Moor Water

Vegetation monitoring – survival and growth of Sphagnum plugs after planting, and progress towards achieving Favourable Condition

2025

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1. Summary

- *Sphagnum* plugs were introduced at five sites within the Bamford Catchment each with different starting conditions.
- Vegetation diversity, cover and *Sphagnum* plug survival and growth were monitored.
- Progress towards achieving Favourable Condition as defined by Common Standards Monitoring (CSM) guidance was investigated.
- 88% of plugs survived the monitoring period, and most surviving plugs underwent some growth. Growth rate and survival varied by site.
- Indicator species frequency was increased by the addition of plugs.
- Although progress was made, at the end of the monitoring, none of the sites met all CSM targets for Favourable Condition.
- One site would have met all attribute targets had *Sphagnum* plugs been surveyed to species level.
- At 4 of the 5 sites, ericoid cover remained too high to meet the CSM attribute target. This was predominantly a combination of common heather (*Calluna vulgaris),* crowberry *(Empetrum nigrum)* and bilberry (*Vaccinium myrtillus*).

2. Introduction

The Moor Water project area lies within the Bamford Catchment in the Peak District National Park and the South Pennine Moors Special Area of Conservation (SAC). As described in the final report of the MoorLIFE 2020 project (Margetts, Pilkington and Spencer 2022), this SAC contains one third of the UK's blanket bog habitat. This is a globally rare resource, with over 10% found in Britain alone. These areas play important roles in flood risk management, drinking water quality and carbon sequestration.

A long history of agricultural exploitation, commercial afforestation, outbreaks of wildfire, together with the effects of atmospheric pollution has led to degradation of these habitats. Keystone *Sphagnum* mosses disappeared, and extensive areas of bare peat were subject to deep erosional gullying. Apart from losing habitat and amenity value, these changes lead to substantially increased emissions of carbon dioxide, reservoir infilling and discoloration of water. In other areas, individual species have come to dominate large areas. These include hare's tail cotton-grass (*Eriophorum vaginatum*), common heather (*Calluna vulgaris*) and purple moor-grass (*Molinia caerulea*).

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 and potentially hydrology may be experienced in blanket bog-designated areas that have become dominated by common heather, cotton-grasses or other species. Thus, the achievement of "favourable condition" status on these sites may require extreme management intervention, including

but not limited to 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.

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 current background deposition of key atmospheric pollutants onto blanket bog habitats has declined to a level which supports vegetation recovery and diversification. Sulphur dioxide pollution has fallen dramatically in the UK since the 1960s, allowing conditions which support the re-establishment of key species. The Making Space for Water project (Pilkington et al, 2015) found that, where areas of bare peat were revegetated, the bare peat area reduced by 90% in the first 4 years after restoration, replaced by a mixture of vegetation species, with the number and % cover of indicator species present increasing year on year. Notably, however, *Sphagnum* mosses did not re-establish themselves within any of the monitored areas. This finding was supported by monitoring at revegetated sites across the South Pennines where *Sphagnum* did not develop any meaningful cover in quadrats, although it was observed in a small number of isolated patches in wet areas outside of quadrats (Maskill et al, 2015).

Sphagnum mosses are known to be key species in blanket bog plant communities. As well as supporting peat accumulation (and therefore carbon sequestration) (Noble et al, 2019), they have been shown to have benefits for water quality (Ritson et al, 2016) and flood mitigation (Holden et al 2008).

The aim of this investigation is therefore to show any progress towards achieving favourable condition on five sites within the Bamford Catchment where interventions have been made through the Moor Water project – specifically the introduction of *Sphagnum* plug plants. This is an opportunity to add to the work of the Making Space for Water project of 2015, and the MoorLIFE 2020 project to further detail the trajectory of restoration sites towards blanket bog favourable condition.

3. Location of project area

Five sites have been selected at which to monitor the success of *Sphagnum* plug application within the Upper Derwent catchment. These have been chosen to encompass a range of different vegetation states and starting conditions and are shown in Figure 1 below.

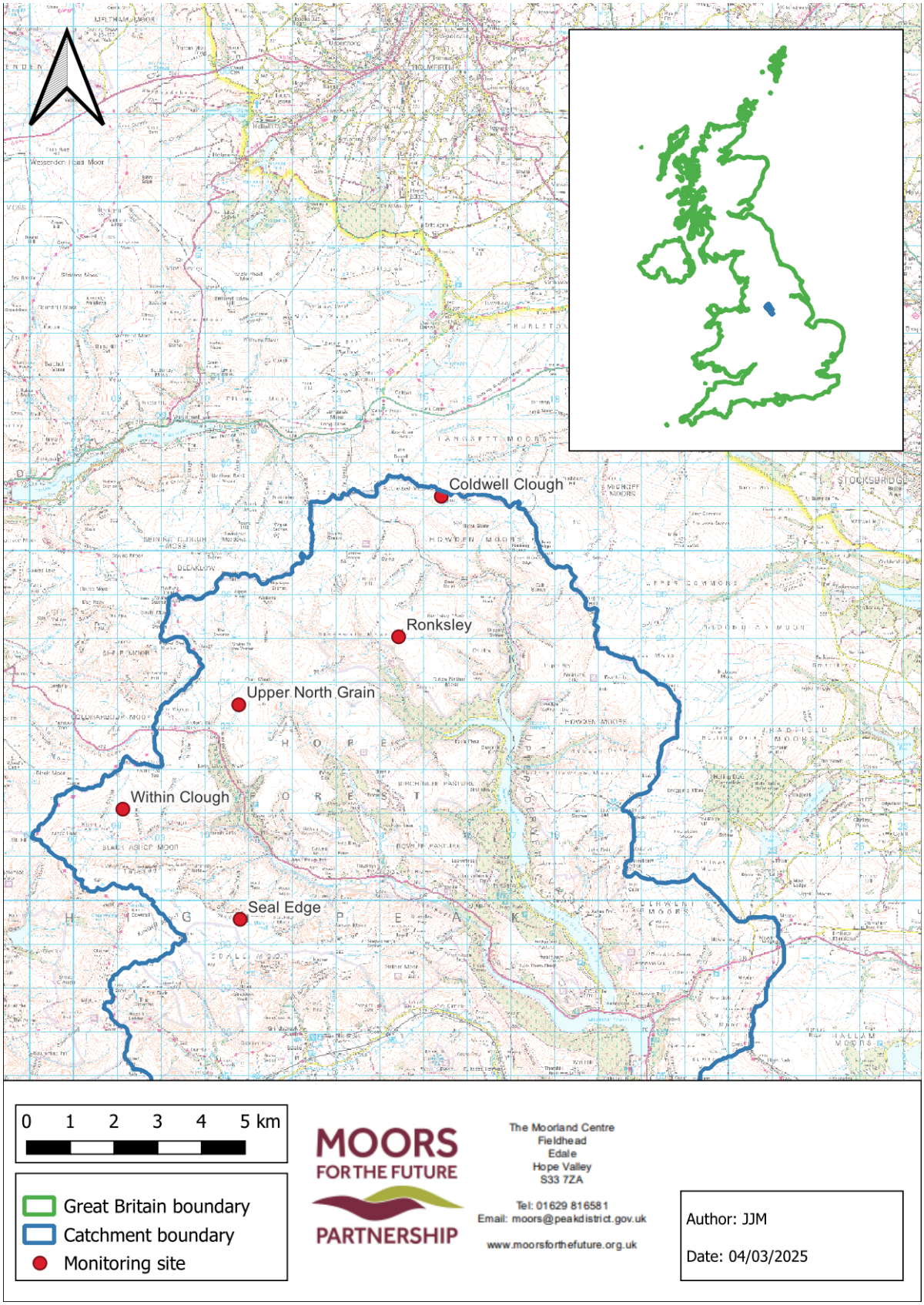

Figure 1. Locations of the five monitoring sites within the Upper Derwent 'Bamford' Catchment.

3.1. Coldwell Clough

This site is located at Coldwell Clough Head on Howden Moor, South Yorkshire just within the upper catchment of the River Derwent (Figure 2). It is approximately 10 kilometres north north east of Kinder Scout. The site is owned by partner organisation the National Trust and is within the boundary of the Peak District National Park. It is located around one kilometre from the county boundary with Derbyshire.

The site is at an elevation of approximately 500 m, and is characterised by cover comprising a mixture of heather (*Calluna vulgaris*), bilberry (*Vaccinium myrtillus*), crowberry (*Empetrum nigrum*) and cotton-grasses with an understorey of feather mosses, covering a peat layer over gritstone bedrock. Small amounts of several other species are also present but infrequent. The landscape visible from the site is open and treeless in all directions.

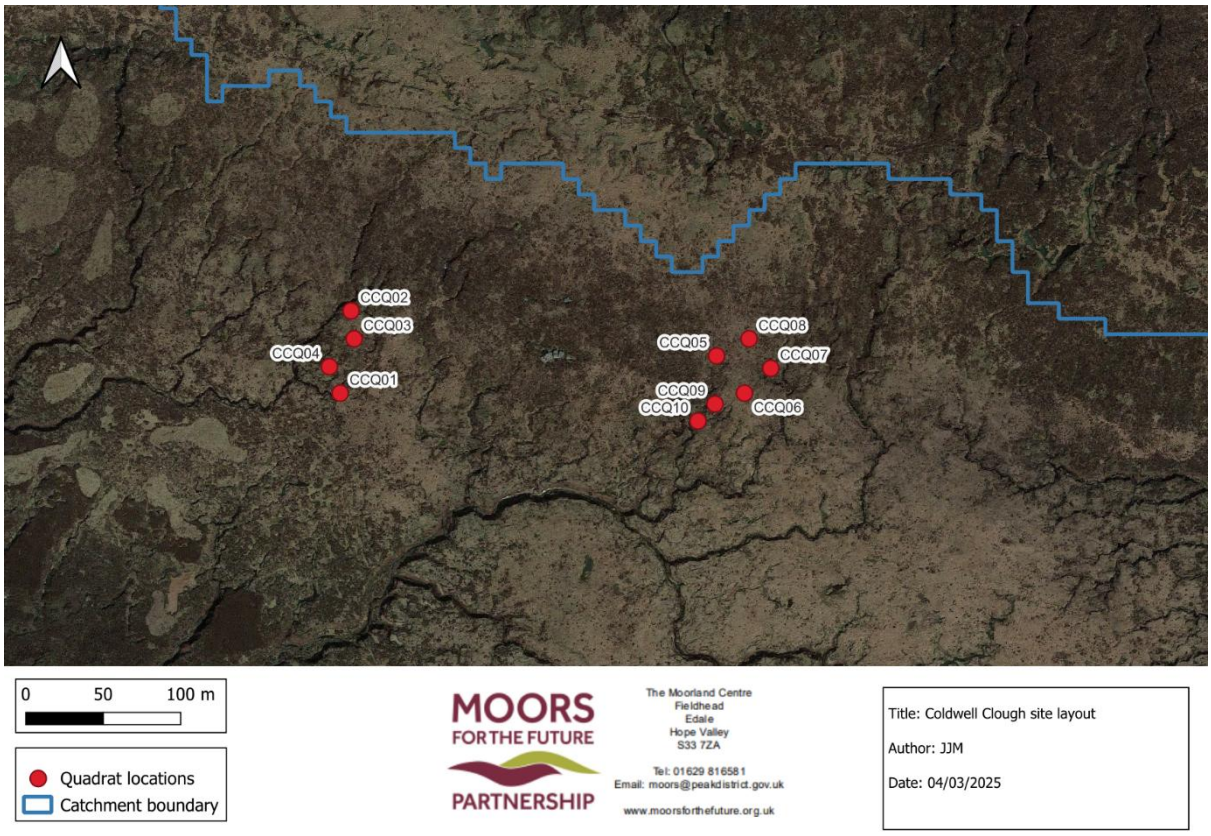

Figure 2. Layout of Coldwell Clough monitoring site.

3.2. Ronksley

This site is located at Ronksley Moor, Derbyshire within the upper catchment of the River Derwent (Figure 3). It is approximately three kilometres north north west of Howden Reservoir. The site is owned by partner organisation the National Trust and is within the boundary of the Peak District National Park.

The site is at an elevation of approximately 500 m, and is characterised by cover comprising a mixture of cotton-grasses, heather and bilberry with an understorey of feather mosses, covering a peat layer over shale grit – sandstone bedrock. Small amounts of several other species are also present but infrequent. The landscape visible from the site is open and treeless in all directions.

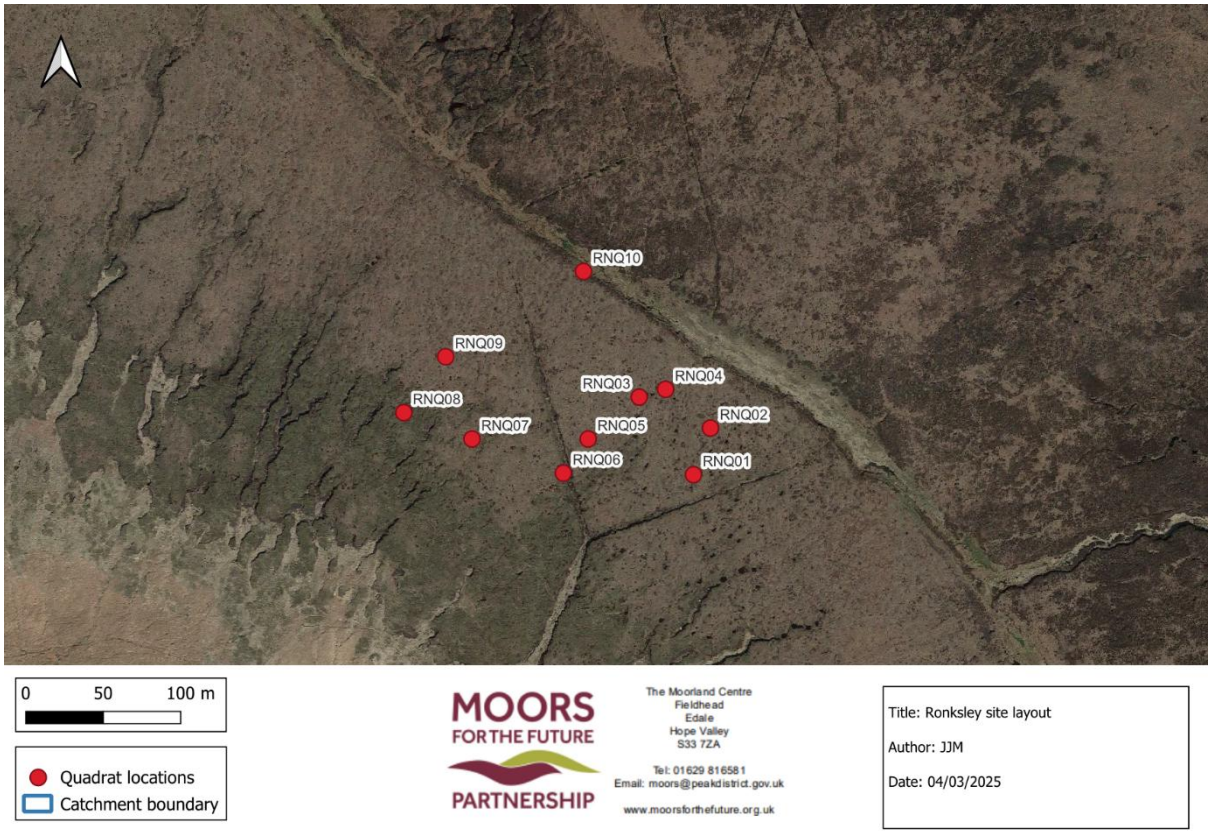

Figure 3. Layout of Ronksley monitoring site.

