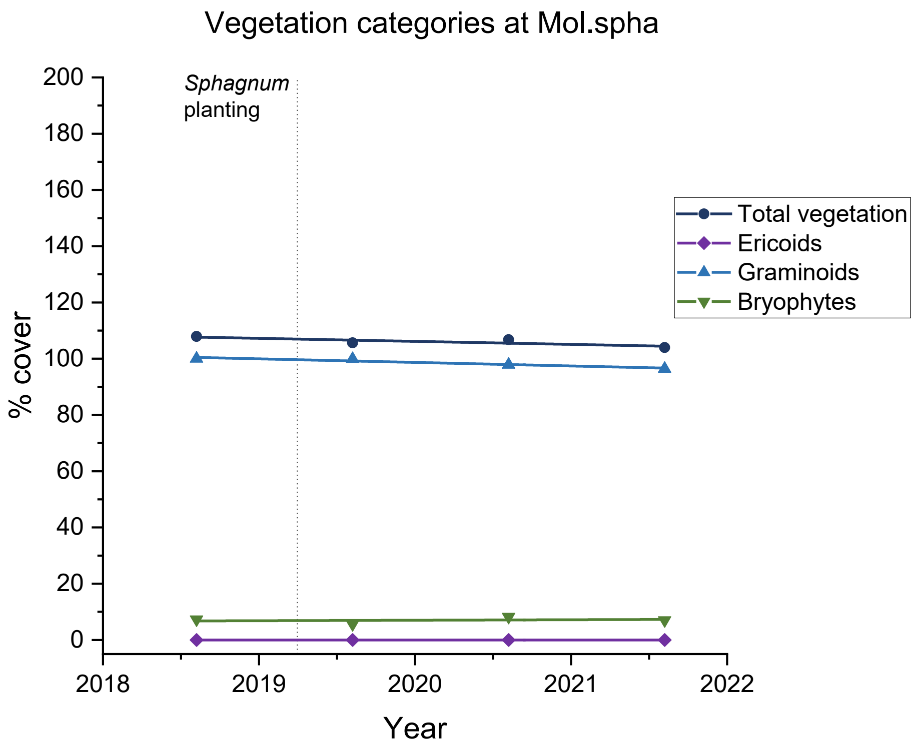


Figure 48. Vegetation category cover at the Mol.Spha
Expressed as mean cover of quadrats in 'cluster area' before treatment (2018) and after (2019–2021). Data points represent the mean of n = 10 in each case.

Figure 48 shows the categories of vegetation present in the *Molinia* site *Sphagnum* (Spha) treatment catchment since monitoring began in 2018. The total vegetation cover stayed broadly stable, showing only a small decrease of <4 percentage points over the four years of monitoring. The bryophyte coverage (which includes *Sphagnum* mosses) stayed stable with <1 percentage points change. Ericoid cover remained at 0% for the period. Graminoid cover remained stable with only a small decrease of <4 percentage points over the period.

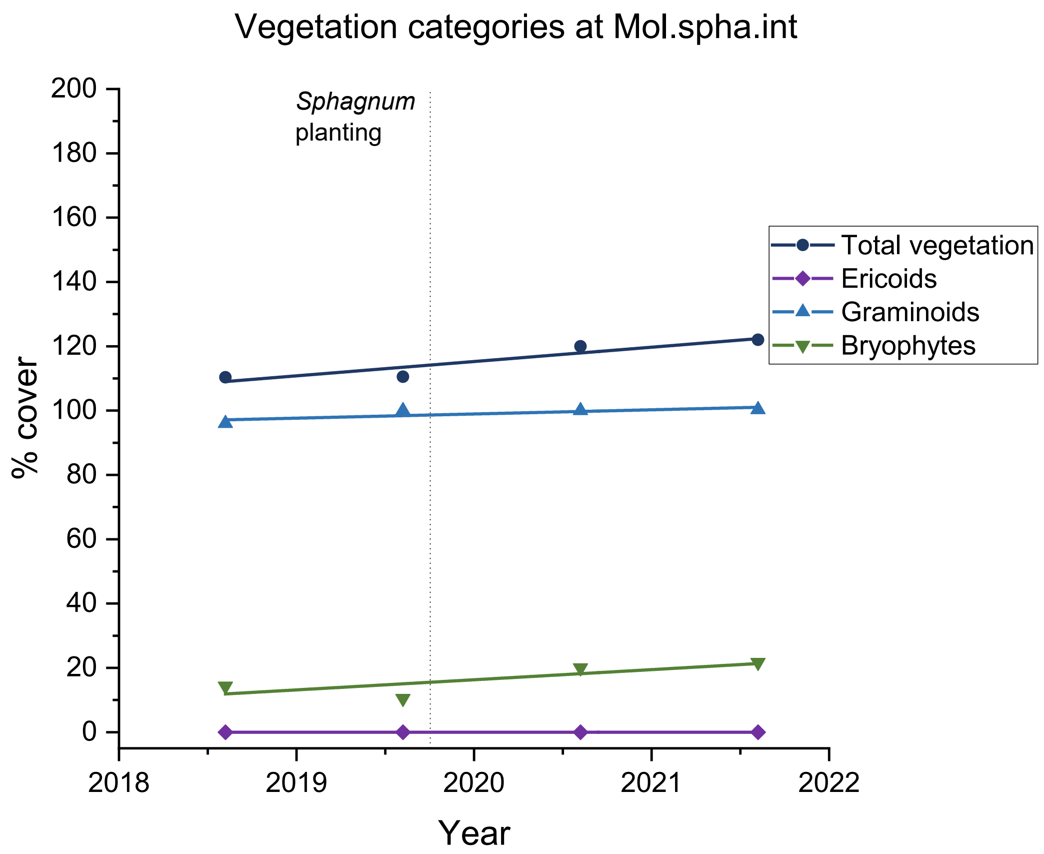


Figure 49. Vegetation category cover at Mol.Spha.Int
Expressed as mean cover of quadrats in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021). Data points represent the mean of n = 3 in each case.

Figure 49 shows the categories of vegetation present in the *Molinia* site *Sphagnum* treatment catchment intensive plot (Spha.int) since monitoring was started in 2018. The total vegetation cover increased slightly by 11.7% over the four years of monitoring. The majority of this change was the result of the introduction of *Sphagnum* plugs, reflected in the bryophyte coverage which increased by ~7 percentage points over the four years. Ericoid cover remained at 0% for the period. Graminoid cover remained relatively stable with only a small increase of <5 percentage points over the period.

4.2.3.2. *Molinia*

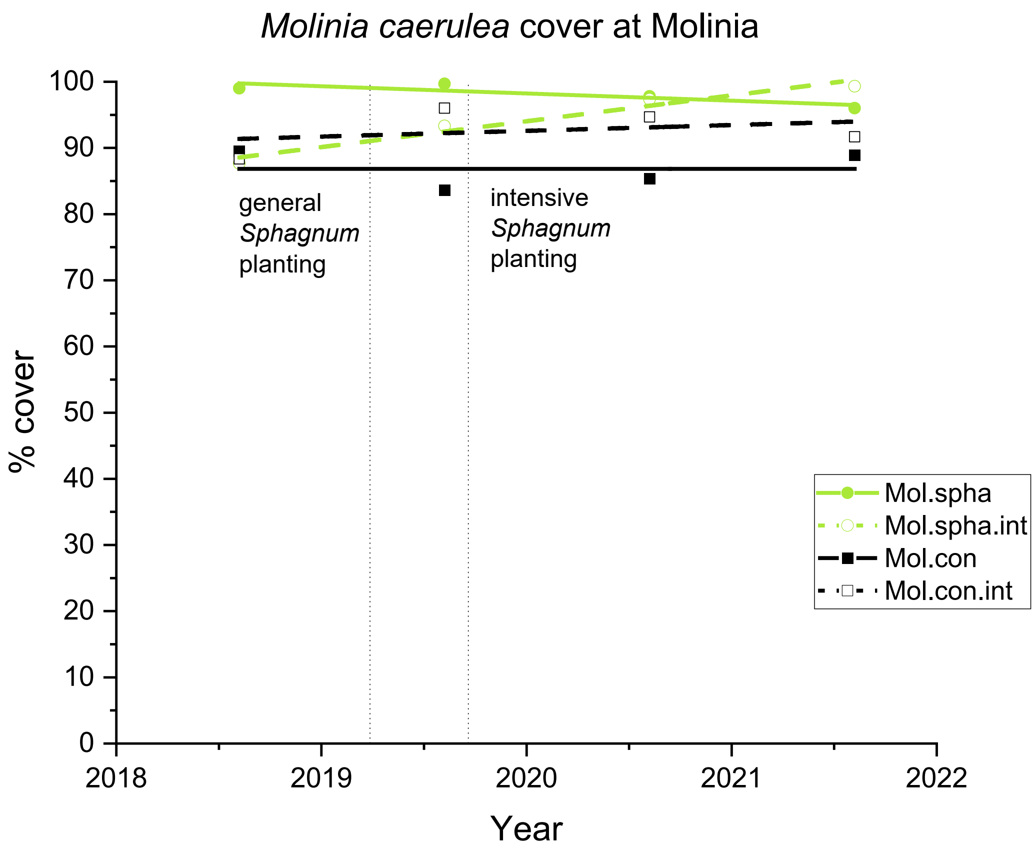


Figure 50. *Molinia* cover at *Molinia* sites.
Dominant species cover at the *Molinia* site is expressed as mean cover in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 50 shows the raw data for *Molinia caerulea* cover across the monitored areas. In the control catchment, little change was observed. Both the cluster and intensive quadrats showed <3.5 percentage points difference between 2018 and 2021 surveys. The treatment cluster showed a similar level of change of 3 percentage points decrease over the period. The intensive plot showed a small increase in cover of ~12 percentage points. These results should be treated with caution due to the error inherent in the survey method and in particular the difficultly in estimating cover of this species.

