A Comparative Study Using Plant and Invertebrate Species as a Qualitative Indicator of Peatland Health.

View across the peatland study sites. [redacted]*. 26th October 2023.*

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Abstract:

Vegetation composition, cover and invertebrate assemblages are compared on three adjacent lowland valley mires in Dorset at different stages; pre-restoration, 6-months post restoration and a reference mire in pristine condition. Sixty-seven quadrats were sampled across the three sites. Percentage cover of plant species was recorded using a grided 2mx2m quadrat. Invertebrates were sampled using dry pitfall-traps left for 24 hours and ground searches conducted within a 2-metre radius. Species richness per quadrat was greatest on the pristine site where positive bioindicator cover of 10-30% was consistent and mean Vegetation Quality Score (VQS) highest. No significant difference in Fauna Species Quality Score (FSQS) between sites were recorded and no correlation could be made between VQS and FSQS. Rewetting interventions 6-months post restoration resulted in the establishment of ruderal vegetation and positive indicator peatland species in 79% of quadrats though future temporal surveys will be valuable to record subsequent successional changes.

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Chapter 1 - Introduction

Introduction:

Peatlands are unique habitats, delivering vital ecosystem services, supporting biodiversity and storing carbon crucial in mitigating climate change. Anthropogenic influences of agriculture and silviculture (Strobl et al., 2020) however, has resulted in 80% of UK peatland sites being degraded (JNCC, 2011; Moxey and Moran, 2014). Given the negative impacts of peatland degradation and the timescale over which peatlands form it is imperative that intact peatlands are protected being the single most important terrestrial carbon store in the UK (Bain, 2011).

The Dorset Peat Project Partnership managed by Dorset Wildlife Trust recently received a 'discovery grant' to restore 16 degraded peatland sites across the county. The sites were required to have a minimum peat depth of 30cm, with restoration completed by 2025. The aim is to re-establish natural hydrological processes and promote the recovery of declining mire vegetation communities enabling peat-forming and carbon storage functions across all sites. This study compares an unrestored peatland, a newly restored site (6 months post restoration) and a peatland in pristine condition to understand the effectiveness of the measures undertaken. The viability and ease of using peatland plant and invertebrates bioindicator species (Hopkinson, 2005) as a reliable indicator for lowland peatlands in southern England (Dorset) is examined. Abiotic factors pH, temperature and water cover are compared to identify the impact on the vegetation and stenotopic invertebrates observed. The overarching purpose of this study is to monitor the success of the Dorset Peatland Partnership (DPP) initiative in restoring the water-table, increasing peat forming specialists and associated tyrphobiontic invertebrates and will contribute to the annual report required by DEFRA.

Aims:

- To evaluate the extent of vegetation recovery in a recently restored peatland by comparing species composition and cover in adjacent mires in pristine condition and pre-restoration.
- Use plant and invertebrate species as a qualitative indicator of peatland health.
- To understand the successional stages in vegetation and invertebrate communities following peatland restoration.

Research questions:

1. Do abiotic factors temperature and pH differ between sites?
2. Does the composition and percentage cover of indicator plant species differ significantly between sites?
3. Can specific plants and invertebrates serve as effective qualitative bioindicators of peatland health?

Literature Review:

Peatlands are terrestrial wetland ecosystems derived from organic matter accumulating more quickly than it decomposes due to the waterlogged, cold, anaerobic conditions inhibiting decomposition by bacteria and fungi (Rydin and Jeglum, 2013a). Areas where peat is actively being formed are termed 'mires' yet encompass a broad spectrum of types, naturally influenced by the climatic conditions, underlying geology, vegetation and hydrology (JNCC, 2011; Tveit et al., 2020). The focus of this study is lowland fen which are designated high priority for restoration under the Red List of European habitats and UK Biodiversity Action Plan (EEA, 2022; JNCC, 2014a, 2014b).