3.3. Seal Edge

This site is located at Seal Edge on the north edge of the Kinder Scout plateau, Derbyshire within the Upper Ashop Catchment which leads downstream to the Derwent Catchment (Figure 4). The site is at an elevation of approximately 600 m. It is approximately six kilometres west of Ladybower Reservoir. The site is owned by partner organisation the National Trust and is within the boundary of the Peak District National Park.

The area encompasses mainly undulating degraded blanket bog, often deeply gullied and with extensive areas which were bare peat until they were revegetated in the 2010s. The area

was in one of the most severely degraded blanket bog habitats in the Dark Peak and South Pennines and probably the most severely degraded upland blanket bog anywhere.

The revegetation work has resulted in almost comprehensive colonisation of the previously bare peat areas, with key 'indicator' species developing cover within the vegetation community.

It is currently characterised by cover comprising a mixture of heather (*Calluna vulgaris*), and graminoids, particularly wavy hair grass (*Deschampsia flexuosa*) with an understorey of feather mosses. There is some bilberry (*Vaccinium myrtillus*), crowberry (*Empetrum nigrum*) and cotton-grasses present. The site comprises of a peat layer over gritstone bedrock. Small amounts of several other species are also present but infrequent. The landscape visible from the site is open and treeless in character.

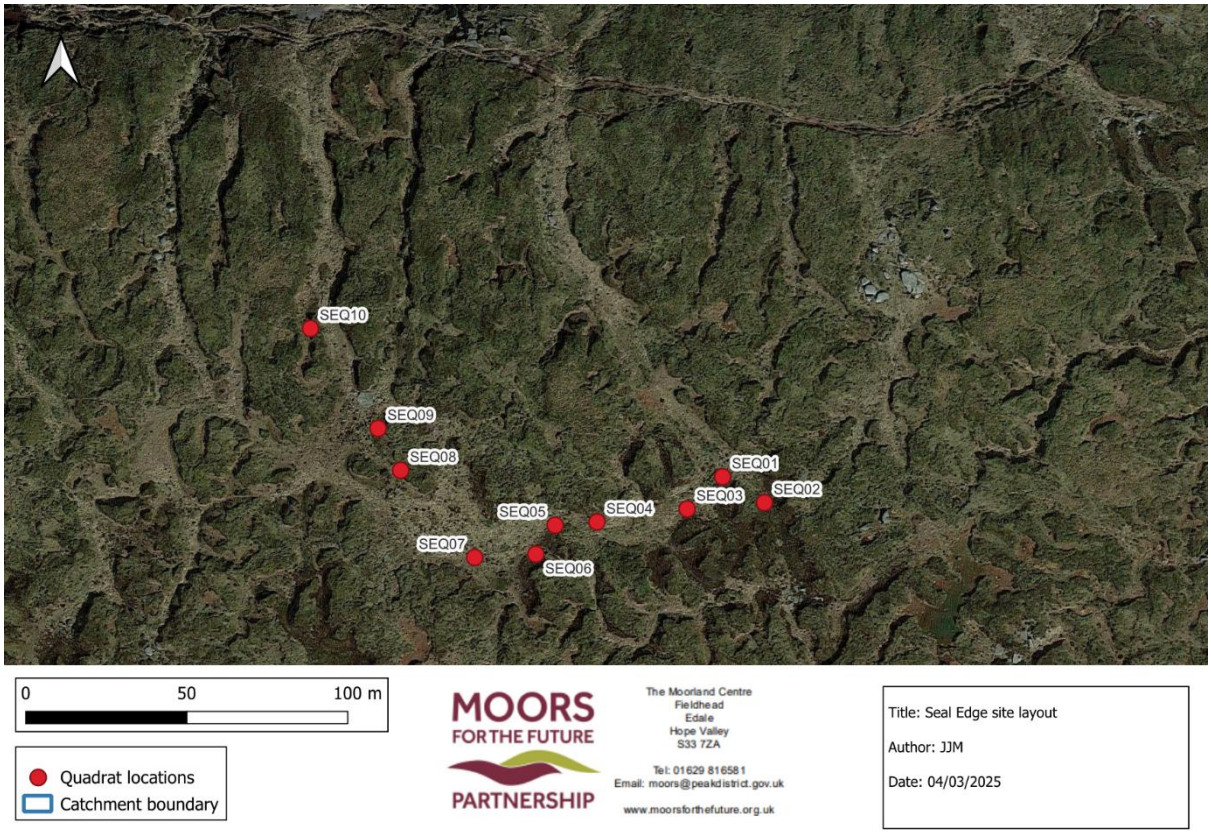

Figure 4. Layout of Seal Edge monitoring site.

3.4. Upper North Grain

This site is located at Upper North Grain, Derbyshire within the upper catchment of the River Derwent (Figure 5). It is approximately six kilometres west of Howden Reservoir. The site is owned by partner organisation the National Trust and is within the boundary of the Peak District National Park.

The site is at an elevation of approximately 500 m, and is characterised by cover comprising mainly of cotton-grasses, with some wavy-hair grass, bilberry and heather present. Bryophytes present consist mainly of feather mosses. The site has a peat layer over shale grit-sandstone bedrock. Small amounts of several other species are also present but infrequent. The landscape visible from the site is open and treeless in all directions. The area has previously undergone restoration actions through various projects which has resulted in treatments including gully blocking with dams of various types (including stone, plastic, timber and heather bale), introduction of dwarf shrub and cotton grass plug plants.

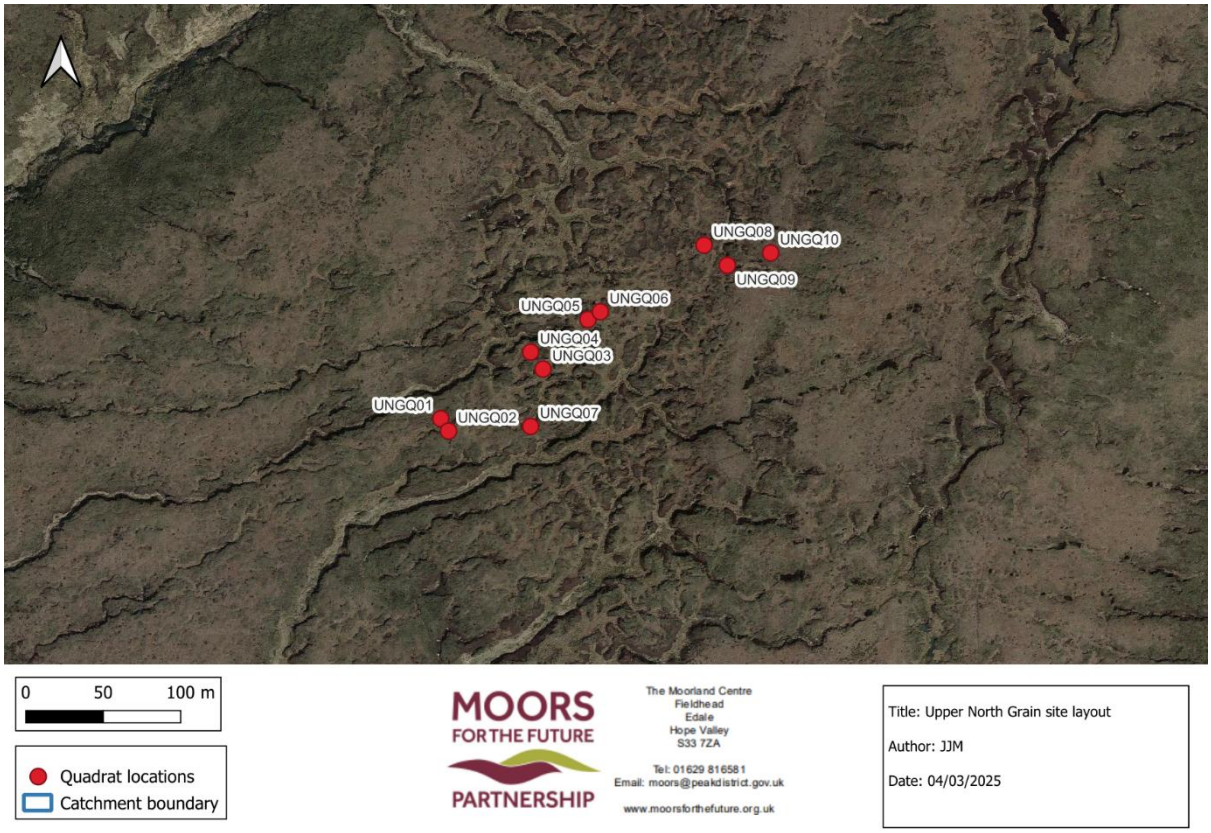

Figure 5. Layout of Upper North Grain monitoring site.

3.5. Within Clough

This site is located in between Within Clough and Red Clough, Derbyshire within the upper catchment of the River Derwent (Figure 6Figure 3). It is approximately one kilometre north of the north-edge of Kinder Scout. The site is owned by partner organisation the National Trust and is within the boundary of the Peak District National Park.

The site is at an elevation of approximately 450 – 500 m, and is characterised by cover comprising mainly of cotton-grasses and heather with other species (such as crowberry and bilberry) present. Bryophytes coverage is minimal. The site has a peat layer over shale grit – sandstone bedrock. Small amounts of several other species are also present but infrequent. The landscape visible from the site is open and treeless in all directions.

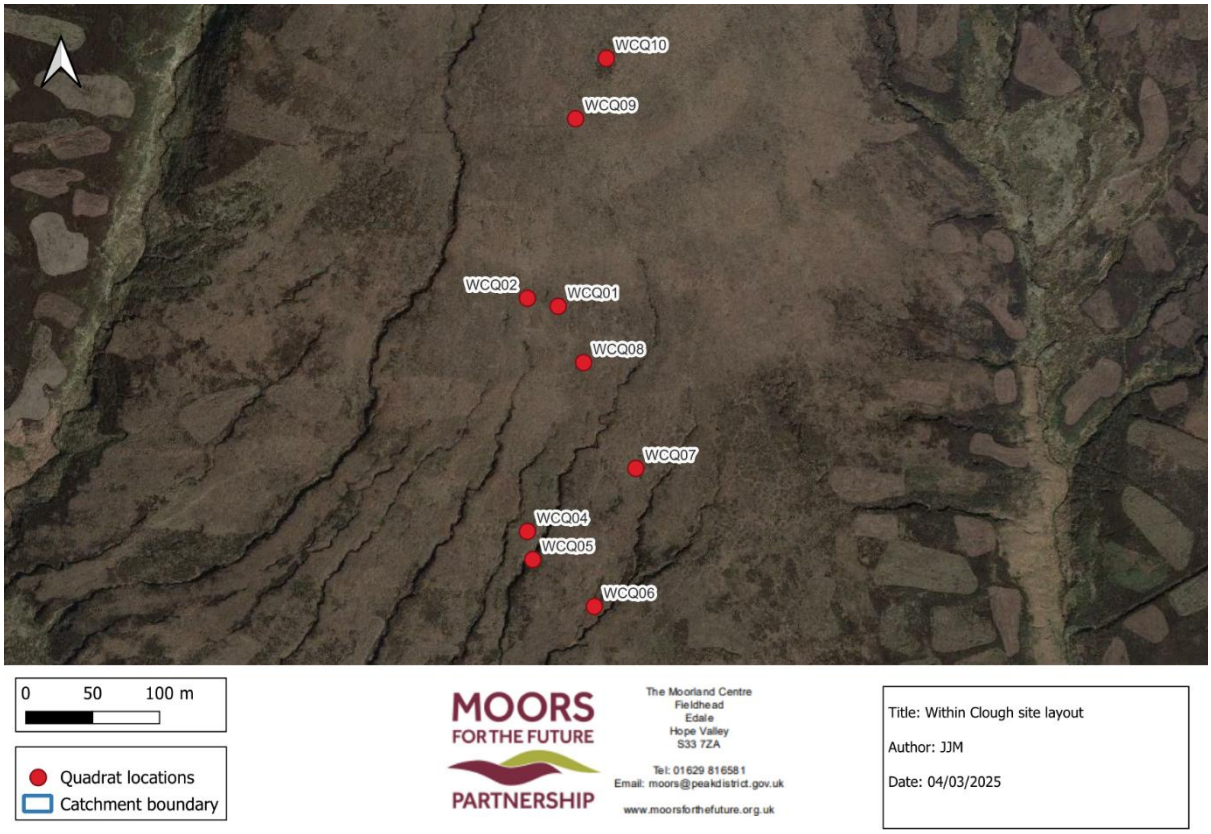

Figure 6. Layout of Within Clough monitoring site.

4. Treatment regimes

All five monitoring sites are positioned within areas inoculated with propagated *Sphagnum* plugs as part of the conservations works package delivered through the Moor Water project. Plugs have been planted at an approximate density of 1,150 plugs per hectare, planted in accordance with MFFP *Sphagnum* planting specifications. The details of the planting area in which each monitoring unit is established are shown below in Table 1. Details of the sphagnum species present in each of the plug mixes used are shown below in Table 2.