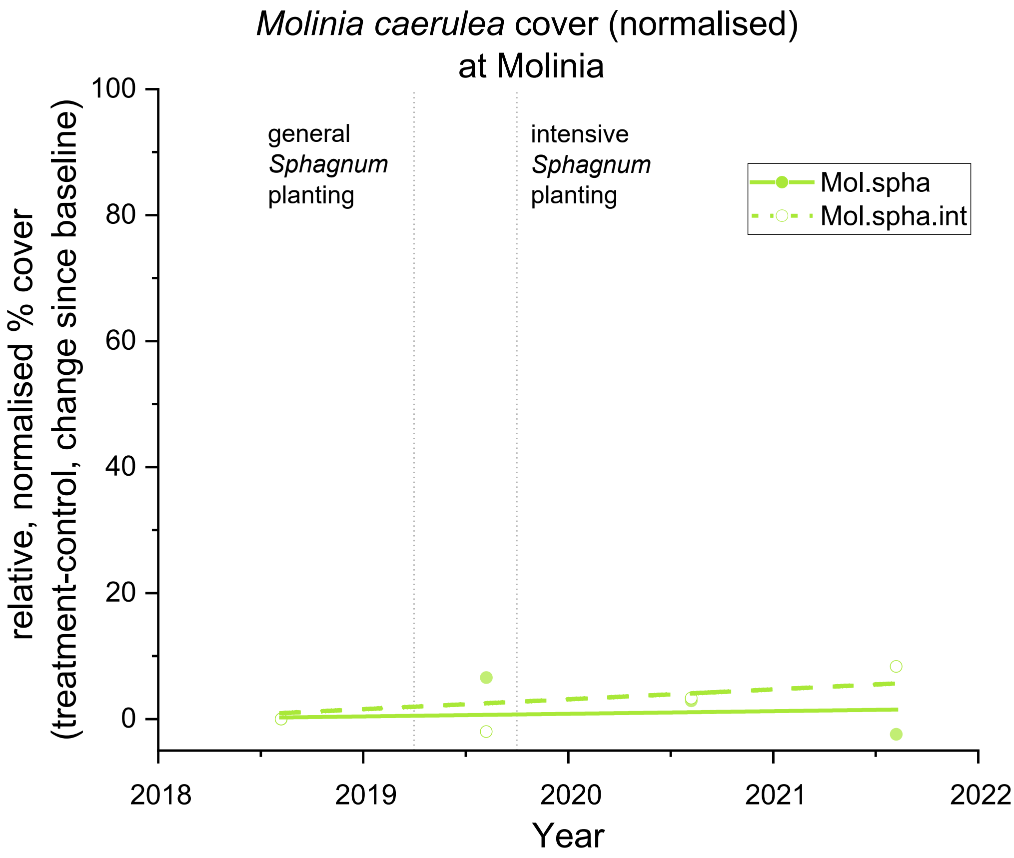


Figure 51. Relative *Molinia* cover on *Molinia* sites, normalised.
Normalised dominant species cover at the *Molinia* site is expressed as mean cover in treatment areas minus mean cover in control areas for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 51 shows data relative to control (treatment-control) normalised to zero for the first year of monitoring in 2018. Only a small amount of change was observed, with an increase of cover of ~8 percentage points in the intensive quadrats being most notable. The trend in the cluster quadrats is less clear. Moreover, the fluctuation seen between survey years is more likely to be a result of recording error inherent in the survey method, than representative of a real change.

4.2.3.3. *Sphagnum*

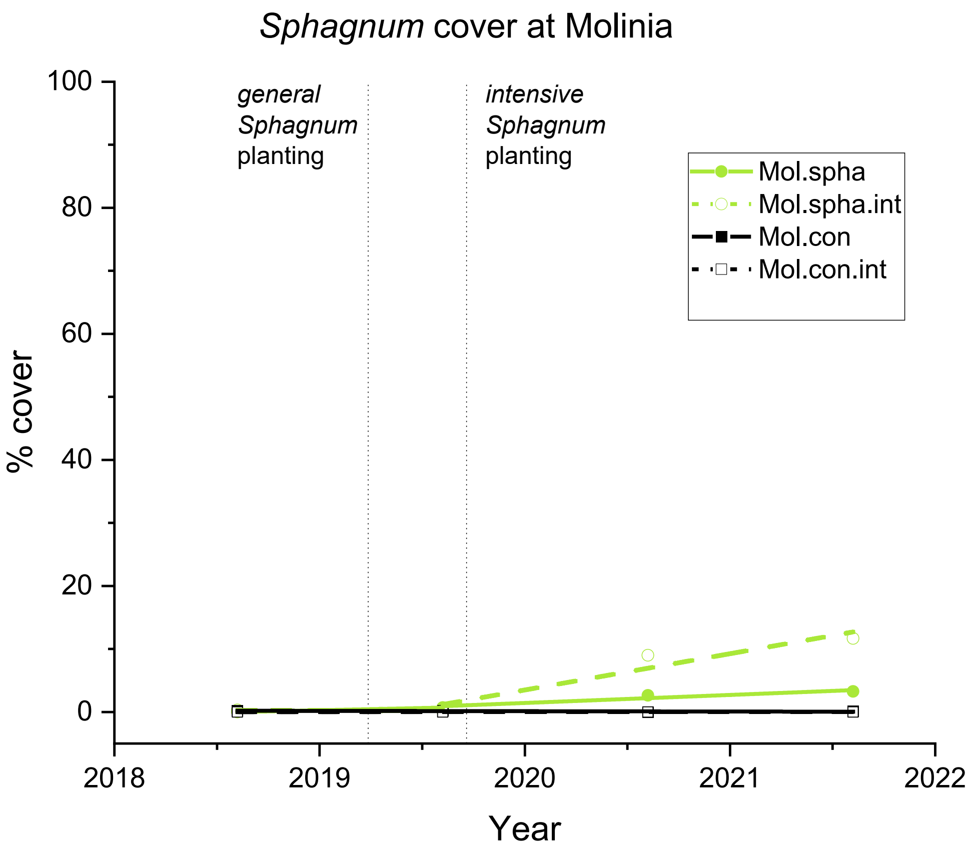


Figure 52. *Sphagnum* cover at *Molinia* sites.
Expressed as mean cover for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 52 shows raw data for *Sphagnum* cover across the monitored areas. A small increase in cover was recorded in intensive treatment sites in the years post-treatment. These showed a mean increase of ~11 percentage points, from a starting point of 0% cover. An example of intensively planted *Sphagnum* growing in *Molinia* can be seen in Figure 64 in the Discussion section of this document. The less intensively planted areas in the wider catchment by contrast showed a smaller increase from 0% *Sphagnum* cover in 2018 to around ~3% cover in 2021. The control catchment showed no change during the recording period remaining at ~0% cover.

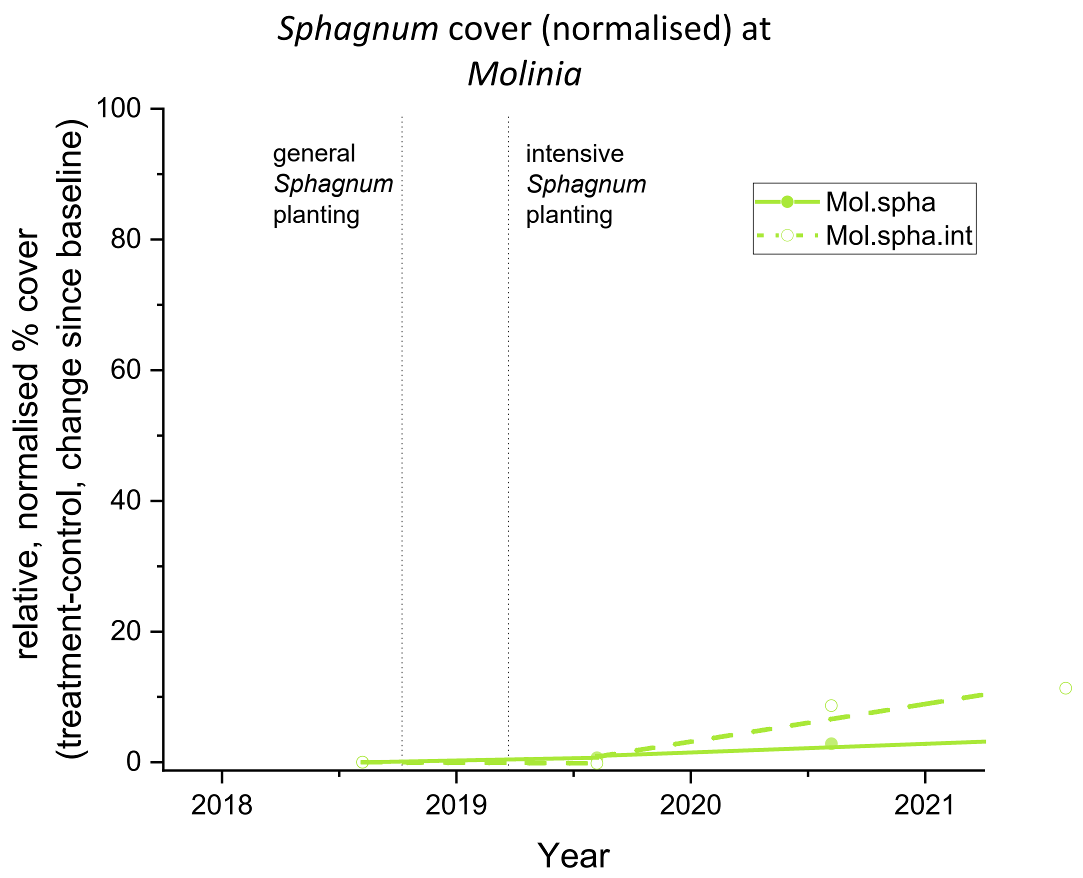


Figure 53. Relative *Sphagnum* cover at *Molinia* sites, normalised.
Normalised *Sphagnum* cover at the *Molinia* site is expressed as mean cover in treatment areas minus mean cover in control areas for quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 53 shows *Sphagnum* cover in the treated areas relative to the control site, normalised to zero for the first year of monitoring in 2018. The changes displayed are almost the same as the raw data, reflecting that no *Sphagnum* was found in the control areas at the start of monitoring, and this did not change by more than 0.2% cover during the four years of monitoring.