The presence or absence of peatland specialists is critical for evaluating peatland condition, restoration potential and progress. Bryophytes, play a pivotal role in the formation of these carbon rich, nutrient deficient soils with high-water tables restricting the growth of competitive, taller and deeper-rooted vascular plants (Bonn et al., 2016; IUCN, 2019; Li et al., 2018). Their conspicuous forms are identifiable using a range of features visible by eye or hand lens. These include colour, shape of the capitulum, number and arrangement of branches in the fascicles, morphology of the branches, splitting or fringing of the stem leaves, recurving of branch leaves and concavity or hooding of leaves (Rydin and Jeglum, 2013b). Sphagnum mosses, known colloquially as 'peat-builders' are uniquely adapted to ombrotrophic bogs surviving in acidic, anoxic conditions, with a number of adaptions including cation exchange at low pH, the ability to conserve nutrients, phenolic compounds protecting against photoinhibition and slowing decay (Freeman et al., 2001; Mellegård et al., 2009; Turetsky et al., 2000). Nevertheless, several specially adapted tracheophytes are successful in peatland environments too. For instance, *Calluna vulgaris* utilising a unique mycorrhizae relationship*, Drosera rotundifolia* overcomes nutrient deficiency by catching and digesting invertebrates and *Eriophorum vaginatum* contains a 'vascular ring' to redistribute solutes between the roots, corm and leaves (Rydin and Jeglum, 2013c). The severe conditions create a niche which enable the distinctive peatland helophytes to thrive utilising K-strategy features, symbiotic relationships and adaptive capacity to low oxygen availability, cold, acidic, oligotrophic conditions (Loisel and Gallego-Sala, 2022; Minayeva et al., 2008, 2017; Minayeva and Sirin, 2012). Indeed, a site's dominant botanical constituents are a reliable indicator of pH, water-level and nutrient availability (Barrow and Hartemink, 2023; Rydin and Jeglum, 2013d). In this study, the vegetation on each site will be evaluated and compared with communities found on sites with similar abiotic factors in pristine condition.

Peatlands worldwide have been drained for agricultural purposes, afforestation and peat extraction for commercial use (Bullock et al., 2012). As water levels drop, the peat dries, eroding up to several centimetres per year depending upon climatic conditions and the addition of lime, fertilisers, sand or clay which augment microbial oxidation (Clymo 1983). Considering peat accumulates at an average of 1mm per year (Charman 2002) this rate of loss will take many years to reverse. Lower water levels also result in the formation of fissures impeding capillary action, degrading its water carrying capacity and causing additional drying and erosion (Joosten, 2016). As conditions change plant species such as *Pteridium aquilinum*, *Ulex sp. Betula sp*, *Pinus sylvestris* outcompete the highly specialised species that intact peatlands support. When in good condition peatlands sequester 0.37 gigatonnes of carbon dioxide (CO2 a year), whilst emissions from drained peatlands are estimated to release 1.9 gigatonnes of CO2 annually, a disproportionate amount considering peatlands cover 3% of landmass worldwide (Hogan et al., 2024).

Destruction of these wetlands also lead to a loss of vital ecosystem services; water filtration, flow regulation and storage capacity resulting in increased risk of flash flooding and wildfires (JNCC, 2011; ONS, 2019; IUCN, n.d., IUCN 2021, IUCN 2019). Given the negative impacts of peatland degradation and the timescale over which peatlands form and can be restored it is imperative that intact peatlands are protected. Studies (Pouliot et al., 2012; Soro et al., 1999) acquiesce that without intervention promoting paludification to kickstart secondary succession, recovery of a degraded peatland is unlikely. The United Nations Framework and Ramsar Convention highlight the importance of peatlands in mitigating greenhouse gas emissions, increasing resilience to climate change and supporting biodiversity (Ramsar, 2018; UNEP, 2022).