Table 1: Overview of the treatment regimes monitored

Site	Plug type	Units planted	Area planted (ha)	Year planted
Coldwell Clough	Moorland mix	20,700	18.7	2022
Ronksley	Moorland mix	36,700	33.5	2023
Seal Edge	Chunky mix	48,750	42.1	2021
Upper North Grain	Moorland mix	16,100	13.6	2022
Within Clough	Chunky mix	45,000	39.5	2021

Table 2. Species of *Sphagnum* present in the plug plant mixes used in the treatment

***Sphagnum* species**	**Moorland mix**	**Chunky mix**
Fallax	✓	
Palustre	✓	✓
Papillosum	✓	✓
Capillifolium	✓	✓
Cuspidatum	✓	
Fimbriatum	✓	
Subnitens	✓	✓
Denticulatum	✓	
Squarrosum	✓	
Tenellum	✓	
Magellanicum (now Medium)	✓	✓

5. 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 the characteristics of each site that are impacting the chances of that status being achieved.

6. Methodology

6.1. Experimental design

Vegetation diversity was monitored before and after inoculation with *Sphagnum* plugs at the sites detailed in section 3 above. *Sphagnum* plug survival and growth was also monitored at the sites once the treatment had taken place. The treatments occurred at different times between 2021 and 2023 at each site (see Table 1 above) so monitoring ran for different lengths of time at each site. Surveys took place before and just after planting, and again in 2024 – the final full year of the project. Any years in-between these points were monitored by fixed-point photography. Wider site fixed point photography was also taken, and is presented in an annex to this report.

6.2. Monitoring vegetation in the field

6.2.1. Locating quadrats

Sets of ten quadrats measuring 2 m x 2 m were established at each monitoring site, and each quadrat was centred around a *Sphagnum* plug planted by contractors. A random sampling approach was not used in the placing of quadrats because of the need to select areas where contractors had planted. In general, however care was taken to minimise the selection of areas containing gully floors, gully sides or hag tops or pre-existing *Sphagnum*. Quadrats were set up on undulating ground representing the surrounding area. These locations were marked by wooden stakes, enabling portable quadrats to be placed in exactly the same position on each repeat of the surveys.

6.2.2. Frequency of surveys

Table 3. Record of timing of surveys by site and type. Fixed-point photography (FPP) occurred at all surveys and is only noted here where it was the sole monitoring type in a given year. Upper North Grain is abbreviated as UNG.

Year	Coldwell Clough	Ronksley	Seal Edge	UNG	Within Clough
2021	-	-	Baseline	-	Baseline
2022	-	-	FPP	Baseline	FPP
2023	Baseline	Baseline	FPP	FPP	FPP
2024	Final surveys	Final surveys	Final surveys	Final surveys	Final surveys

6.2.3. Calculating percentage coverage 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) or graminoids (grasses).

6.2.4. Calculating *Sphagnum* plug size

Identifying *Sphagna* to individual species level can be difficult in the field, especially in the initial years following planting as small plugs – before they take on their characteristic colouration and forms. For this reason, any species of *Sphagnum* observed during the general surveys were recorded to genus level only 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.

Individual measurements of each *Sphagnum* patch within each quadrat was recorded at the end of the penultimate and final growth seasons of the project (winter 23/24 and 24/25). Measurements were taken in three dimensions – width, length and depth to allow for modelling of approximate plug area and volume.

7. Data analysis

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. 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 by this measure, 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.

In addition, individual *Sphagnum* plug measurements were analysed to show: (i) change in volume of plugs since baseline (ii) survival rate (iii) a 3D visualization of modelled plug volume change. In order to model plug size, their area covered was simplified to a circle using a mean of X and Y measurements to calculate an average diameter. To model volume, this was multiplied by depth (Z) to calculate the volume of a cylinder. It is acknowledged that this model is imperfect as plugs can take on various shapes sometimes akin to a dome and often more elongated in one of either X or Y dimensions. However, this method allows for an approximate comparison of growth rates at each site.

As each site was treated at a different time, results have been normalized to show time since treatment, either in days or growth seasons.

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

8. Results

Results are presented below for three key variables at each site: (i) bare peat cover, (ii) indicator species cover and (iii) indicator species count. In addition, the percentage of quadrats satisfying the conditions for three key equivalent 'attribute targets' required for Favourable Condition (90% of quadrats being the minimum): (iv) at most 10% cover of bare peat; (v) at least 50% vegetative cover to be composed of at least three indicator species; (vi) at least six indicator species. These latter three attributes are singled out because either one or a combination of these is most often the reason for failure to achieve Favourable Condition. Any other notable failures to meet CSM criteria are also be presented. These results are presented separately for each site for reasons of clarity. A summary of the results is presented below in Table 6.

However, results from the monitoring of *Sphagnum* plug survival and growth at all sites are presented together at the end of this section, to allow for comparison.

Table 6. Summary of attribute targets met (90% of quadrats meeting criterion) at each site in 2024. * denotes unclear or caveated result – see discussion section.

	Coldwell Clough	Ronksley	Seal Edge	UNG	Within Clough
<10 % bare peat	✗	✓	✓	✓	✓*
≥ 50% cover of >2 indicator species	✓	✓	✗	✓	✓
≥ 6 indicator species	✓	✓	✗*	✓	✗*
<75% ericoid cover	✗	✗	✗	✗	✓

8.1. Coldwell clough

Figure 7. Overview of Coldwell Clough monitoring site.

8.1.1. Bare peat

Bare peat cover at this site has remained stable throughout the monitoring period at around 5% on average, as shown in Figure 8 below. However, currently the site does not satisfy the CSM target for bare peat, with only ~80% of the quadrats containing <10% bare peat, fewer than the 90% required, as shown in Figure 9.

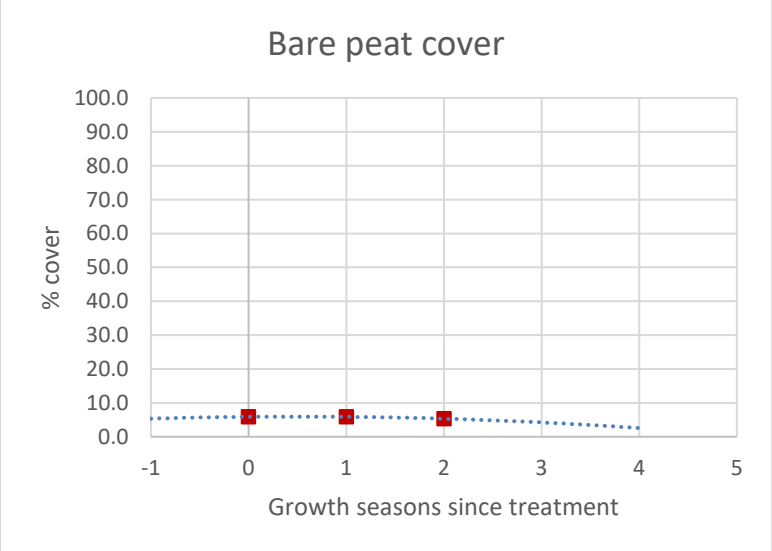

Figure 8. Mean cover of bare peat at Coldwell Clough.

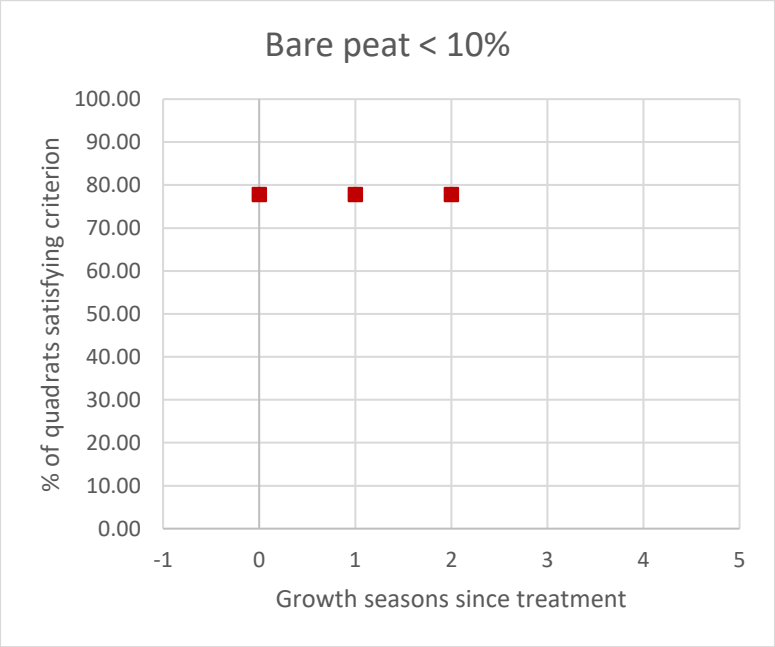

Figure 9. Proportion of quadrats at Coldwell Clough meeting CSM criterion of less than 10% bare peat cover. To achieve favourable condition, at least 90% of quadrats should satisfy this criterion.

8.1.2. Indicator species

Total indicator species cover appears to be lower in year two than year one; however, it is likely that this is not a real effect but the result of difference in surveyor estimates, as all but one of the indicator species have lower estimated cover in year two compared to year one. A survey in year three may help to resolve the disparity. However, the frequency of indicator species rose from seven before the introduction of *Sphagnum* plugs, to (at least) eight after. The site meets and criteria for CSM favourable condition shown in Figure 12 and Figure 13 below, with 100% of the quadrats meeting the attribute targets.

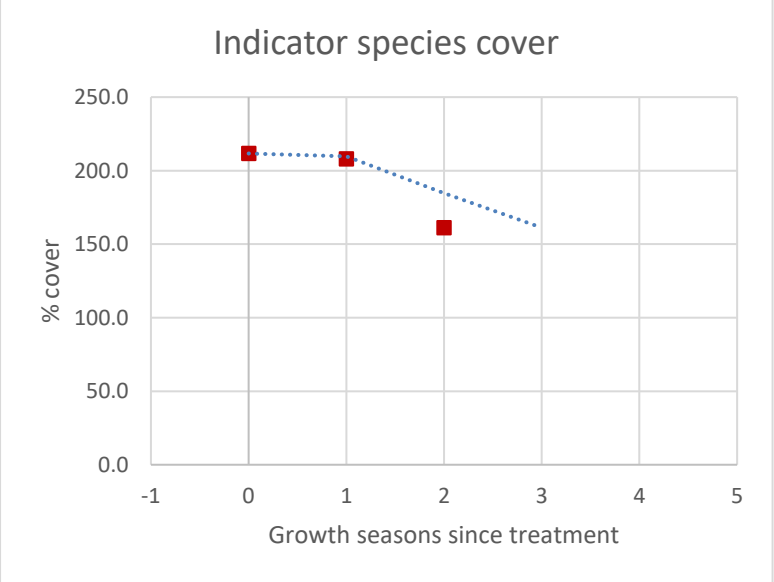

Figure 10. Average total cover of indicator species recorded at Coldwell Clough.

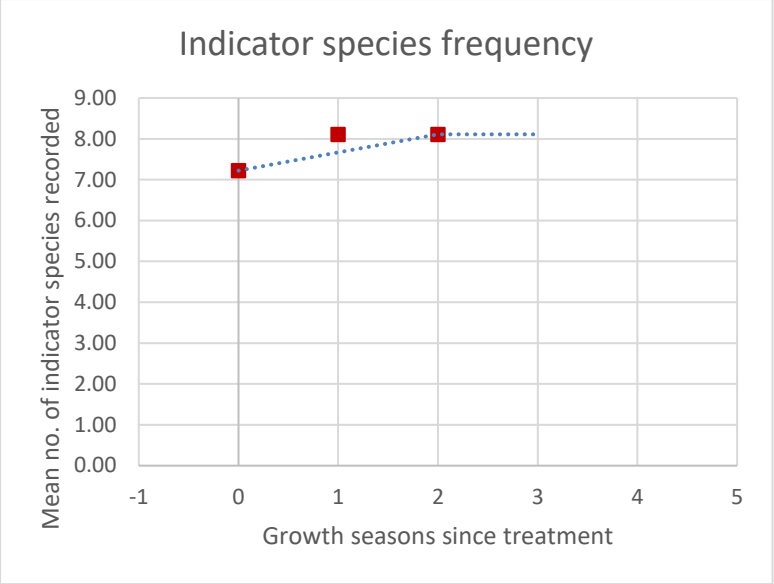

Figure 11. Mean frequency of indicator species recorded at Coldwell Clough.

8.1.3. ≥ 50% cover of >2 indicator species

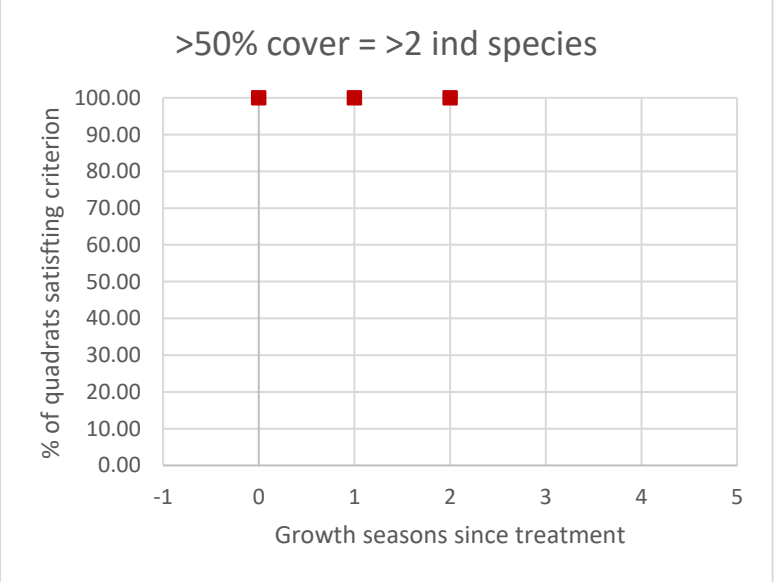

Figure 12. Proportion of quadrats at Coldwell Clough meeting CSM criterion of more than 50% cover of 3 or more indicator species.