Differences between treatment cluster *Sphagnum* cover and that in the control catchment were tested for statistical significance for each year of the study. The cover recorded in the treatment catchment increased each year after planting (but not before), and the differences to the control catchment were significant (Table 10). It was not possible to test for differences between the intensive plots due to the small sample size (n = 3), but a clear increase in *Sphagnum* cover was observed.

Table 10. Statistical testing for *Sphagnum* cover at *Molinia* site
Values in the table are p-values resulting from the non-parametric Mann-Whitney U test for differences between the control and treatment areas. Significant differences at p < 0.05 are highlighted in grey; marginally significant values are lighter grey. Vertical lines indicate time of treatment.

Cover type	Mini-catchment	2018	2019	2020	2021
Sphagnum	Mol.Spha	0.481	0.003	0.000	0.000

4.2.3.4. Bryophytes

Given the largest change in *Sphagnum* was observed in the intensive plots, the changes in other bryophytes in these areas should also be examined.

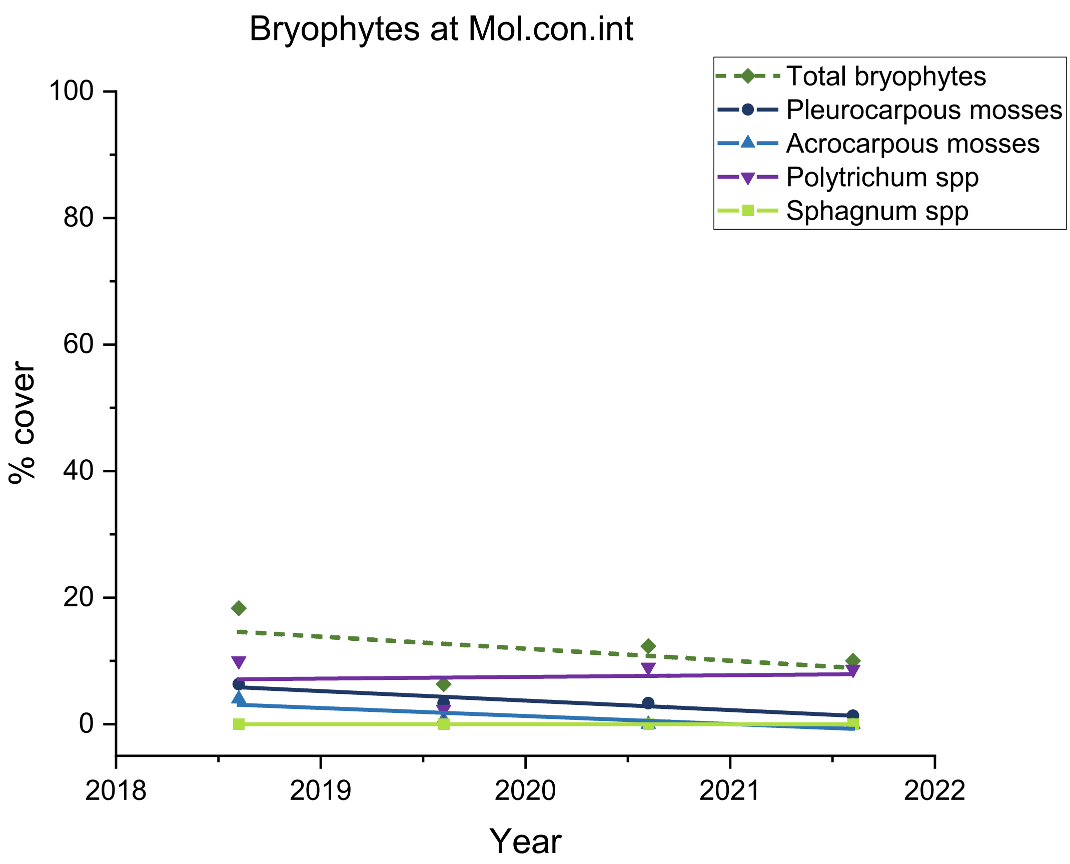


Figure 54. Bryophyte cover in *Molinia* site control catchment intensive plots.
Expressed as mean species cover in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 54 displays the control site intensive plot, and shows a small decrease (~8 percentage points) in total bryophyte cover over the monitoring period; the majority of this accounted for by an observed decrease in pleurocarpous (feather) and acrocarpous (cushion) mosses of around 5 and 4 percentage points respectively. *Polytrichum* remained stable throughout at, and there was no *Sphagnum* present during the monitoring period.

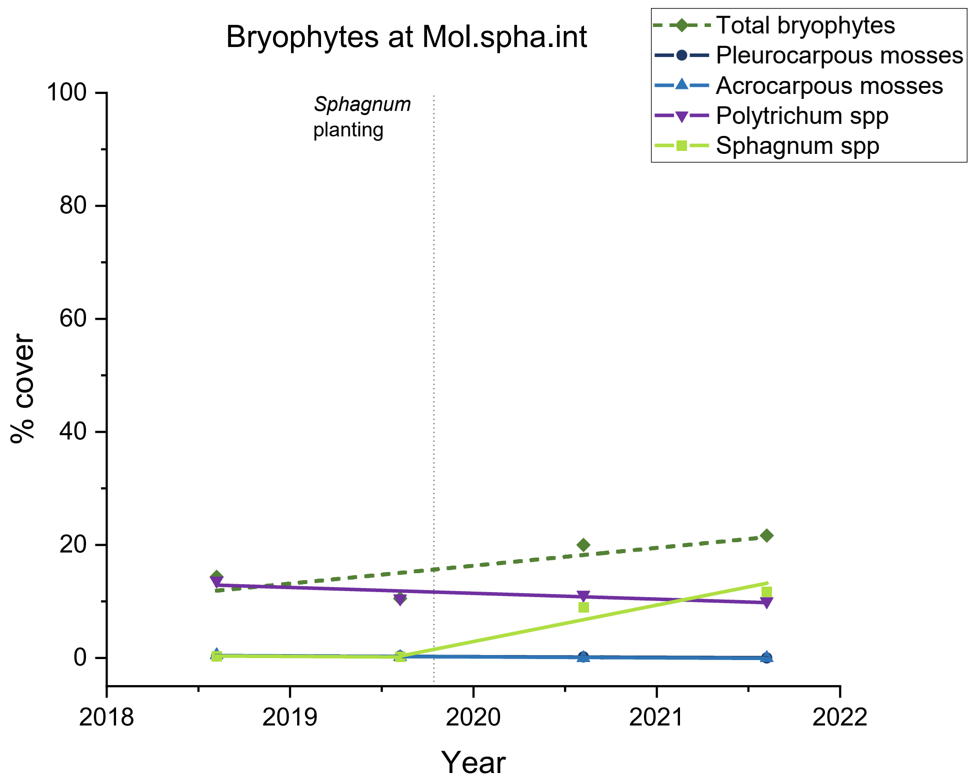


Figure 55. Bryophyte cover in *Molinia* site *Sphagnum* treatment catchment intensive plots. Expressed as mean species cover in 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

In contrast, Figure 55 shows that in the *Sphagnum* site intensive plots an ~11% increase in *Sphagnum* two years after plug introduction, added to a very small decrease in acrocarpous and pleurocarpous mosses, resulted in an overall increase in bryophyte cover.

4.2.3.5. Indicator species

The indicator species count and percentage cover of indicator species are presented for all mini-catchments and treatment types on the *Molinia* site. *Sphagnum* mosses were not recorded to species level, so it is known that the indicator species count for all sites where *Sphagnum* is present will be an underestimate. *Sphagnum* plugs introduced contained up to 11 species at the time of planting.