Numerous studies recognise that rewetting is necessary to reduce or prevent net carbon loss (Günther et al., 2020) and stimulate carbon sequestration (Mrotzek et al., 2020; Zerbe et al., 2013) Rewetting offers a clear path to meeting the United Nations' Sustainable Development Goals (SDGs) (Tanneberger et al., 2021) and Nationally Determined Contributions (NDCs) of the Paris Climate Change Agreement (Seddon et al., 2019). Subsequently, sizable amounts of money have been invested to restore damaged peatlands. A comprehensive meta-analysis of restoration methods (Allan et al., 2024) provides an excellent overview of practices and discusses their relative cost effectiveness. Allan advocates active restoration, long-term biodiversity monitoring particularly of Sphagnum mosses and overall vegetation composition and calls for further studies on restored peatlands to evaluate their resilience and value as novel ecosystems. These studies reiterate that restoring the water table is a necessary step (Klimkowska et al., 2010; Lunt P, et al., 2010). Providing a diversity of niches in restoration work such as pools and hollows is important to encourage habitat heterogeneity (Glaser, 1992) promoting species richness of peatland specialists (Andrus et al., 1983; Granath et al., 2010; Hájek and Vicherová, 2014). In severely disturbed temperate fens oxidation alters the physical characteristics of peat by reducing its porosity, hydraulic conductivity and storage capacity resulting in episodic water inundations, causing peaks in methane emissions (Kreyling et al., 2021).

DPP have undertaken rewetting interventions using peat-bunds, dams to raise the water table in addition to scrub removal. Given the substantial capital investment required for peatland reestablishment, monitoring and evaluation of progress is essential (Zak and McInnes, 2022) with studies identifying variability in vegetation recovery (Bellamy et al., 2012). Indeed, Gatis et al. (2023) emphasise that expectations on the timescale and outcomes of peatland restoration projects need to be realistic with effects on photosynthesis, ecosystem respiration and dissolved organic carbon loads leaving the site, taking longer to reestablish than hydrological changes.

To determine peatland health, researchers have used invertebrate bioindicators due to their life-cycle lengths and rapid recolonisation of disturbed ecosystems (Gerlach et al., 2013; Hodkinson and Jackson, 2005; Spitzer and Danks, 2006). Recent research found invertebrates communities returned to a rewetted peatland within four months of restoration, though routine monitoring is required to confirm trends over the longer term (Beadle et al., 2023). Our study utilises tyrphophilous and tyrphobiontic invertebrates and vegetation as bioindicators to assess peatland health.

Chapter 2 - Methodology

Study Site:

Three adjacent mires, located within the Purbeck Heaths National Nature Reserve (NNR) were compared (Figure 1). Pristine peatland (Site A) is in the upper part of the Eastern Valley, fed by acidic groundwater flowing through the underlying nutrient poor sands, gravels and clays, forming an oligotrophic valley mire.

Site B contained deep, incised channels, with fast-flowing water causing increased erosion, exacerbated by modifications to the channel downstream. Enrichment of water supplies in the upper section of the catchment area from the golf course, have resulted in vigorous *Molinia caerulea, Schoenus nigricans* and *sallow* growth. Restoration work completed in January 2024 on site B focused on using peat bunds, heather bales and plastic/timber dams to raise the water table and slow the flow of water across the mire (Figure 2). Vegetation such as *Molinia caerulea, Ulex europaeus* and *Betula pendula* were cleared to reduce their dominance and drying by evapotranspiration.

Site C will undergo restoration in August 2024. Planned interventions include flailing the *Molinia caerulea* tussocks, flattening ridge and furrows, disruption of drainage channels and creation of contour bunds to more effectively retain water on the site (Figure 3). Historically *Pinus nigra* plantations were established across Site C in the 1940s. Though many of these areas have since been felled, some remain and natural regeneration of pines is evident. Ridge and furrows along with drainage channels result in fluctuating water levels on the site, with sediment deposits visible on vegetation. This site was surveyed pre-restoration (June 2024).

Figure 1 Map showing the locations of the three survey sites.