8.1.4. Six or more indicator species

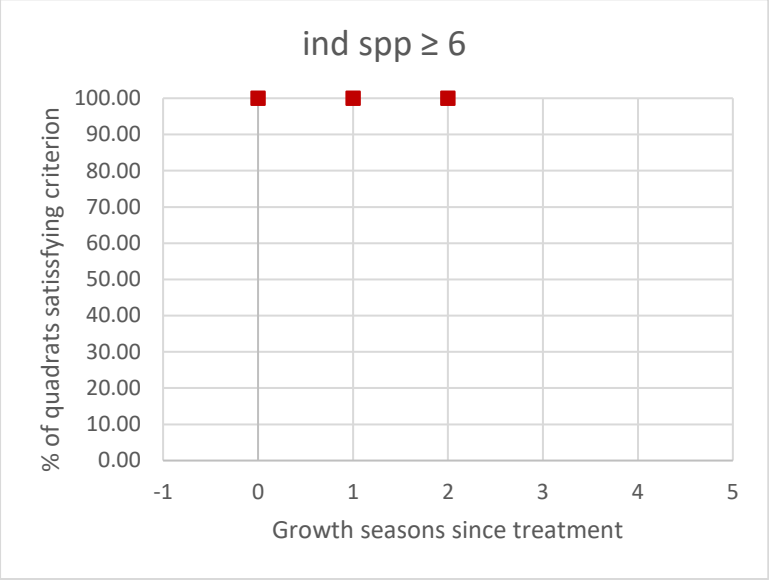

Figure 13. Proportion of quadrats at Coldwell Clough meeting CSM criterion of six or more indicator species.

8.1.5. Other notable criteria

Currently this site also fails another key target, with around two thirds of quadrats containing more than 75% ericoid cover.

8.2. Ronksley

Figure 14. Overview of Ronksley monitoring site

8.2.1. Bare peat

Bare peat cover remained stable with a mean of ~3% throughout the monitoring period, as shown in Figure 15. 90% of the quadrats met the CSM favourable condition criterion (Figure 16), containing <10% bare peat, with only one quadrat (Q03) containing around 25-30% bare peat cover.

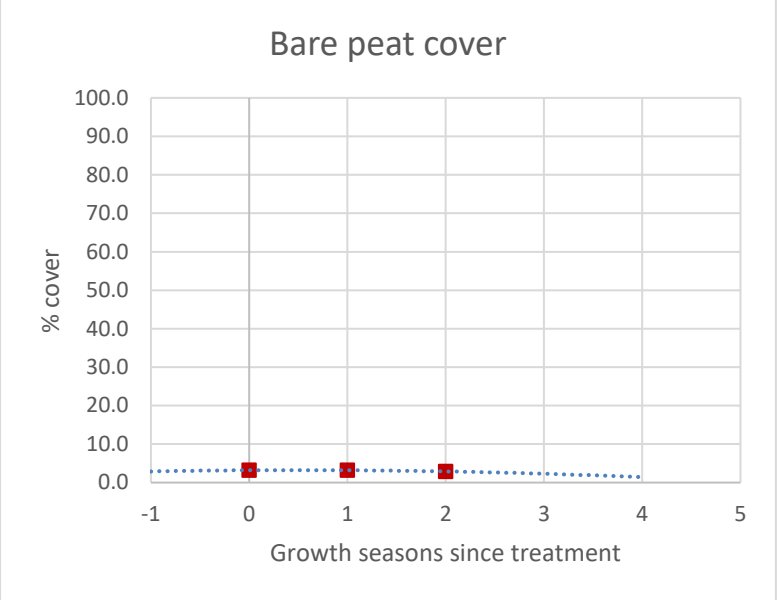

Figure 15. Mean cover of bare peat at Ronksley.

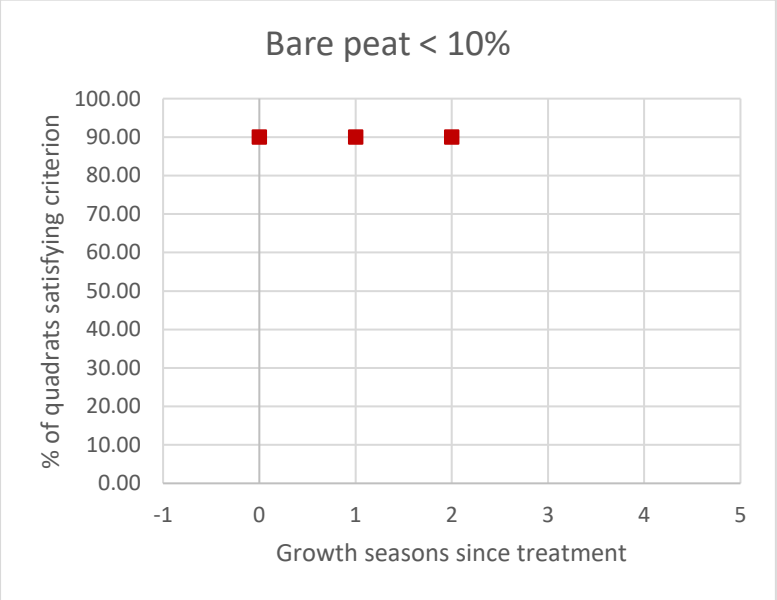

Figure 16. Proportion of quadrats at Coldwell Clough meeting CSM criterion of less than 10% bare peat cover. To achieve favourable condition, at least 90% of quadrats should satisfy this criterion.

8.2.2. Indicator species

Total indicator species cover appears to be similar (~150 – 170%) through the monitoring period, but is slightly lower in year two than year one. However, it is likely that this is not a real effect but the result of difference in surveyor estimates. A survey in year three may help

to resolve the disparity (Figure 17). However, the frequency of indicator species rose from a mean of 7.4 before the introduction of *Sphagnum* plugs, to 8.3 after (Figure 18). The site meets and criteria for CSM favourable condition shown in Figure 19 and Figure 20 below, with 100% of the quadrats meeting the attribute targets.

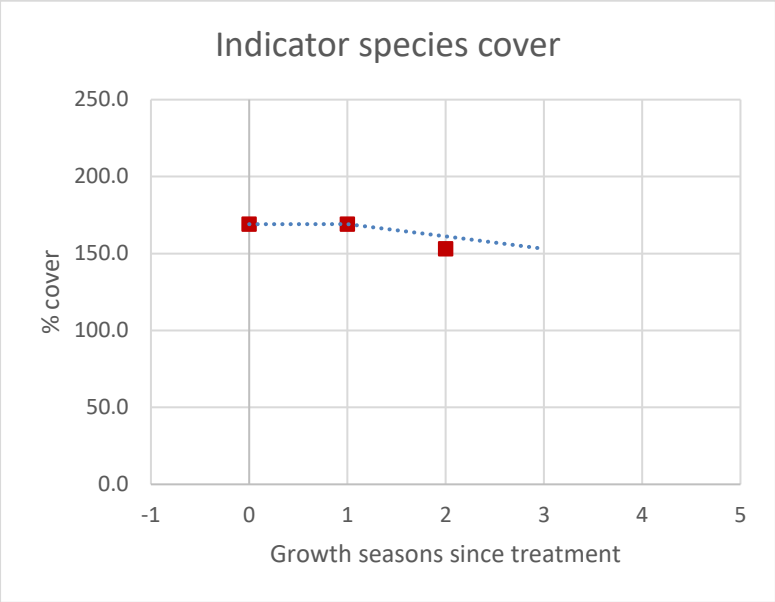

Figure 17. Average total cover of indicator species recorded at Ronksley.

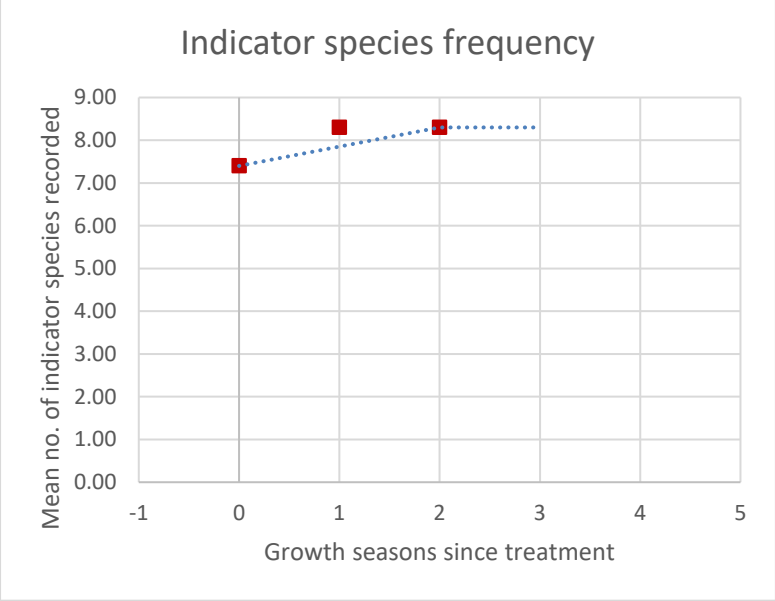

Figure 18. Mean frequency of indicator species recorded at Ronksley.

8.2.3. ≥ 50% cover of >2 indicator species

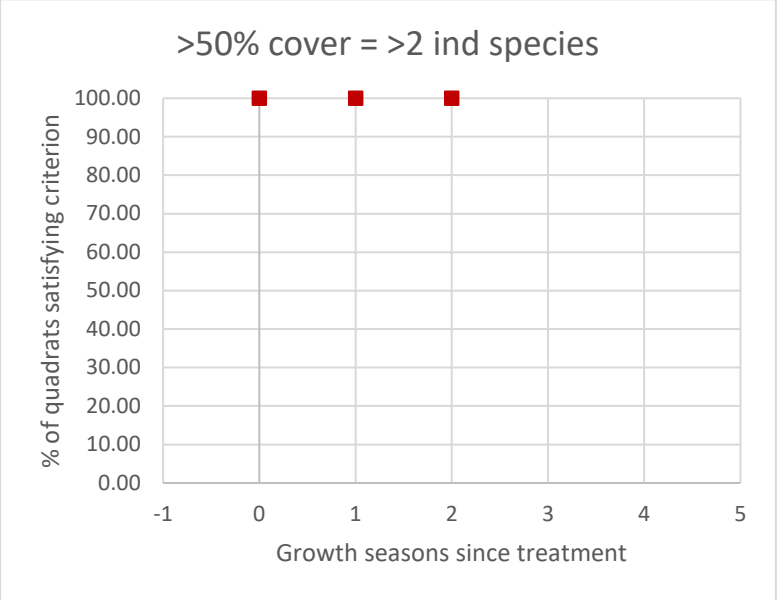

Figure 19. Proportion of quadrats at Ronksley meeting CSM criterion of more than 50% cover of 3 or more indicator species.

8.2.4. Six or more indicator species

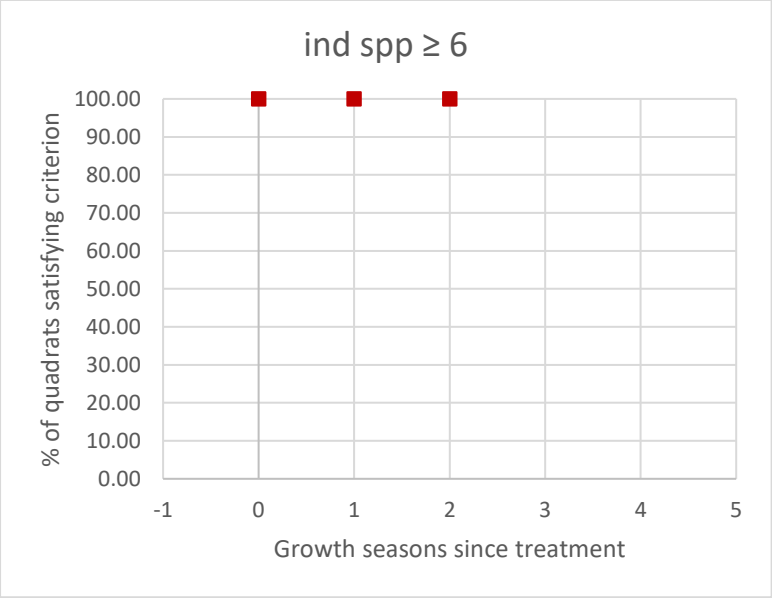

Figure 20. Proportion of quadrats at Ronksley meeting CSM criterion of six or more indicator species.

8.2.5. Other notable criteria

Currently this site fails another key target, with 30% of quadrats containing more than 75% ericoid cover.

8.3. Seal Edge

Figure 21. Overview of Seal Edge monitoring site.

8.3.1. Bare peat

Bare peat cover remained stable with a mean of ~1% throughout the monitoring period, as shown in Figure 22. 100% of the quadrats met the CSM favourable condition criterion (Figure 23), containing <10% bare peat, with only one quadrat containing more than 5% bare peat cover during the monitoring period.

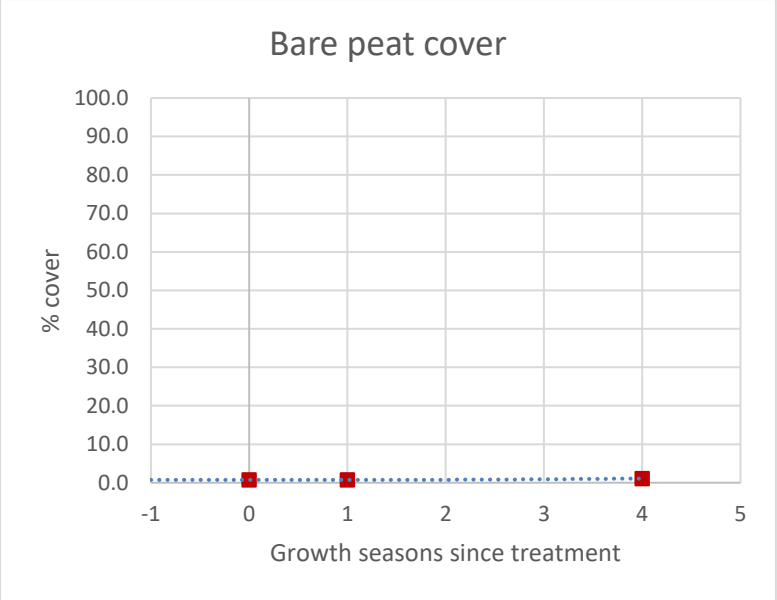

Figure 22. Mean cover of bare peat at Seal Edge.