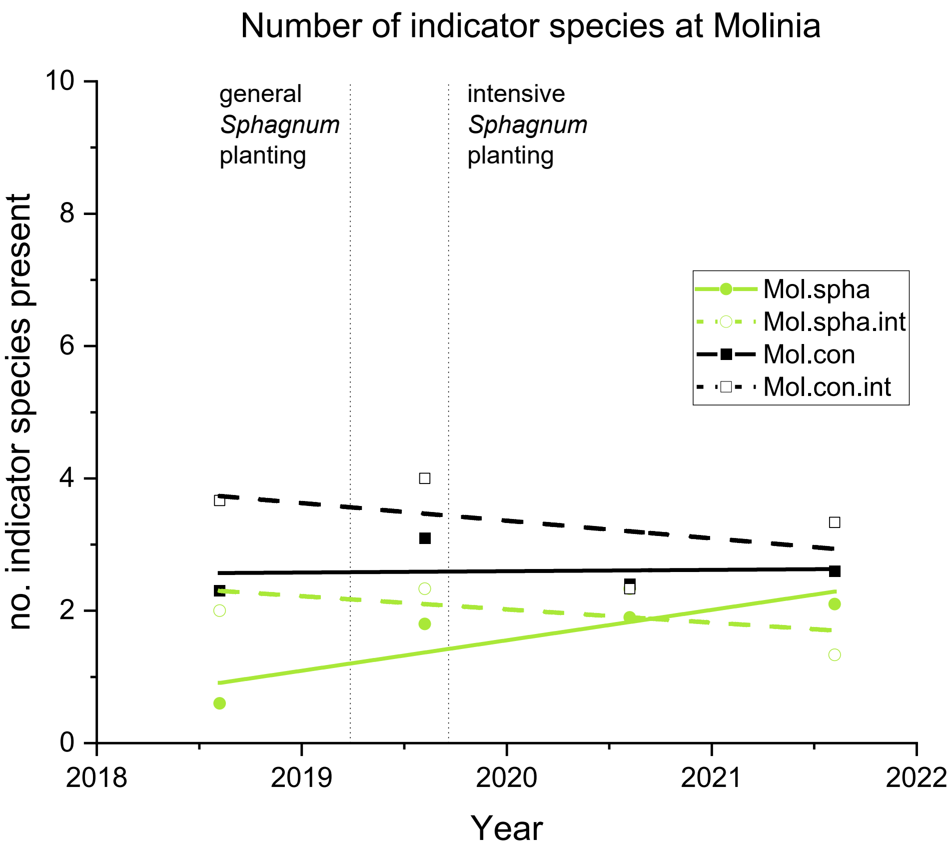


Figure 56. *Molinia* site indicator species count.
Expressed as mean species number in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 56 shows the mean number of indicator species recorded in each area throughout the four years monitored. The control catchment remains broadly stable with a mean of 4 or fewer indicator species present during this time. The Spha intensive plots show a very small decreased mean from baseline, of 0.7 species. However, it appears *E. vaginatum* and feather mosses were not recorded in one quadrat in the 2021 survey. The low number (n=3) of replicates means this decrease is probably the result of survey noise, and it is unlikely it reflects a real decrease. The other treatment areas show a mean increase of 1.5 species. This equates to mean totals in 2021 of 1.3 and 2.1 indicator species respectively.

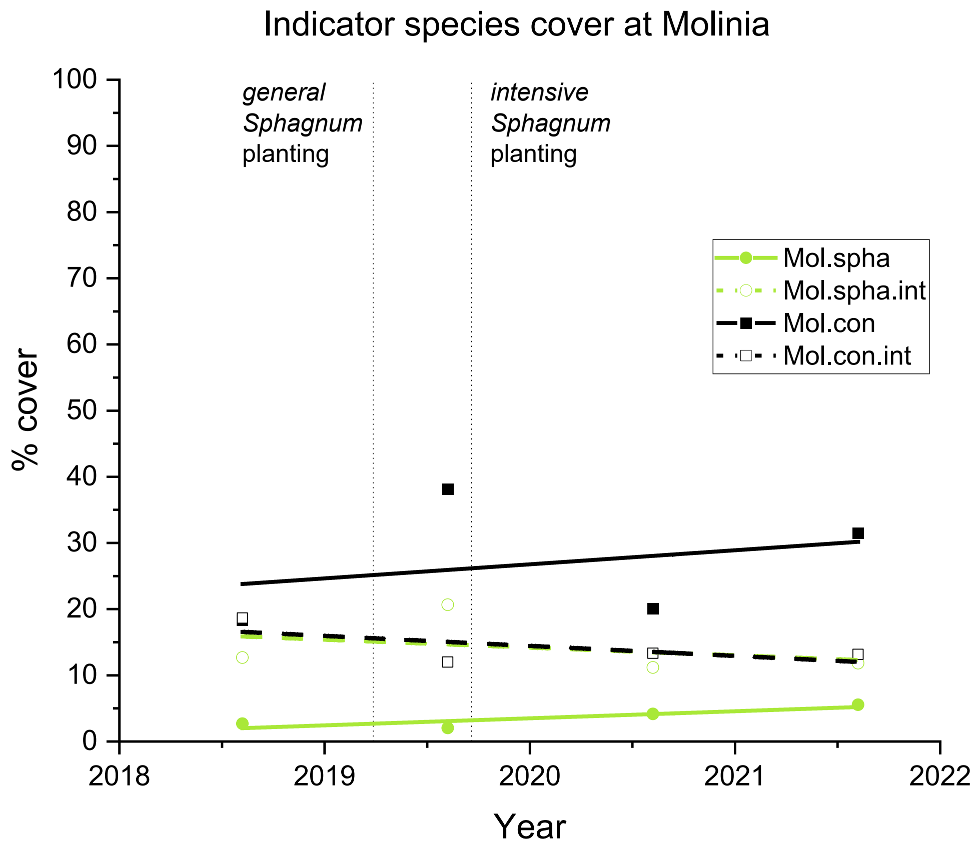


Figure 57. *Molinia* site indicator species cover.
Expressed as mean cover in quadrats in 'cluster' areas before treatment (2018) and after (2019–2021) – data points represent the mean of n = 10; and 'intensive plots' before treatment (2018 and 2019) and after (2020–2021) – data points represent the mean of n = 3 in each case.

Figure 57 shows mean indicator species cover. The intensive plots in both mini-catchments showed a slight downward trend in indicator species cover. A decrease of 0.8% and 5.5 percentage points was observed in the treatment and control intensive plots respectively. Conversely, the cluster equivalents showed an increase in mean indicator species cover over time of ~3 percentage points (treatment) and ~13 percentage points (control). It should be noted that changes in percentage cover over this short time period should be treated with caution. The decline observed in the treatment catchment intensive plot was due to an apparent reduction in cover of *Eriophorum* species from a mean of 12% to 0.17% cover during the survey period. This is likely to reflect difficulty in accurately surveying these species rather than a genuine trend. If *Eriophorum* cover is discounted, the indicator species cover trend is reversed – from a mean 0.7% in 2018 to 11.7% in 2021, almost entirely due to an increase in *Sphagnum* cover from plug plant introduction. In the control catchment intensive plots, the apparent reduction in cover is accounted for by a recorded decrease in *E. vaginatum* and pleurocarpous mosses. Again, these small changes should be treated with caution.

4.2.3.6. Favourable condition at *Molinia* dominated site

Common Standards Monitoring criteria were applied to the intensive plots rather than the wider mini-catchment, to examine what factors are preventing them from reaching a condition that could be categorised as 'favourable', and progress towards this status made during the limited period of this experiment. Each figure features a threshold for the % of quadrats monitored that would need to meet each criterion in order for 'favourable' condition to be achieved.

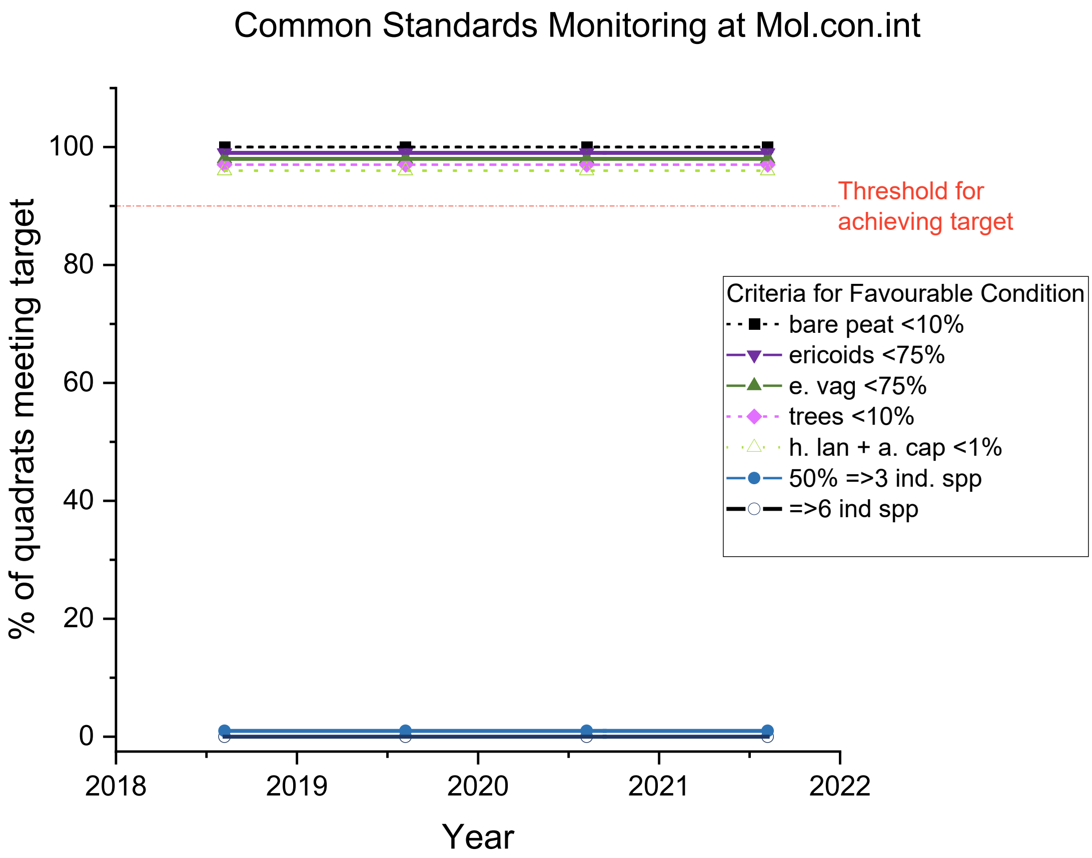


Figure 58. Common Standards Monitoring at *Molinia* control catchment intensive plots. Data points represent the percentage of quadrats in the catchment meeting the criteria for achieving favourable condition during survey period 2018–2021.