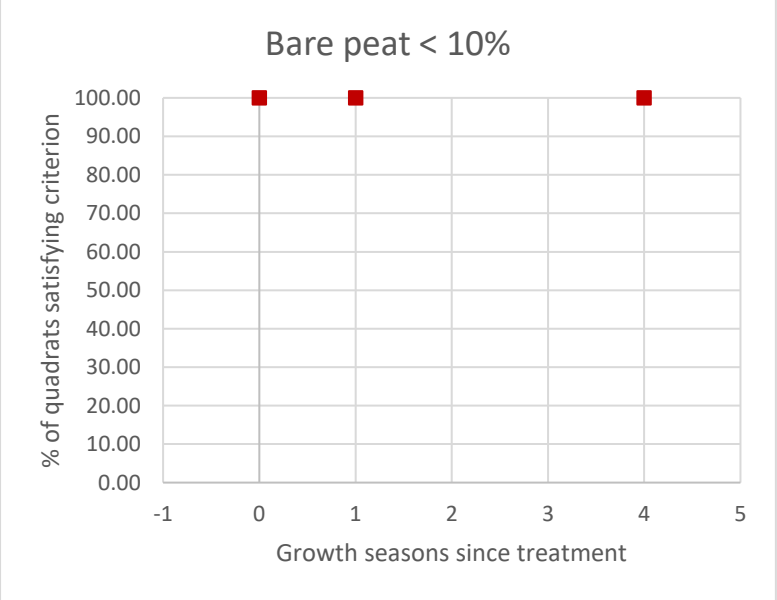

Figure 23. Proportion of quadrats at Seal Edge meeting CSM criterion of less than 10% bare peat cover. To achieve favourable condition, at least 90% of quadrats should satisfy this criterion.

8.3.2. Indicator species

Indicator species cover remained stable through the monitoring period at around 110% as shown in Figure 24. After *Sphagnum* planting, indicator species frequency rose from an average of 4.5 species to 5.5 (Figure 25). Three years after planting (2024) this rose to 5.8 species due to bilberry (*Vaccinium myrtillus*), hare's tail cotton-grass (*Eriophorum vaginatum*), Cladonia (a genus of lichenized fungi), and feather mosses being noted more frequently than in 2021. However, the site continued to fail the CSM attribute targets of more than 50% cover of 3 or more indicator species, and 90% of quadrats containing six or more indicator species and shown in Figure 26 and Figure 27 below.

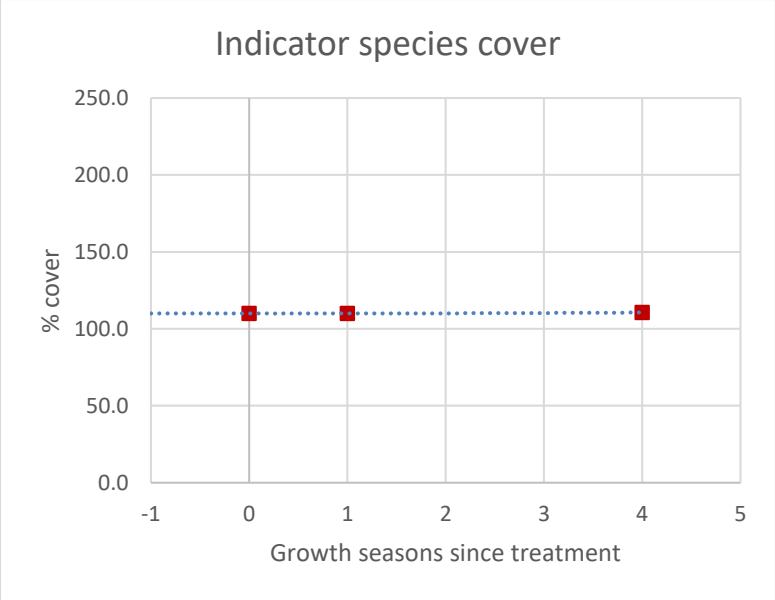

Figure 24. Average total cover of indicator species recorded at Seal Edge.

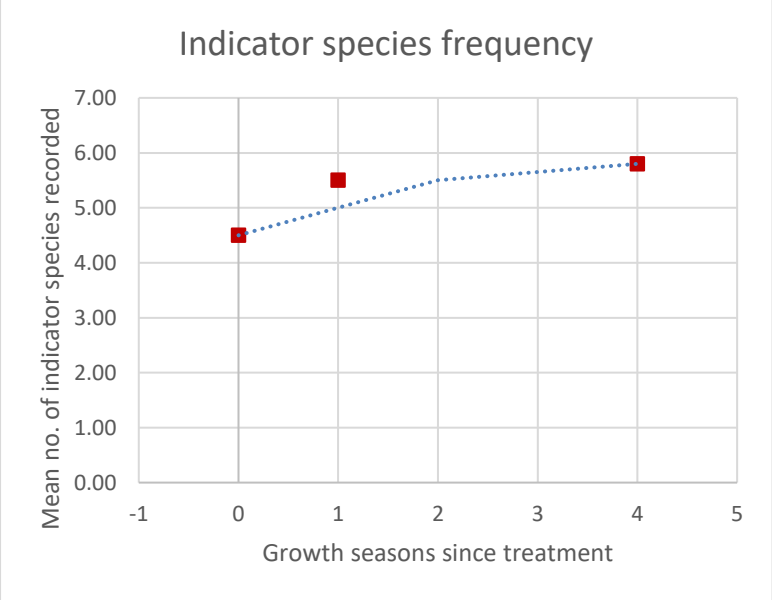

Figure 25. Mean frequency of indicator species recorded at Seal Edge.

8.3.3. ≥ 50% cover of >2 indicator species

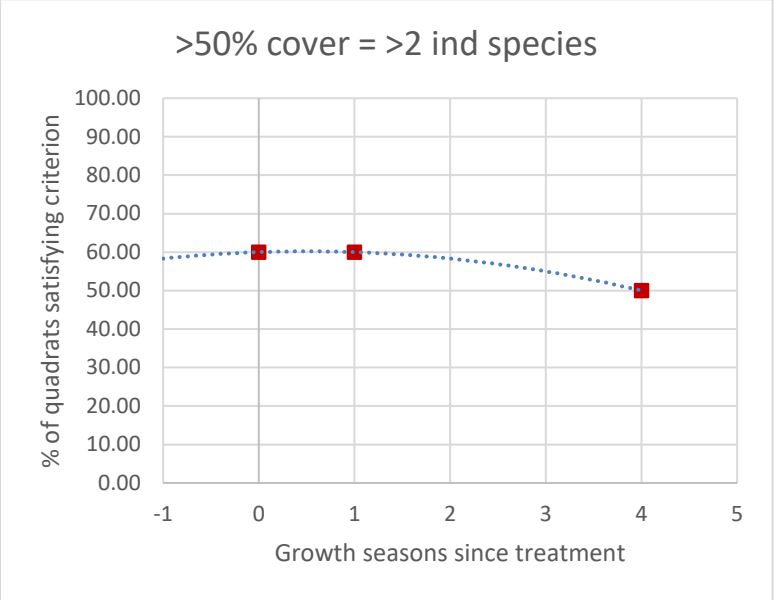

Figure 26. Proportion of quadrats at Seal Edge meeting CSM criterion of more than 50% cover of 3 or more indicator species.

8.3.4. Six or more indicator species

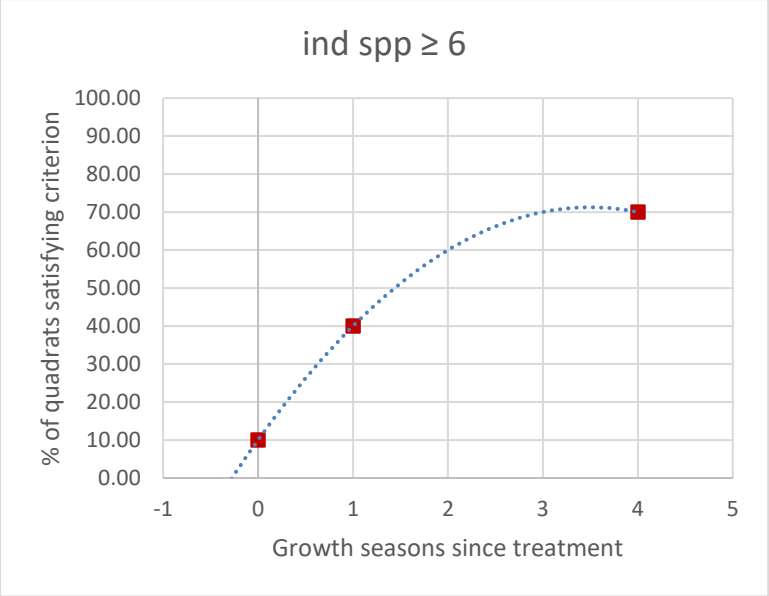

Figure 27. Proportion of quadrats at Seal Edge meeting CSM criterion of six or more indicator species.

8.3.5. Other notable criteria

Currently this site fails another key target, with 20% of quadrats containing more than 75% ericoid cover.

8.4. Upper North Grain

Figure 28. Overview of Upper North Grain monitoring site.

8.4.1. Bare peat

Bare peat cover remained stable with a mean of <1% throughout the monitoring period, as shown in Figure 29. 100% of the quadrats met the CSM favourable condition criterion (Figure 30), containing <10% bare peat, with all quadrats containing less than 5% bare peat cover during the monitoring period.

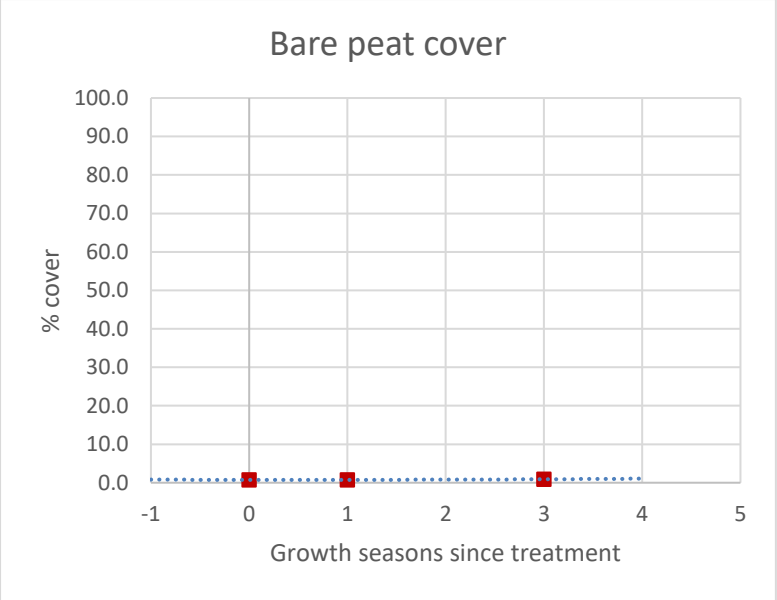

Figure 29. Mean cover of bare peat at Upper North Grain.

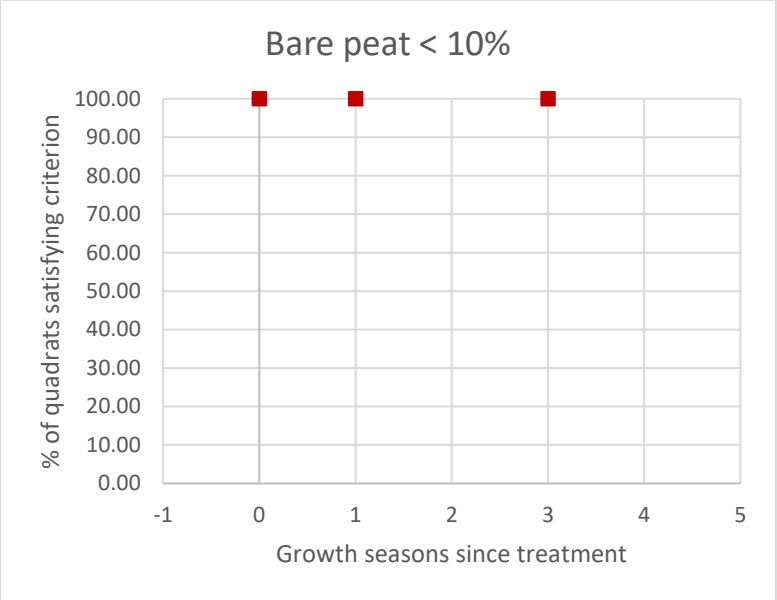

Figure 30. Proportion of quadrats at Upper North Grain meeting CSM criterion of less than 10% bare peat cover. To achieve favourable condition, at least 90% of quadrats should satisfy this criterion.

8.4.2. Indicator species

Indicator species cover remained broadly stable through the monitoring period at around 170–180% as shown in Figure 31. After *Sphagnum* planting, indicator species frequency rose from an average of 6.4 species to 7.10 (Figure 32). At the most recent survey (2024) this rose to 7.4 species due to common heather (*Calluna vulgaris*), cross-leaved heath (*Erica tetralix*) and Crowberry (*Empetrum nigrum*) being noted more frequently than in 2021. The site continued to meet the CSM attribute targets of more than 50% cover of 3 or more indicator species, and 90% of quadrats containing six or more indicator species and shown in Figure 33 and Figure 34 below.

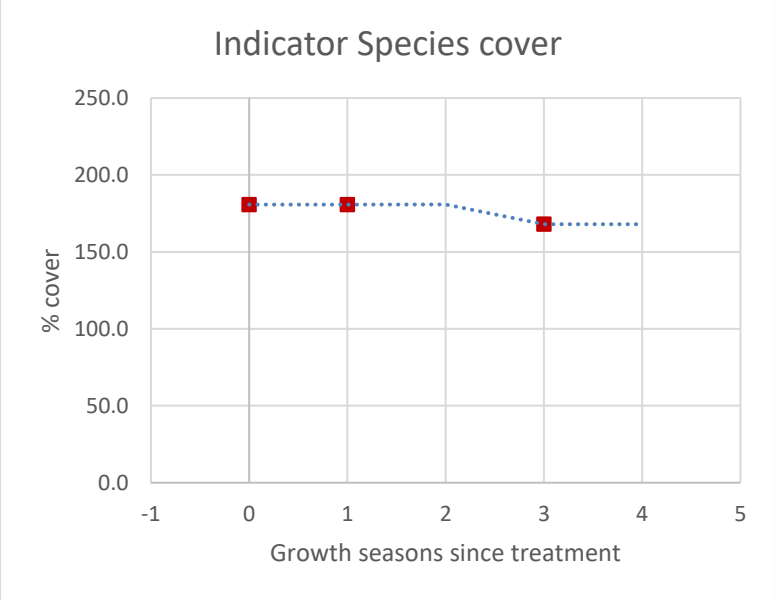

Figure 31. Average total cover of indicator species recorded at Upper North Grain.

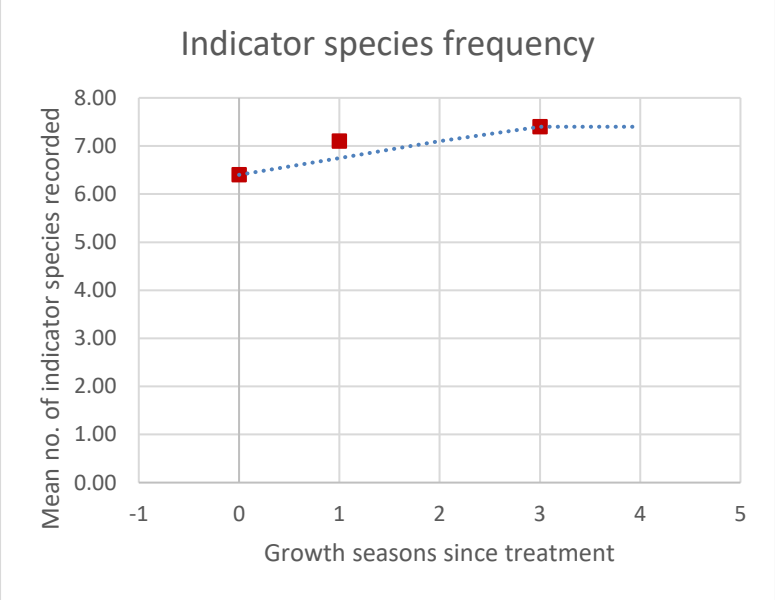

Figure 32. Mean frequency of indicator species recorded at Upper North Grain.

8.4.3. ≥ 50% cover of >2 indicator species

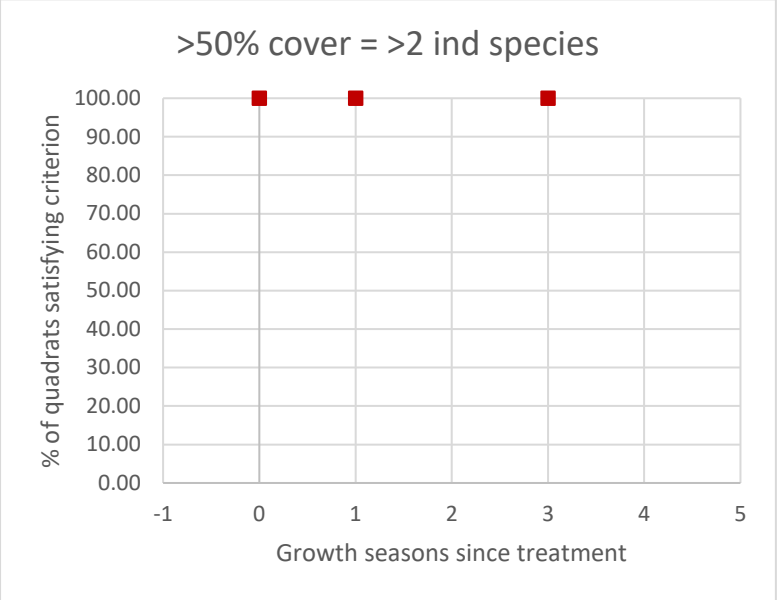

Figure 33. Proportion of quadrats at Upper North Grain meeting CSM criterion of more than 50% cover of 3 or more indicator species.

8.4.4. Six or more indicator species

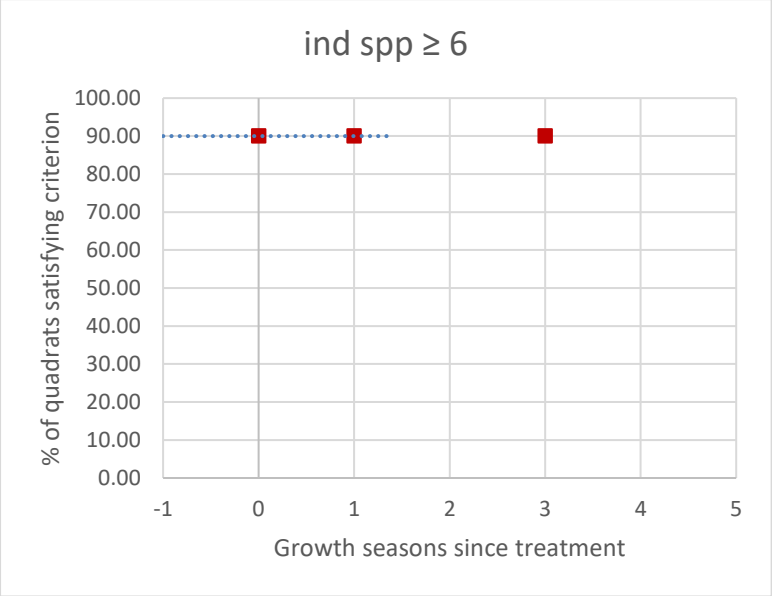

Figure 34. Proportion of quadrats at Upper North Grain meeting CSM criterion of six or more indicator species.

8.4.5. Other notable criteria

Currently this site fails another key target, with 40% of quadrats containing more than 75% ericoid cover.

8.5. Within Clough

Figure 35. Overview of Within Clough monitoring site

8.5.1. Bare peat

Bare peat cover remained stable with a mean of <5% throughout the monitoring period, as shown in Figure 36. At the final survey in 2024, 100% of the quadrats met the CSM favourable condition criterion (Figure 37), containing <10% bare peat. At the initial survey in 2021, two quadrats were recorded with >10% cover of bare peat. The discrepancy could be due to a number of factors – surveyor error in placement of quadrat, the winter survey time of the initial survey (carried out at time of planting) meaning more standing water was present or a genuine reduction in bare peat – the latter seeming the least likely. However, the site as a whole does feature some deep gullying with bare peat sides, so although this criterion was technically met in 2024 by the area within the quadrats, it is possible the site as a whole would fail to meet this attribute target hence the caveat in the summarised results in Table 6 above.

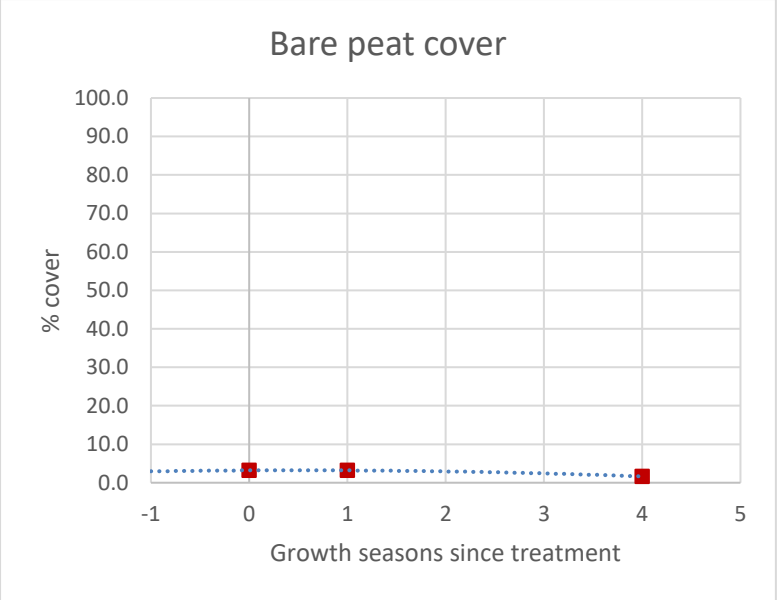

Figure 36. Mean cover of bare peat at Within Clough.

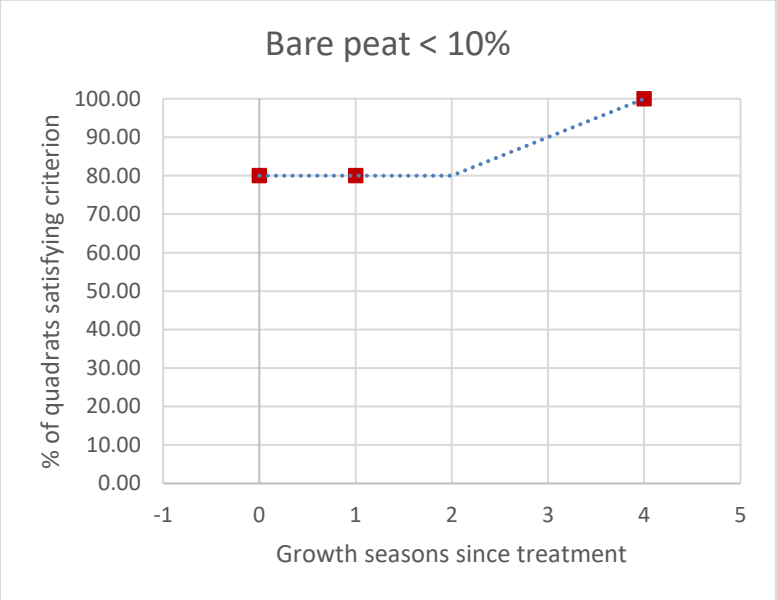

Figure 37. Proportion of quadrats at Within Clough meeting CSM criterion of less than 10% bare peat cover. To achieve favourable condition, at least 90% of quadrats should satisfy this criterion.

8.5.2. Indicator species

Indicator species cover remained broadly stable through the monitoring period at around 125 – 135% as shown in Figure 38. After *Sphagnum* planting, indicator species frequency rose from an average of ~5 species to ~6 species (Figure 39Figure 32). The site continued to meet the CSM attribute targets of more than 50% cover of 3 or more indicator species throughout the monitoring period. Before treatment, 30% of quadrats contained six or more indicator species, and by 2024 this had risen to 80%, as shown in Figure 40 and Figure 41 below. Although the site failed to meet this criterion, is appears progress was being made due to the introduction of *Sphagnum* plugs, and 90% of quadrats contained five or more indicator species by 2024.

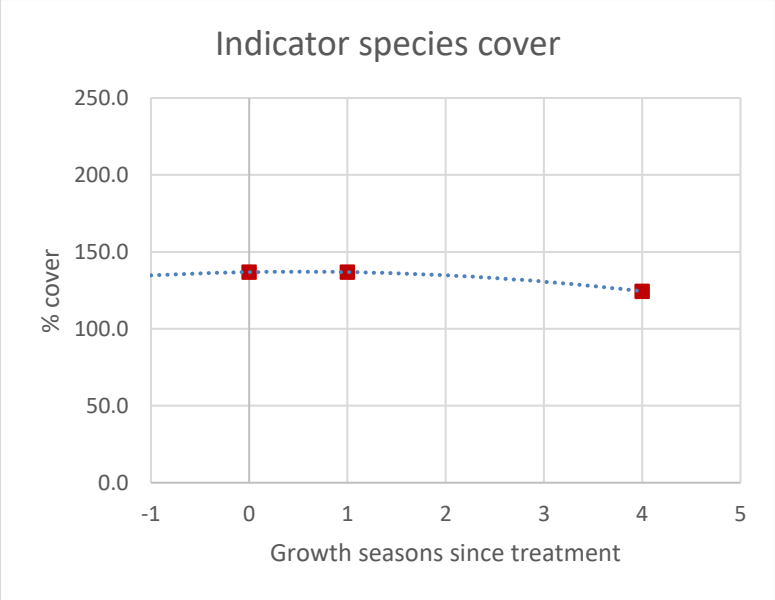

Figure 38. Average total cover of indicator species recorded at Within Clough.

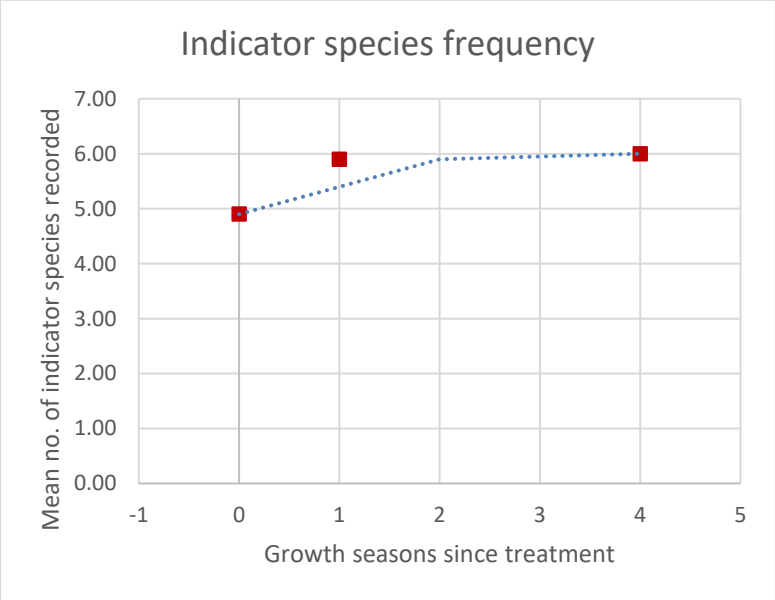

Figure 39. Mean frequency of indicator species recorded at Within Clough.