Figure 58 shows Common Standards Monitoring criteria for the control mini-catchment. It can be seen that the factor preventing the site from being classed as favourable are the low proportion (0%) of quadrats containing more than six indicator species. However, the levels of bare peat, ericoids, *Eriophorum vaginatum*, trees and grasses would be considered acceptable.

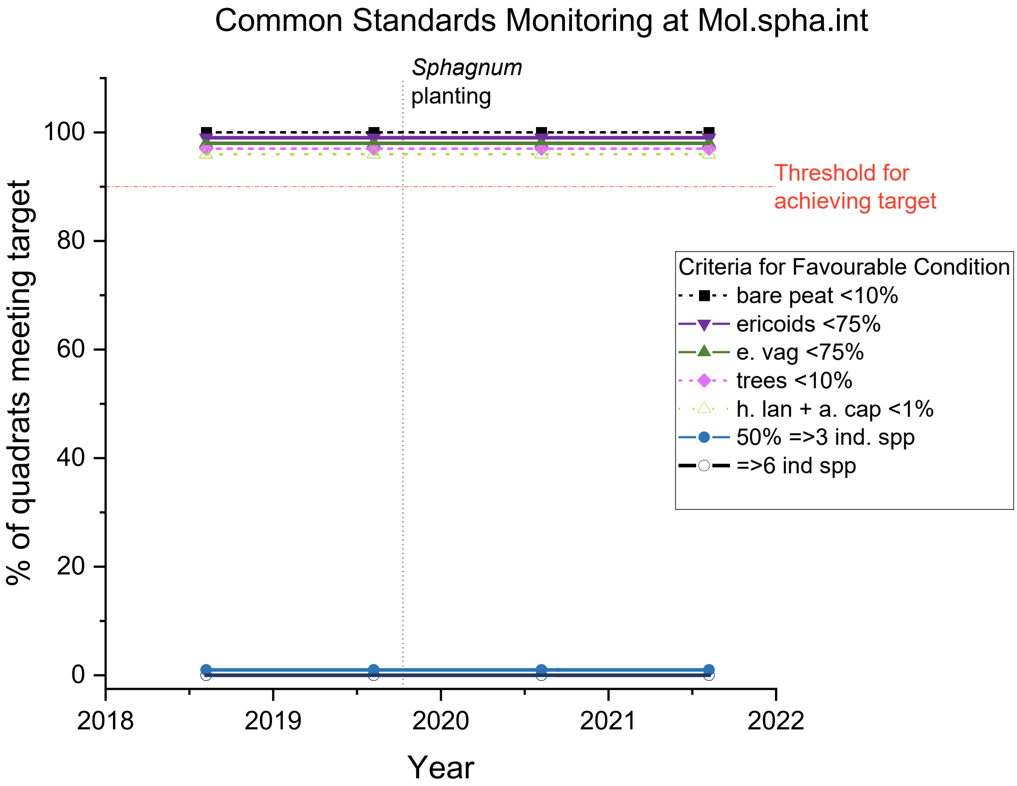


Figure 59. Common Standards Monitoring at *Molinia* treatment (*Sphagnum*) catchment intensive plots. Data points represent the percentage of quadrats in the catchment meeting the criteria for achieving favourable condition, before and after treatment in 2019.

Figure 59 shows Common Standards Monitoring criteria for the *Sphagnum* treated mini-catchment. Similarly to the control, the low number of indicator species present is the factor preventing the site from achieving favourable condition status. During the monitoring, no quadrats were found to meet the criteria of six indicator species present. However, it should be remembered that *Sphagnum* mosses were only surveyed to genus level, and the plugs planted in 2019 contained up to 11 species at the time of planting. Therefore, it is very likely that all quadrats contain more indicator species than were recorded.

5. Discussion

5.1. Limitations of survey method and data analysis

The same method was used at every quadrat in every year to estimate vegetation diversity. However, there are sources of uncertainty in these data – in successfully identifying each species (in particular, some graminoids when small and not in flower are difficult) and in estimating % cover. Estimation of % cover by different people each year may not be accurate enough to detect small changes with confidence, especially in graminoids. It should also be noted that the low number of replicates (n = 3) of intensively treated plots on the species dominated sites mean that less confidence can be placed in the trends derived from these samples than from the wider catchments where ten quadrats were monitored.

5.2. Bare peat

The results from the bare peat sites presented above were consistent with the findings of Alderson *et al* (2019). The additional years of data (and in particular the focus on *Sphagnum* reintroduction) provided an important extension and expansion of the already existing dataset.

5.2.1. Additional quadrats

It became clear at some bare peat sites after the start of monitoring that additional quadrats would provide extra detail and confidence in results. At site T (untreated control on Bleaklow), extra quadrats were added in the second and fourth years of monitoring. One of these quadrats had 20% vegetation cover in its first year of monitoring (10% *Calluna vulgaris* and 10% *Deschampsia flexuosa*). This creates an apparent increase in vegetation cover relative to baseline while, in reality, vegetation cover didn't actually increase at the site, it was just added into the control dataset.

On Kinder Scout, a set of 10 quadrats were installed across an area within mini-catchment O and immediately adjacent to (but not within) mini-catchment N; these quadrats were designed to assess vegetation diversity following the standard revegetation treatment applied to both mini-catchments. At this point, the *Sphagnum* planting at N had not been planned. When it was decided to plant *Sphagnum* at N (2015), an additional 10 quadrats were installed within the N mini-catchment, to assess the growth of the *Sphagnum*. A comparison of the data from the original and new N-specific quadrats in 2015 showed that ericoid, nurse crop grasses and bare peat cover were similar; graminoids and bryophytes were significantly different (Table 11). For years 2010–2014, data from the original quadrats were used for O and N. There is therefore some uncertainty in the first five years of the trajectory at N, although it is almost certain that there was 100% bare peat in all quadrats at N before treatment.

Table 11. Comparison of quadrat data at study sites O and N in 2015.
'Original' quadrats were located in mini-catchment O but were used to monitor O and N until 2015, when 'N-specific' quadrats were installed in mini-catchment N

	Species group total cover (%)				
Quadrat set	**Ericoids**	**Graminoids**	**Nurse crop grasses**	**Bryophytes**	**Bare peat**
Original	25	20	23	81	4
N-specific	27	36	11	32	2
Significant difference?	No (M-W U=54; p=0.796	Yes (M-W U=81; p=0.019)	No (M-W U=74; p=0.075)	Yes (M-W U=6; p<0.001)	No (M-W U=63; p=0.353)

5.2.2. Vegetation community composition

Superficially, when viewed on site, all monitoring sites appeared in recent years to be vegetated by a mixture of ericoids and graminoids, with areas of dominance of each category, and areas of heterogeneity. Analysis of the quadrat data show that revegetation was driven in years 1–5 by graminoids, but these were then succeeded by a bryophyte layer which became the dominant category from around year 5. The ericoid layer established more gradually than the graminoid layer at all sites, and stabilised at similar % cover to the graminoid layer from around nine growing seasons following initial treatment.

5.2.3. Ericoids

Within the ericoids, *Calluna vulgaris* was the dominant species. At the field lab sites O and N, there was some evidence of decline from years 8–11, with signs of dieback recorded during surveys. The cause of this is unknown – it could be heather beetle. This decline was not observed in the data from the wider context sites, which cover a longer term timescale. This would suggest that the apparent decline on Kinder Scout has a local cause, rather than a standard part of a succession process. Across the field labs and the wider context sites, results suggest that *Calluna vulgaris* is not coming to dominate the vegetation community as a result of restoration.

5.2.4. Graminoids

Within the graminoids, *Agrostis castellana* and *Festuca ovina* were the most successful of the nurse crop grasses applied as part of the treatment. These declined once repeat applications of fertiliser were stopped (after the 3rd growing season after initial treatment) but have remained at low levels at some sites to the end of monitoring. As described above, *Agrostis* and *Festuca* spp were not surveyed to individual species level. It is therefore unclear from the ongoing presence of both *Agrostis* and *Festuca* spp whether the nurse crop species applied have persisted at low levels or have been replaced by more common highland species of the same genus. It is possible for *Agrostis castellana* to hybridise with *Agrostis capillaris* (Hubbard, 1984), although unlikely in the moorlands in this study as *Agrostis capillaris* is not typically found at these altitudes (Rodwell *et al*, 1991). It was anticipated that *Agrostis castellana* would survive for 5–10 years after the cessation of fertiliser application (Drury, 2005) so the remaining *Agrostis* spp could be the last remnants of the *Agrostis castellana* or could indicate that hybridisation with *Agrostis capillaris* has in fact taken place.