8.5.3. ≥ 50% cover of >2 indicator species

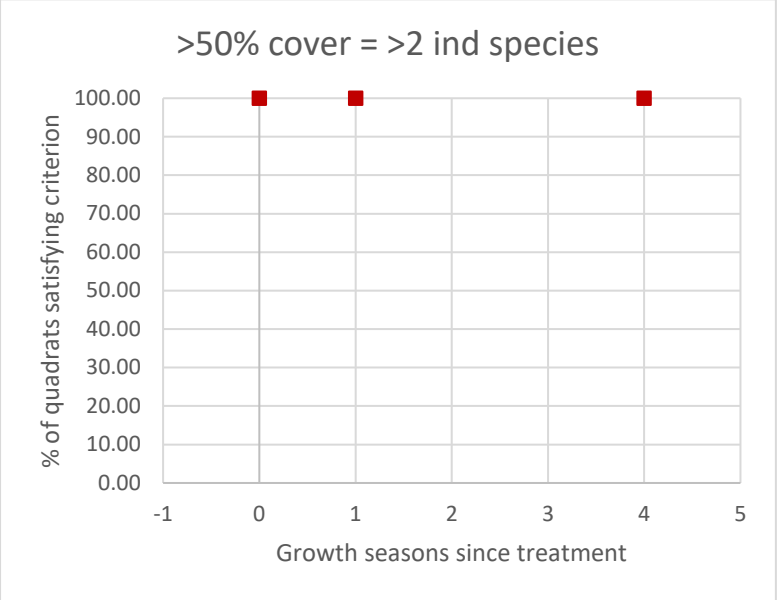

Figure 40. Proportion of quadrats at Within Clough meeting CSM criterion of more than 50% cover of 3 or more indicator species.

8.5.4. Six or more indicator species

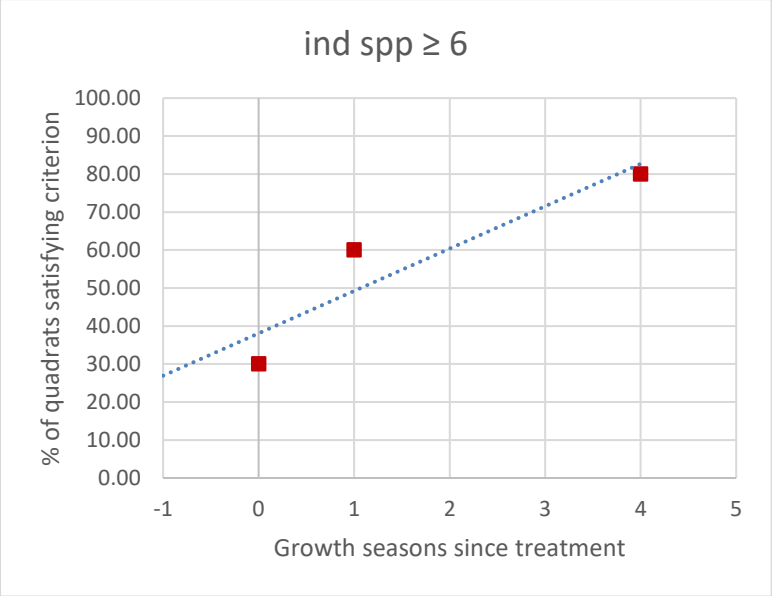

Figure 41. Proportion of quadrats at Within Clough meeting CSM criterion of six or more indicator species.

8.6. All sites

In addition to the summer vegetation surveys recording % cover, the results of which are presented above, individual *Sphagnum* plugs were monitored through direct measurement during the winter months when they are generally easiest to locate and access with a ruler. Some key results from all sites are presented below:

8.6.1. Sphagnum plug survival

A survival rate of 100% was found at three of the sites, and 90% at Upper North Grain. At Seal Edge, 50% of the plugs planted had survived after 2.7 years, as shown in Figure 42 below.

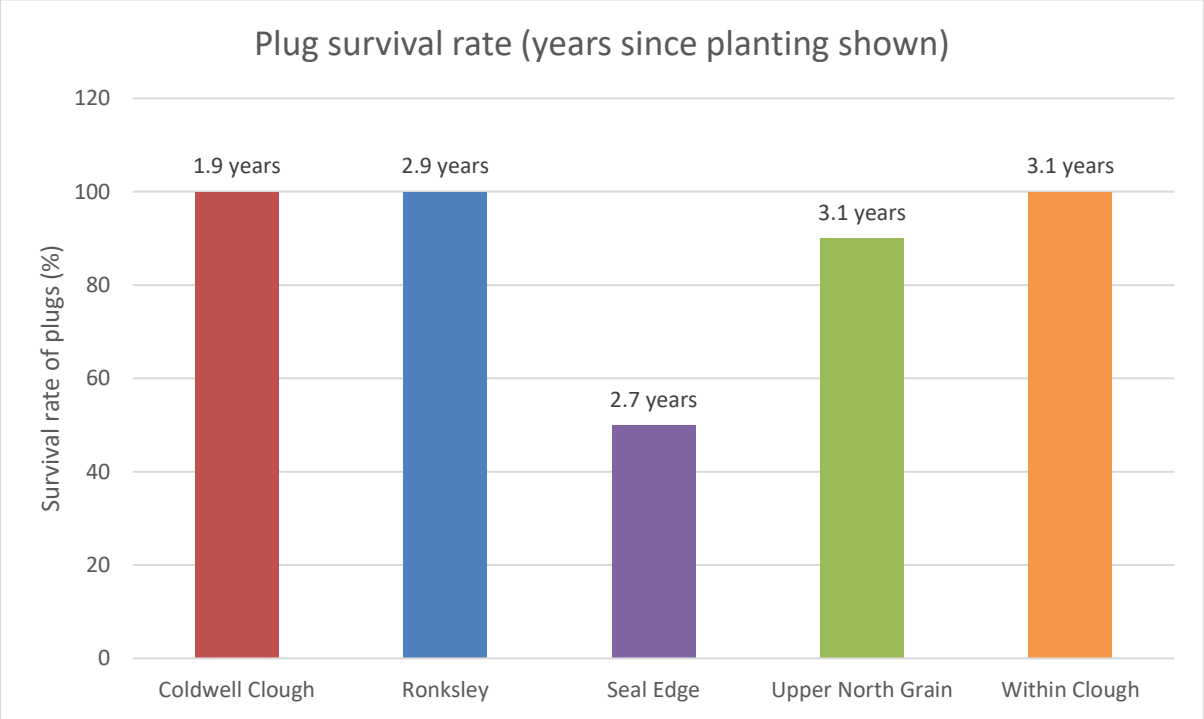

Figure 42. The proportion of plugs at each site surviving by the time of final survey in 2024.

Subsequently, a peat depth measurement was taken at each quadrat whilst seeking possible explanations for the lower survival rate at Seal Edge. The peat here was significantly shallower (see Figure 43) with a mean depth of 33 cm, which was on average ~150 to ~250 cm shallower than the other sites. Three of the Seal Edge quadrats also has a very shallow peat depth of 5 cm or less.

The depths measured at the quadrats of the plugs which did not survive were 41 cm, 4 cm, 5 cm, 47 cm and 41 cm. It is possible that these areas of shallower peat had a higher loss rate due to more extensive drying during periods of low precipitation. However, one plug planted in ~5cm at this site of peat did survive, and micro-topography and other vegetation may also have contributed (e.g. through varied levels of shading and moisture availability).

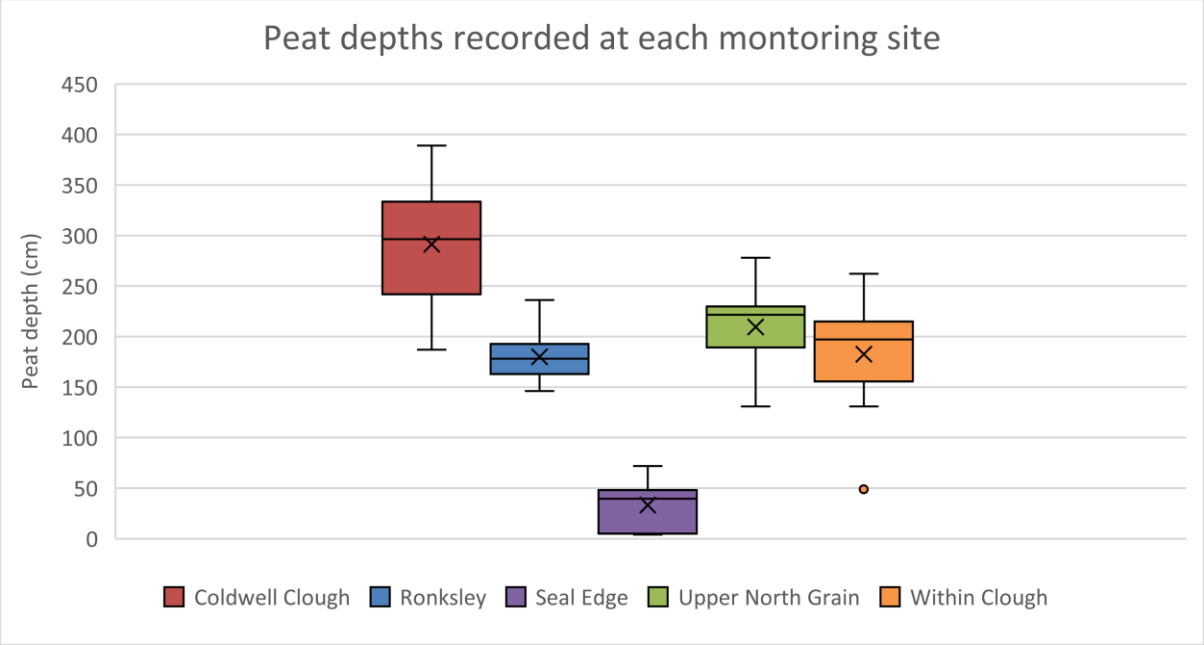

Figure 43. Box and whisker plots showing peat depths recorded at each monitoring site.

8.6.2. Sphagnum plug growth

Direct measurement of the surviving plugs in three dimensions (X, Y and Z) during winter 23/24 and winter 24/25 enabled plug areas and volumes to be modelled, and their growth during the monitoring period charted.

Each plug size varies slightly at the time of planting, so an average diameter and depth of 561 plugs (measured when planted on another site – Snailsden) was used, with an assumed starting area of 9.1 cm^2 and volume of 18.8 cm^3 per plug.

Table 7. Mean modelled volumes (cm^3) of surviving plugs at each site and % increase in volume by time of final survey

	Planting vol.	Days since planting	Final survey vol.	% increase
Coldwell Clough	18.8	796	471.3	2507
Ronksley	18.8	682	221.3	1178
Seal Edge	18.8	1127	87.3	465
Upper North Grain	18.8	989	523.8	2787
Within Clough	18.8	1119	847.7	4511

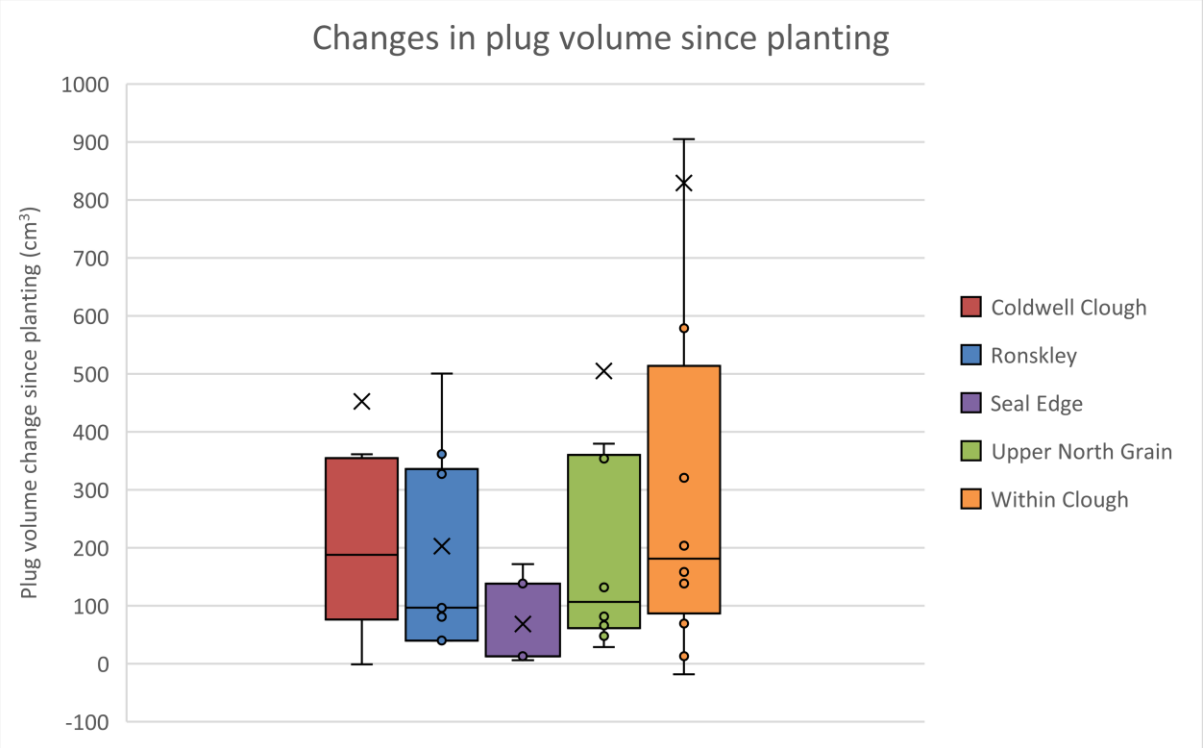

Figure 44. Box and whisker plots showing changes in plug volume (cm³) since planting, excluding outliers with very large increases in size at Coldwell Clough, Upper North Grain and Within Clough to enable clarity of plot.

Figure 44, above, shows the distribution of volume increases or decreased calculated for each plug monitored at each site by the time of the final survey in 2024. Within Clough showed the largest overall increase in volumes with many of the plugs found to be thriving, with a small number of very large patch sizes skewing the mean above the median. A similar pattern was also seen at Coldwell Clough and Upper North Grain. Baselined trajectories of growth accounting for the different planting times over the course of the project can be seen in Figure 45 below.

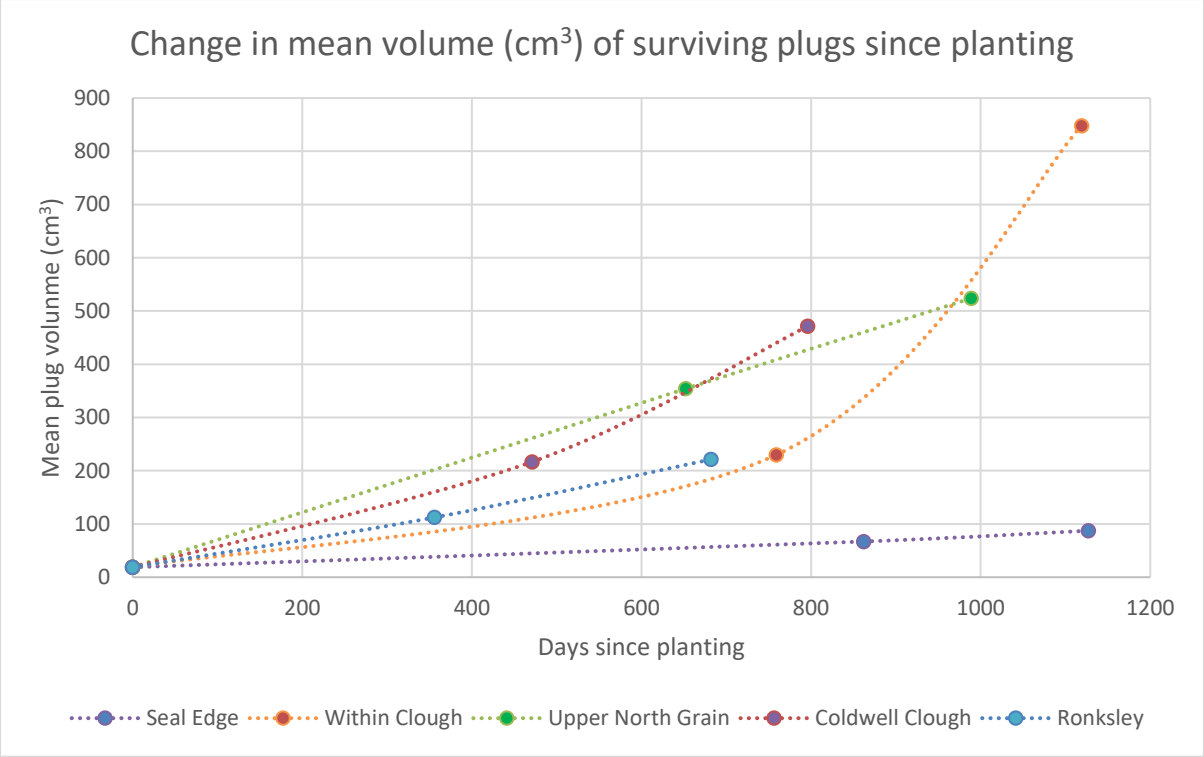

Figure 45. Trajectories of mean modelled plug volume increase since planting at each site

8.6.3. Graphic representation of plug growth

Scale diagrams of mean plug volume for each site are shown below, where plugs are modelled as cylinders as discussed in section 7 above. The smaller darker green 'plugs' at the centre of each diagram represent the mean volume of the plugs at the time of planting, and the larger light green 'plugs' they sit within represent the mean volume at the time of the final survey in 2024. These are intended to help visualise the average amount of growth recorded at each site, and as such the area at base of each cylinder was calculated after first applying the mean depth (Z) increase at each site.

8.6.3.1. Coldwell clough

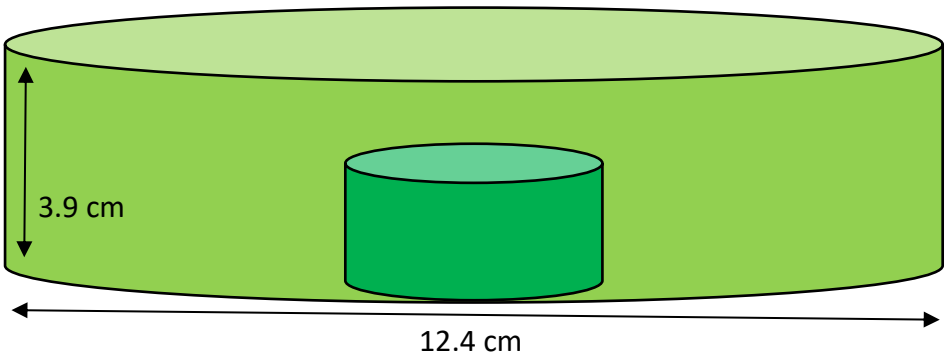

Figure 46. Graphic representation of mean plug volume increase at Coldwell Clough monitoring site

8.6.3.2. Ronksley

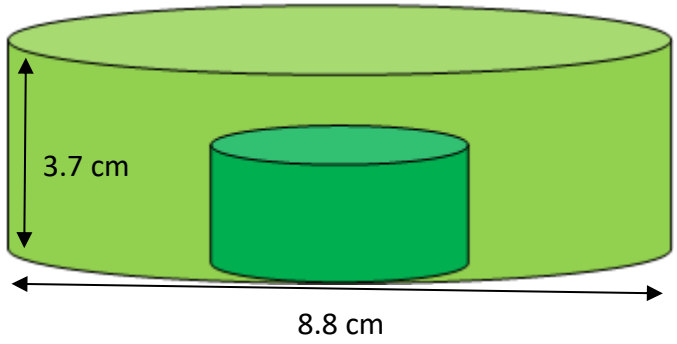

Figure 47. Graphic representation of mean plug volume increase at Ronksley monitoring site

8.6.3.3. Seal Edge

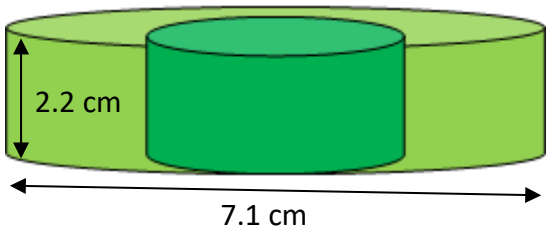

Figure 48. Graphic representation of mean plug volume increase at Seal Edge monitoring site

8.6.3.4. Upper North Grain

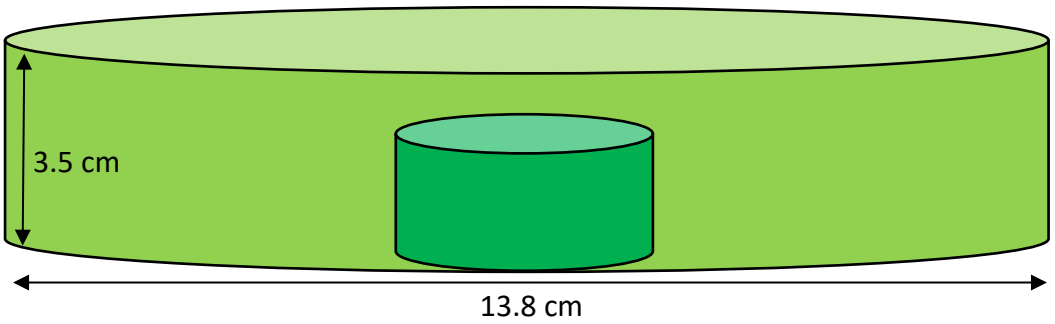

Figure 49. Graphic representation of mean plug volume increase at Upper North Grain monitoring site

8.6.3.5. Within Clough

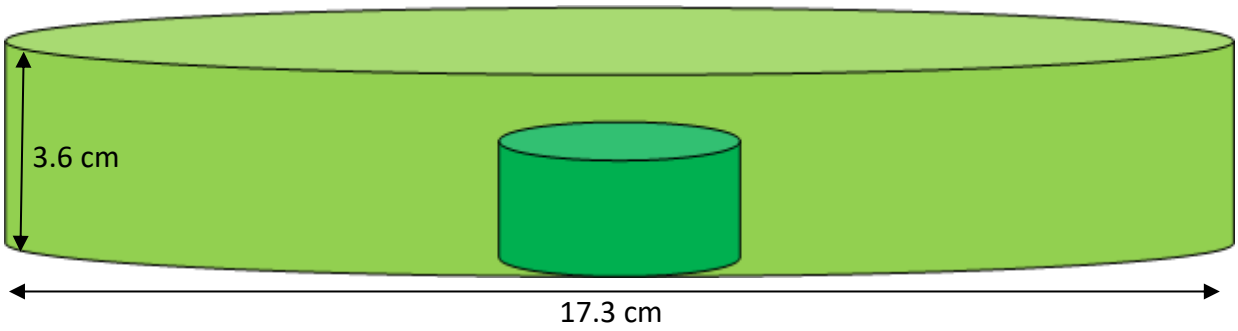

Figure 50. Graphic representation of mean plug volume increase at Within Clough monitoring site

8.6.4. Photographic record of plug growth

Below are some examples of plug growth from each monitoring site. Two pairs of images have been selected from surviving plugs at each site, showing a range of growth during the monitoring period in order to demonstrate the range of success at each site.

8.6.4.1. Coldwell Clough

Figure 51. Plug in quadrat CC04; A) 2022 and B) in 2024. This plug has increased in area and depth and is beginning to exhibit a range of colourations and forms as the different species contained within it develop.

Figure 52. Plug in quadrat CC03; A) 2022 and B) in 2024. This plug has survived but shown only a small increase size.

8.6.4.2. Ronksley

Figure 53. Plug in quadrat RN02; A) 2023 and B) in 2024. This plug has increased in area and depth and has enveloped common cotton-grass stem to left of images. Note blurring in image A is possibly caused by water on camera lens. Sphagnum plug in image B is frozen, hence washed out colouration.

Figure 54. Plug in quadrat RN07; A) 2023 and B) in 2024. This plug survived but has shown minimal growth during the monitoring period.

8.6.4.3. Seal Edge

Figure 55. Plug in quadrat SE06; A) 2022 and B) in 2024. This plug has grown well and started to take on characteristic colouration and form of *Sphagnum capillifolium*.

Figure 56. Plug in quadrat SE03; A) 2021 and B) in 2024. This plug survived and has started to take on characteristic colouration and forms but shown limited growth during the monitoring period.

8.6.4.4. Upper North Grain

Figure 57. Plug in quadrat UNG05; A) 2022 and B) in 2024. This plug has grown well and has started to take on characteristic species colourations and forms.

Figure 58. Plug in quadrat UNG07; A) 2022 and B) in 2024. This plug survived but has shown limited growth during the monitoring period.

8.6.4.5. Within Clough

Figure 59. Plug in quadrat WC09; A) 2021 and B) in 2024. This plug has grown very well and has started to take on characteristic species colourations and forms.

Figure 60. Plug in quadrat WC05; A) 2021 and B) in 2024. Whilst this plug has now grown as well that above, and has started to take on characteristic species colourations and forms.

8.6.5. Fixed-point photos – site-wide

Overview photographs of each site were taken from fixed points, over the monitoring period. These can be found in Annex 1.

9. Discussion and limitations

9.1. Plug survival and growth

Inoculation with *Sphagnum* plugs at the five monitoring sites selected has produced a good overall success rate in terms of plug survival at four of the five sites. Seal Edge on Kinder Scout was an exception to this finding, with only 50% of plugs surviving and several more exhibiting very limited growth during the three years of monitoring. It is hypothesised that the relatively shallow peat and low water tables found in this area may have contributed to this outcome. This is in contrast to the success of *Sphagnum* plugs introduced at another experimental site ('Nogson') on the North Edge of Kinder Scout, which has seen a high success rate and extensive coverage achieved (Margetts, Pilkington and Spencer, 2022). This site had some notable differences including (i) higher plug planting density (ii) 'Moorland Mix' plugs used containing 11 different species, rather than the five species 'Chunky Mix' applied at Seal Edge (iii) location is further from edge of peat mass, and probably most importantly (iv) extensive gully blocking with wooden dams. Any combination of these factors or others not listed above (such as precipitation levels around the time of planting and in the early years of establishment) may have impacted the differing outcomes, but possibly serve to highlight the importance of hydrological restoration (through techniques such as gully blocking and/or bunding) alongside *Sphagnum* introduction in highly degraded areas.

9.2. Progress towards Favourable Condition

The number and cover of indicator species present at all five sites was increased through the introduction of *Sphagnum* plugs. In terms of indicator species frequency, it is known that the true figure was underestimated due to the *Sphagnum* genus being counted as one species for the purposes of the surveys (it being difficult to differentiate plug species in the field in the early stages of their development). By 2024, the attribute target for 90% of quadrats to contain six or more indicator species was met at three of the five sites. Seal Edge and Within Clough did not meet this threshold, but it is likely they would have done had it been possible to determine individual *Sphagnum* species within each plug. Therefore, re-surveying these plugs to species level in future years could be a worthwhile exercise.

The attribute target for 90% of quadrats to contain less than 10% of bare peat was met at four of the five sites. Coldwell Clough was just below this target. Within Clough did not meet the target at site set-up in 2021 but did technically meet the target in 2024. It is unclear whether this was caused by a difference in surveyor estimate rather than a real change. However, many of the sites still contain areas of bare peat on steep gully sides (for example Upper North Grain (See Annex 1 for images)) where quadrats were generally not placed, so the survey figures are not fully representative of the sites as whole. Because quadrat placement was not random other biases in data may have been present. Care was taken to avoid placing a quadrat where any natural *Sphagnum* did exist, for example – so

site-wide coverage may have been slightly higher than estimated especially if there were any concentrations in vegetated flow pathways. In addition, it was not always possible to for the same surveyor to revisit each site, so differences in estimates of % coverage are very likely and add noise to the data. As sites are revisited in future years, it may become more difficult to differentiate *Sphagnum* plugs from any natural patches, and for this reason it is recommended that permanent ground-level markers be added in a fixed position adjacent to monitored plugs (20 cm directly north, to give an example) to aid in their relocation and add to confidence in data collected.

All sites with the exception of Seal Edge met the attribute target that quadrats should contain 50% or more cover of at least 3 indicator species, with only around half of samples meeting this threshold on that site. Perhaps more importantly, four of the five sites failed to meet the attribute that at least 90% of quadrats should have 75% or less cover of ericoids. This was primarily due to the levels of common heather, bilberry and crowberry present – possibly indicating that these locations remain hydrologically damaged, may have been exposed to fire in the past, or both.

10. Conclusion

Inoculation with *Sphagnum* plugs at these locations has generally been successful in terms of survival rate, but has unsurprisingly seen mixed results in terms of growth rates – likely to be related to the differing starting conditions of each site. Their addition has increased the number of indicator species present at all sites. For 80% of the sites, the high level of ericoid cover is a key attribute target preventing Favourable Condition from being achieved.

11. References

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12. Figures

13. Tables