Deschampsia flexuosa, a common moorland grass included at low levels in the nurse crop seed mix, established rapidly at most treatment sites. It could also have been imported with the heather brash, its seed could have been blown in on wind, or it could have been present in the onsite seedbank and/or in areas of extant vegetation. Following an initial rapid increase, *Deschampsia flexuosa* stabilised and/or declined for several years but then increased again around 9 years after initial treatment at some sites. It is unknown whether this is a temporary fluctuation or a long-term trend. While there is no official criterion within Common Standards Monitoring for *Deschampsia flexuosa* to remain below a specified threshold, it is held as common practice to regard cover of less than 75% of any individual species at a minimum of 90% of quadrats as being a condition of designation of a site as being in favourable condition. If this target is applied for *Deschampsia flexuosa*, mini-catchment N would not achieve the threshold.

Eriophorum angustifolium and *Eriophorum vaginatum* both established at all sites; neither came to dominate by the end of monitoring. *Lolium perenne* was included in the nurse crop seed mix at all sites but did not establish in any quadrats, suggesting that it is not a suitable species for this application (although it has been observed anecdotally at restoration sites in the first Spring following application and so may serve an initial function before dying out prior to vegetation surveys – Buckler *et al*, 2013). *Molinia caerulea* is a species of concern due to its tendency to dominate at the expense of other species but it did not develop any significant cover at any monitored sites and so it may be concluded that it is at most a marginal risk in this context.

5.2.5. Bryophytes

Within the bryophytes, the acrocarpous mosses, which are tolerant of disturbance, functioned as the pioneer species in the first 5 growing seasons following treatment. These then declined and were succeeded as the dominant group by pleurocarpous mosses at most sites (although not at O, where *Polytrichum* spp became the most extensive).

Where *Sphagnum* mosses were planted they established well, increasing in cover to ~25% over 6 years (Figure 9). As reported in Benson *et al* (2022), *Sphagnum* cover increased significantly more rapidly on undulating and low-lying ground than on hag tops due to the increased availability of moisture. In some of the wettest areas – in particular flow pathways, *Sphagnum* spp cover was approaching 100% by the end of monitoring (Figure 12). This may have important implications for hydrological functions such as water table depth, soil moisture, overland flow generation, in-channel streamflow, sediment transport and water chemistry.

On sites where *Sphagnum* mosses were not planted, they did not establish within the vegetation quadrats. Some patches of *Sphagnum* were been observed in the wetter areas near quadrat locations, but these had not colonised into the quadrats in the 17 years following treatment.

At all sites, the bryophyte layer covered around 90% of the ground in quadrats. Pleurocarpous mosses, dominant within this layer, are classified as an indicator species so this may be viewed as an indication of good health of the vegetation community.

5.2.6. Invasive Species

Importing heather brash from donor sites is associated with some biosecurity risks (Matthew Buckler, pers comms). Measures to mitigate these focused on testing donor sites for presence of pests (*Lochmaea suturalis* – heather beetle) and diseases (*Phytophthora ramorum*) before harvesting brash to apply on restoration sites. There was also some concern that importing heather brash could introduce invasive plant species. In particular, *Chamaenerion angustifolium* presence was recorded at low levels in quadrat data at most sites. Extensive *Chamaenerion angustifolium* was also observed in some areas around quadrats. In some of these areas, where *Sphagnum* spp had been planted, the *Sphagna* were growing well underneath the *Chamaenerion angustifolium.* Anecdotally, less *Chamaenerion angustifolium* was observed at some of the wider context sites than others. The cause of this is unknown but could be related to where the *Calluna vulgaris* brash applied to the sites as part of the treatment work was harvested from. If invasive species cover is of concern to bare peat restoration, proximity of *Chamaenerion angustifolium* to potential *Calluna vulgaris* brash harvesting sites could be considered when selecting harvesting sites, in addition to the standard biosecurity measures focusing on pests and diseases.

5.2.7. Trees

Salix spp cover was extensive in some areas outside of quadrats, while cover appeared to stabilise at low levels in the quadrat data. Tree heights appeared to have reached a limit due to growing conditions. Whether this limit remains for the long term remains to be seen. The implications for hydrological function such as water table depth and soil moisture of extensive but short tree cover are not known but could be important and require further monitoring.

Some *Picea* spp (Sitka spruce) was observed to have established in the field lab mini-catchments (not in quadrats) and across restored areas generally. Some were in excess of 1.5m and therefore appeared not to be restricted by conditions to the same extent as the other tree species.

5.2.8. Common Standards Monitoring

At mini-catchment O and the wider context sites (which all received standard revegetation treatment and, in some cases, gully-blocking), two of the key criteria for designation as favourable condition were not met – and they were not close to being met. These were the requirements for 90% of quadrats to have:

i) At least 6 indicator species present
ii) At least 50% of the vegetation present comprised of at least 3 indicator species

If these criteria were to be relaxed slightly, it becomes clear that these sites may be approaching achievement of these targets, but they are still a way off.

At mini-catchment N (which received standard revegetation treatment, gully-blocking and planting of *Sphagnum* mosses), these key criteria were met, as were all others with the exception of the requirement for at least 90% of quadrats to have less than 1% cover of *Holcus lanatus*, *Agrostis capillaris*, *Phragmites australis, Pteridium aquilinum* and *Ranunculus repens* combined (Figure 16).

Agrostis castellana was included in the nurse crop seed application in the initial treatment and so was inevitably present from that point – and given that *Agrostis* was not surveyed to individual species level, it is not known whether the *Agrostis* recorded in the later years was *Agrostis castellana* or had been replaced by *Agrostis capillaris* (a common generalist grass commonly found in moist grasslands, meadows and disturbed areas). Regardless, *Holcus lanatus* was present at sufficiently high percentage cover as to fail to meet the target on its own, although ~80% of quadrats had less than 1% cover of *Holcus lanatus* in years 10–11, suggesting that if the *Agrostis* present was not *Agrostis capillaris,* mini-catchment N was very close to achieving favourable condition according to the official criteria.

It should also be noted, however, that within this site, there were extensive areas of invasive species (primarily *Chamaenerion angustifolium*), a large number of tree saplings (although these appear to be restricted in their growth by the conditions and so far have not grown to any significant size), and extensive and severe gullying from historic erosion.

5.3. Species dominated

5.3.1. *Calluna* site

Ericoids, specifically *Calluna vulgaris* remained the dominant vegetation type across the three mini-catchments. Cover remained broadly stable in both the control and treatment mini-catchments. There was a suggestion of weak trends (both small increases and small decreases) in *Calluna* cover, however several further years of monitoring will be required to determine if these are real changes or artefacts of survey method limitations.

Changes in bryophytes and specifically *Sphagnum* moss cover presented a clearer picture, however. The intensively planted areas (100 plugs m^{-2}) showed a clear increase in *Sphagnum* cover whilst the control catchment remained unchanged at ~0% cover. Of the treatment catchments, the *Sphagnum* and gully blocked mini-catchment (SphaGB) intensive plots showed the larger change (48% point increase) compared to a 22% point increase for the *Sphagnum* mini-catchment (Spha) intensive plots.

It is likely that this difference may be at least in part due to variation in incline, proximity to erosion gullies and the pre-treatment dominance level of *Calluna*, rather than solely the installation of gully blocks. The SphaGB mini-catchment is located on a flatter area of ground, further from erosion gully edges, and was less dominated by *Calluna* before treatment, compared to the Spha mini-catchment. These factors (in addition to the installation of gully blocks) may all have led to the water table being nearer to the surface (a finding confirmed by dipwell analysis in the water table chapter of this report) and hence would be likely to favour *Sphagnum* growth.

Figure 60. *Sphagnum* plugs begin to coalesce in the *Sphagnum* and Gully blocked intensive plots. Photo taken 17/08/2021, approximately two years after planting.

A smaller increase (from ~0% to ~5%) in *Sphagnum* cover was also observed in the cluster areas (planted at 4 plugs per m^2) whilst the control catchment remained relatively unchanged with almost no *Sphagnum* cover present. This finding suggests that the *Sphagnum* plugs have become successfully established in dense *Calluna* cover in both treatment mini-catchments, despite some drought periods (e.g. Spring 2020) during the first years of growth. Further monitoring is required to track their trajectory of change over future years.

Anecdotal evidence from casual on-site observation in addition to fixed-point photography showed that many of the *Sphagnum* plugs planted at a lower density (1 plugs m^{-2}) in the wider catchment have expanded their area more than those planted at very high density (100 plug m^{-2}) in the intensive plots. They are often double the size or more, even where they are present only a few metres outside the intensive plots (Figure 61). Despite this observation, the latter are on the point of coalescing into a *Sphagnum* carpet after two years of growth (particularly in the SphaGB intensive plots, see Figure 60), whereas the lower density plugs remain widely spaced.

Although the intensive plot plugs were planted around five months after the wider catchment, this alone may not account for the size differences apparent. A possible explanation for the difference is the very localised drainage effects at the intensive plots, caused by the insertion of the gutter and plywood edges into the peat surface, which may have reduced the proportion of time plug plants had access to water, compared to those areas further away from the plot. In addition, there is evidence of trampling in the area around the outside of plots, and potentially therefore a lower % cover of *Calluna* in comparison with the cover within the plot boundary – although this was not measured.

Figure 61. Examples of typical *Sphagnum* plug sizes on 17/08/2021 inside intensive plots (left, 7cm) and outside intensive plots (right, 14cm).

In the intensively treated plots at the *Calluna* site, the treatment meant that some progress was made towards meeting Common Standards Monitoring (CSM) favourable condition criteria. These plots were selected for analysis due to the dense *Sphagnum* planting regime being designed to give an accelerated view of changes that could occur across the wider site in future. Indicator species count increased post treatment on both the *Sphagnum* (Spha) and *Sphagnum* and gully blocked (SphaGB) catchments. In the case of the Spha catchment, the dense cover of *Calluna* remained, meaning 0% of the quadrats (n = 3) contained less than 75% *Calluna* cover. The % of quadrats with more than six indicator species appeared to be on an upward trajectory, but still fell short of the 90% threshold.

However, in the SphaGB catchment intensive plot, where the *Calluna* cover was less dense than the Spha catchment from the start of monitoring (<75% cover in all quadrats), the treatment and resultant increase in indicator species count meant that 100% of quadrats (n = 3) met all CSM criteria for achieving favourable condition indicating that the wider catchment may move towards this condition in time.

In contrast, the control catchment intensive plot remained unchanged, with the dense *Calluna* cover and lack of sufficient indicator species meaning that site did not meet favourable condition criteria at any point.

However, the small sample size of intensive plots in each catchment (n = 3) should be noted when considering the representativeness of these results. It should also be noted that in reality species count would be considerably higher than that recorded in the treated plots. This is because each *Sphagnum* plug introduced contained up to 11 species; but *Sphagnum* was recorded to genus level during surveys – so only accounts for once species in the indicator species count. This undercounting occurred because mixed-species *Sphagnum* plugs are very difficult to identify to species level in the field – it takes some years before individual species take on their characteristic forms.

5.3.1.1. Limitations

On 11/08/2020 portions of the *Calluna* site including both control and treatment catchments were subjected to a light aerial application of lime pellets unintentionally jettisoned from a helicopter applying the pellets to an adjacent site. This overspill was identified on the day of occurrence, and with no rain occurring overnight, steps were taken to mitigate the issue during the following day. A team manually removed the pellets from within all vegetation quadrats effected, including the intensive plots. It is thought that a high proportion of the lime was removed from these areas and it what remained was so minimal as to be unlikely to contribute to any significant changes in vegetation.

5.3.2. *Eriophorum* site

Graminoids, specifically *Eriophorum vaginatum,* remained the dominant vegetation type across the two mini-catchments during the monitoring period. Cover remained broadly stable with a possible weak decrease in cover in intensive plots. Conversely, a small increase in cover was observed in the wider cluster areas. However, there was a good deal of variation in the cover observed year to year. This variation is likely to be due to the challenges involved in estimating graminoid cover, rather than a reflection of real change.

When examining the Common Standards Monitoring (CSM) trends, intensive plots were selected for analysis due to the dense *Sphagnum* planting regime being designed to give an accelerated view of changes which could occur across the wider site in future. However, the apparent downward trend in the % of intensive plot quadrats meeting the CSM derived *E. vaginatum* <75% cover criterion is likely to be the result of small number of replicates (n =3) meaning that only possible results are 0%, 33.3%, 66.6% or 100% of quadrats meeting the criterion.

Of these only 100% would be above the 90% threshold for favourable condition. This course resolution coupled with likely surveyor error (caused by the difficulty in surveying this species accurately), means the trend must be treated with caution.

The average cover of *E. vaginatum* recorded in the intensive plots in the four years 2018–2021 was 67%, 77%, 40% and 75% respectively. This suggests this species was under-recorded in 2020 (most likely recorded as *Deschampsia flexuosa*), and in reality the cover has remained largely unchanged – at around 75% in most cases. ~75% cover is very similar to the CSM criterion, meaning that a relatively minor reduction in *E. vaginatum* cover in future years would allow these plots to reach the CSM favourable condition criteria. This also means that a small change in only one or two quadrats could cause a switch between the site meeting and not meeting the relevant criterion. It would be therefore be advantageous to collect several more years of data before drawing any firm conclusions.

Changes in bryophyte cover, specifically *Sphagnum* mosses presented a clearer picture. An increase in cover in the treatment catchment (both intensive plots and the wider catchment) was recorded. This was found to be significant in the wider catchment quadrats. It was not possible to test intensive plots for significance due to the small sample size (n = 3). However, the large increase recorded in the treatment plots (from a mean cover of 0% to 53%) clearly represented a significant change.

The increase in the total vegetation cover observed in the treatment intensive plots and wider catchment was in large part due to the establishment of a *Sphagnum* layer beneath and amongst the dominant *Eriophorum* spp layer. In addition, a smaller increase in other bryophytes (acrocarpous and pleurocarpous mosses) was noted in the intensive plots.

Fixed point photography showed that *Sphagnum* plugs became successfully established in many places, remaining in place and often expanding in size though the period of the study. Examples can be seen in Figure 62 and Figure 63.

Figure 62. Fixed point photographs of *Sphagnum* plug growth between April 2019 (above) and November 2021 (below)

Figure 63. 13 months of *Sphagnum* plug growth in wider catchment area of *Eriophorum* site between August 2019 (above) and November 2020 (Below).

5.3.3. *Molinia* site

Molinia remained the dominant vegetation type across both mini-catchments at 85–100% cover. There are not yet any obvious indications that the treatment has had an effect on this cover. However, there was some success in establishing *Sphagnum* plugs within the *Molinia*, and a relatively small but significant increase in cover of ~10% and ~8% was seen in the years immediately after treatment in both the intensive plots and the cluster area respectively, reflecting the findings of Pilkington *et al*. 2021.

Anecdotally, *Sphagnum* plug growth form differed somewhat from that seen on both the *Calluna* and *Eriophorum* treatment sites, being less compact and more etiolated in form, as seen in Figure 64.

Figure 64. *Sphagnum* plug growth amongst *Molinia* in treatment plot Mol.Spha.Int1, November 2021.

This effect is likely to be due to competition for light with the *Molinia* in which the *Sphagnum* was growing. This factor may be a limit on *Sphagnum* growth in future years. It should also be noted that the density of the *Molinia* hummocks meant that detecting *Sphagnum* during the summer months was considerably more difficult than when the *Molinia* growth has died back in the winter. It is therefore possible that the *Sphagnum* cover recorded by the surveyors was an underestimate.

It is interesting to note that the mean number of indicator species recorded in the intensively treated quadrats remained below the >6 required to achieve favourable condition. However, had the *Sphagnum* present been surveyed to species level rather than genus only, and had that reflected the ~11 species known to be present in the plugs when planted, then all of the official CSM condition criteria would have been met aside from the dominance of Molinia at >75% cover.

6. Conclusions

6.1. Bare peat

Treating areas of bare peat (including large sites dominated by bare peat with minimal extant vegetation) with applications of heather brash, lime, seed, fertiliser and plug plants (as detailed in the introductory chapter of this report), results in comprehensive vegetation cover within five years, dominated by nurse crop grasses included in the seed mix. Over the following years, the vegetation community undergoes a succession process through which more natural moorland and blanket bog species increase in % cover. While there is variation between sites, the vegetation community tends to comprise ericoids, graminoids and bryophytes in roughly equal proportions, from around seven years after initial treatment.

Within the graminoids, *Deschampsia flexuosa* became the dominant species at several sites, establishing more than 75% cover in some cases, which is more than may be considered ideal – but unlikely to be as a direct result of these restoration methods as its seed was only applied at very low rates. It may rather be that conditions at these sites favour *Deschampsia flexuosa* as it is a generalist graminoid tolerant of a range of soil moistures. Due to historic degradation of these sites, and associated lowering of water tables, conditions may not be wet enough for blanket bog specialists to thrive in the same abundance as *Deschampsia flexuosa* at some sites. *Eriophorum angustifolium* and *Eriophorum vaginatum* (both indicator graminoid species) were present at almost all sites. There is no evidence of *Molinia caerulea* developing any significant presence as a result of these restoration methods.

Within the ericoids, *Calluna vulgaris*, while establishing at almost all sites, did not come to dominate at the expense of other species. There was some evidence of decline in *Calluna vulgaris* at some sites (including the field lab sites O and N on Kinder Scout) in recent years. The cause of this was unknown but likely to be a local effect (for example heather beetle) as opposed to a succession process as it was not observed consistently in the wider context sites. Future monitoring is required to determine whether the apparent decline on Kinder Scout is a short-term fluctuation or a long-term trend.

Within the bryophytes a consistent succession process was observed, with pioneer acrocarpous mosses being replaced by *Polytrichum* spp and/or pleurocarpous mosses once a consolidated vegetation cover had been established. *Sphagnum* mosses did not develop any meaningful presence within the monitored quadrats, even after 17 years following initial treatment, suggesting that they will not recolonise as part of a short-medium term succession process unless they are actively reintroduced. Data from field lab N, where *Sphagnum* plug plants were planted, show that *Sphagnum* mosses can thrive even on heavily degraded sites, as little as five years after initial revegetation from a bare peat starting state. Six years after planting, *Sphagnum* had achieved ~25% cover on undulating ground. By this point, ~70% of the flow pathway network within the catchment was covered by *Sphagnum* (this is based on rough walkover surveys and is an estimate only), increasing to ~85% seven years after planting – and was approaching 100% cover in many stretches. This highlights that *Sphagnum* moss planting can be highly successful on recently bare peat sites, and is required if *Sphagnum* recolonisation is to be achieved.

On sites where *Sphagnum* mosses were not planted, favourable condition (as per CSM guidelines for blanket bogs) was not achieved, 17 years following initial revegetation – and these sites were not close to achieving favourable condition. At field lab N, where 11 *Sphagnum* species were planted in mixed-species plugs, favourable condition was nearly (but not quite) achieved. The barrier to this site achieving favourable condition status was the presence of *Holcus lanatus* (at low but consistent levels) and possible *Agrostis capillaris*. *Agrostis* spp were not surveyed to individual species level so it is unknown whether the *Agrostis* observed was *Agrostis castellana* (Highland Bent, included in the nurse crop seed mix) or *Agrostis capillaris* (Common Bent, which could have succeeded/hybridised with the *Agrostis castellana*). If future surveying could identify which *Agrostis* species is now present at this site – and if this were to confirm it is *Agrostis castellana* – the site would be on the verge of achieving favourable condition. This would likely be the first record of a blanket bog site restored from a bare peat starting state achieving favourable condition under CSM guidelines and would represent a significant milestone in peatland restoration. It should be noted, however, that this site still has an extensive and severe gully network and therefore does not look like an intact blanket bog.

6.2. Species dominated

Two survey seasons after their introduction, *Sphagnum* mosses had become successfully established in all three types of dominant vegetation – *Calluna vulgaris*, *Eriophorum vaginatum* and *Molinia caerulea*. Almost no change in *Sphagnum* cover was recorded in the untreated control areas at all sites, while statistically significant increases in cover were recorded in all treatment mini-catchments.

The largest increases were recorded in the intensive plots, where *Sphagnum* plugs had been introduced at a density of 100 plugs m^{-2}, but significant increases in cover were also recorded in the cluster areas where introduction was at the density of 4 plugs m^{-2}.

Ranked *Sphagnum* cover increases, relative to control, are shown in Table 12 alongside dominant vegetation types, their cover at the start of the monitoring, and *Sphagnum* plug planting densities. Figures are rounded to the nearest whole number. Starting cover of *Eriophorum* marked * is a conservative estimate based on the mean of four years monitoring.

Table 12. *Sphagnum* cover increases by dominant vegetation and planting density

***Sphagnum* cover increase**	**Dominant vegetation (initial cover)**	**Plug planting density**
53% points	*Eriophorum (67%)*	100 m^{-2}
48% points	*Calluna (GB) (50%)*	100 m^{-2}
22% points	*Calluna (87%)*	100 m^{-2}
11% points	*Molinia (88%)*	100 m^{-2}
10% points	*Eriophorum (54%*)*	4 m^{-2}
05% points	*Calluna (GB) (77%)*	4 m^{-2}
05% points	*Calluna (86%)*	4 m^{-2}
03% points	*Molinia (99%)*	4 m^{-2}

Sphagnum cover showed the largest increase on the *Eriophorum* dominated site, followed by the *Calluna* dominated and increased least on the *Molinia* dominated site.

During the monitoring period, there were no clear trends in dominant vegetation cover observed on any of the treatment sites.

On the *Calluna* site, a slight decrease in *Calluna vulgaris* in the treated Spha and SphaGB catchments was observed alongside a small increase in cover in the intensive plot Spha.Int. However, when control (Con) was subtracted this resulted in little change in the Spha of SphaGB catchments, and an increase in cover in the Spha.Int and SphaGB.Int plots. Further years of monitoring will be needed to detect any trends and account for the apparent noise in the data generated as a result of the survey methodology. Fixed-point photography suggests there has not yet been any dramatic change on this site.

On the *Eriophorum* site, *Eriophorum vaginatum* was observed to increase, decrease, then increase again in cover in the cluster areas (Con and Spha). The same pattern was recorded to a lesser degree in the intensive plots (Con.Int and Spha.Int). As noted in the Discussion section above, this pattern is strongly suggestive of noise in data recording due to the survey method. Fixed-point photography suggests there has not yet been any dramatic change in cover on this site.

On the *Molinia* site, *Molinia caerulea* remained at 85–100% cover on both treatment and control catchments (being consistently higher on the treatment catchment both before and after treatment), and where *Sphagnum* was introduced at different planting densities. There was no clear change observed over the monitoring period. This finding is corroborated by fixed-point photography.

However, some changes in indicator species number were observed as a result of the treatment. The *Calluna* site intensive plots (SphaGB.Int) showed a mean increase of 2.7 indicator species; while other treated areas showed an increase of ~1 species. The *Eriophorum* site intensive plots (Spha.Int) showed a mean increase of 0.7 indicator species; while the wider catchment showed an increase of 1.9 species. On the *Molinia* site, the wider catchment showed a mean increase of 1.5 indicator species, while the intensive plot had a decrease of 0.7 species, however as discussed above, the latter is unlikely to reflect reality. It should also be noted that all the increases resulting from *Sphagnum* introduction will be an underestimate. *Sphagnum* was surveyed only to genus level, but each plug may contain up to 11 species.

The increase in indicator species observed in the *Calluna* site *Sphagnum* and Gully Blocked intensive plots (SphaGB.Int) meant that in 2021 for the first time these plots met Common Standards Monitoring (CSM) criteria for achieving favourable condition. This was due to the increased number of indicator species, and consistently lower cover of *Calluna* than other parts of the site. The Spha.Int plots were close to achieving favourable condition, with the number of indicator species on an upward trajectory, but were prevented from meeting the criteria due to a consistently high *Calluna* cover.

Similarly, the *Sphagnum*-treated intensive plots at the *Eriophorum* site were prevented from achieving favourable condition by the continued dominance of *E. vaginatum*, but all other factors including indicator species count met the threshold throughout the monitoring period. It was found that a relatively minor reduction in cover would be needed to take *E. vaginatum* to <75%; thus meeting all CSM criteria.

The low number of indicator species on the *Molinia* site meant that it did not meet the CSM criteria tested for during the monitoring period. However, if the *Sphagnum* plugs had been surveyed to species level, then >6 indicator species would very likely have been found in all intensive quadrats in 2020 and 2021. In reality, the continued dominance of *M. caerulea* would prevent favourable condition status from being achieved.

7. References

Alderson, DM, Evans, MG, Shuttleworth, EL, Pilkington, M, Spencer, T, Walker, J & Allott, TEH (2019). 'Trajectories of ecosystem change in restored blanket peatlands', *Science of the Total Environment*, vol. 665, pp. 785–796. https://doi.org/10.1016/j.scitotenv.2019.02.095

Benson J., Crouch, T., Spencer, T. & Pilkington, M. (2022) Monitoring *Sphagnum* growth from propagules applied to re-vegetated degraded blanket bog; Kinder Scout *Sphagnum* Trials: 2020 Update Report. Moors for the Future Report, Edale.

Buckler, M., Proctor, S., Walker, J.S., Wittram, B., Straton, P., Maskill, R.M (2013) Recommendations for bare peat restoration; treatment prescriptions and monitoring ten years of moorland restoration across Bleaklow, Black Hill and Kinder (2003–2013). Moors for the Future Partnership, Edale.

Drury, S. (2005). Back on Track. *Horticulture Week*. December 15, 2005, 26–27.

Hubbard, C. E. (1984) Grasses : A Guide to their Structure, Identification, Uses, and Distribution in the British Isles. Penguin Press Science.

JNCC, 2009. *Common Standards Monitoring Guidance for Upland Habitats* Version July 2009 http://jncc.defra.gov.uk/page-2237 accessed May 2015

Maskill, R., Walker, J.S., Buckler, M., King, L., and Wittram, B. (2015) MoorLIFE: Vegetation Report. Moors for the Future Report, Edale.

Natural England, 2015. *Summary of evidence: Biodiversity*. Natural England Access to Evidence Information Note EIN004. http://publications.naturalengland.org.uk/category/5856835374415872 accessed Dec 2021.

Natural England, 2020. Sites of special scientific interest: managing your land. https://www.gov.uk/guidance/protected-areas-sites-of-special-scientific-interest#sssi-condition-and-assessment accessed December 2021.

PAA, 2003. *United Utilities Water PLC – Assessment of SSSIs in Unfavourable Condition* Volume 4: South Pennine Moors – Worsthorne Moor. Ref. No. 030629, July 2003. Penny Anderson Associates Limited, 'Park Lea', 60 Park Road, Buxton, Derbyshire, SK17 6SN

PAA, 2005. *Yorkshire Water Moorland SSSI recovery project*, Penny Anderson Associates Limited, 'Park Lea', 60 Park Road, Buxton, Derbyshire, SK17 6SN

Pilkington, M., Walker, J., Maskill, R. (2015). *Annex 2: The development of plant diversity*. In Pilkington M.G. *et al.* (2015) Restoration of blanket bogs; flood risk reduction and other ecosystem benefits. Final report of the Making Space for Water project: Moors for the Future Partnership, Edale.

Pilkington, M., Walker, J., Fry, C., Eades, P., Meade, R., Pollett, N., Rogers, T., Helliwell, T., Chandler, D., Fawcett, E., & Keatley, T. (2021). Diversification of *Molinia*-dominated blanket bogs using *Sphagnum* propagules. Ecological Solutions and Evidence, e12113.

Rodwell, J., (Ed.) (1991). *British Plant Communities, Volume 2: Mires and Heaths.* Cambridge University Press, Cambridge.

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