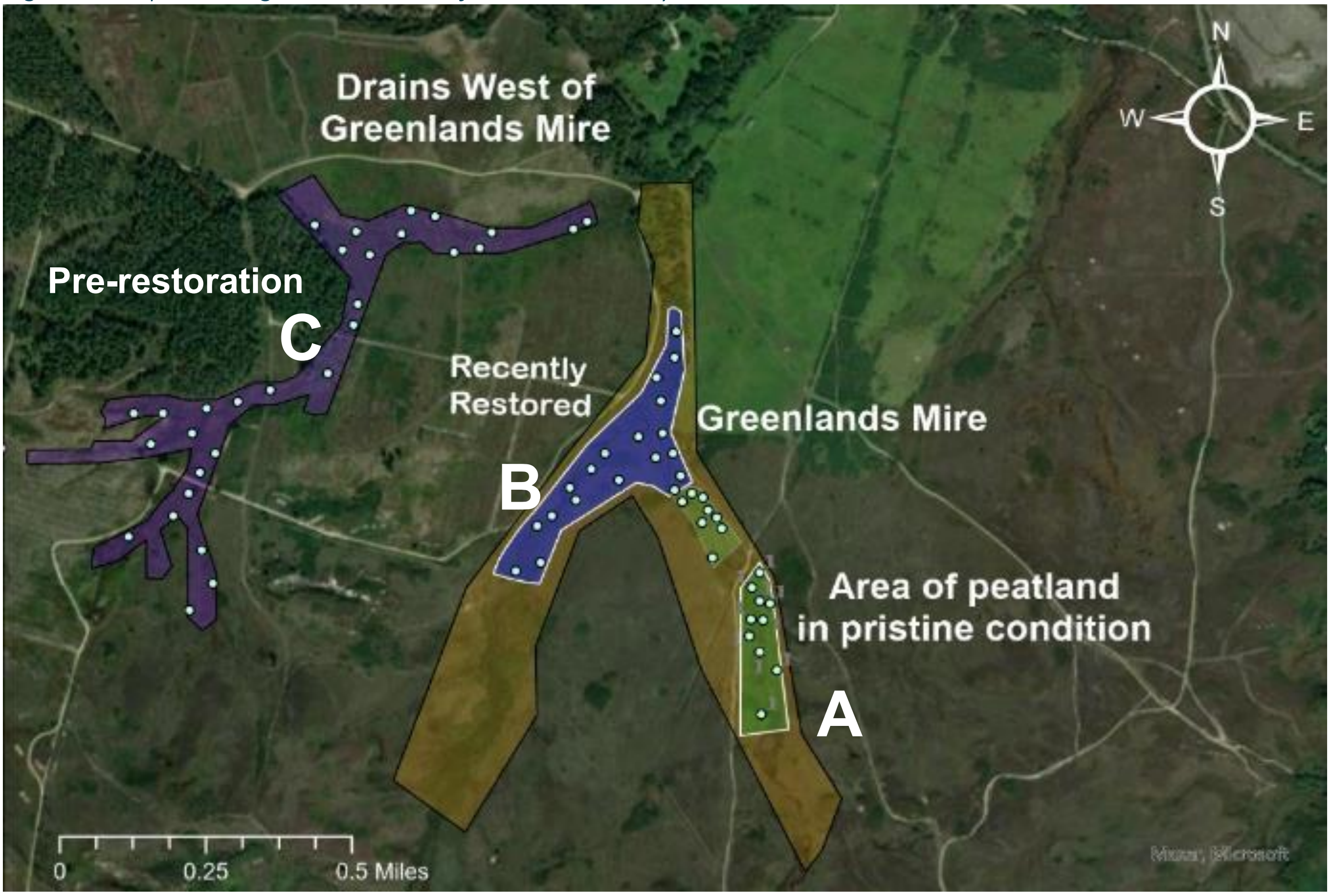


Figure 3 Site restoration plan for Site B based upon the hydrologists report by Dr Peter Stone, October 2022.

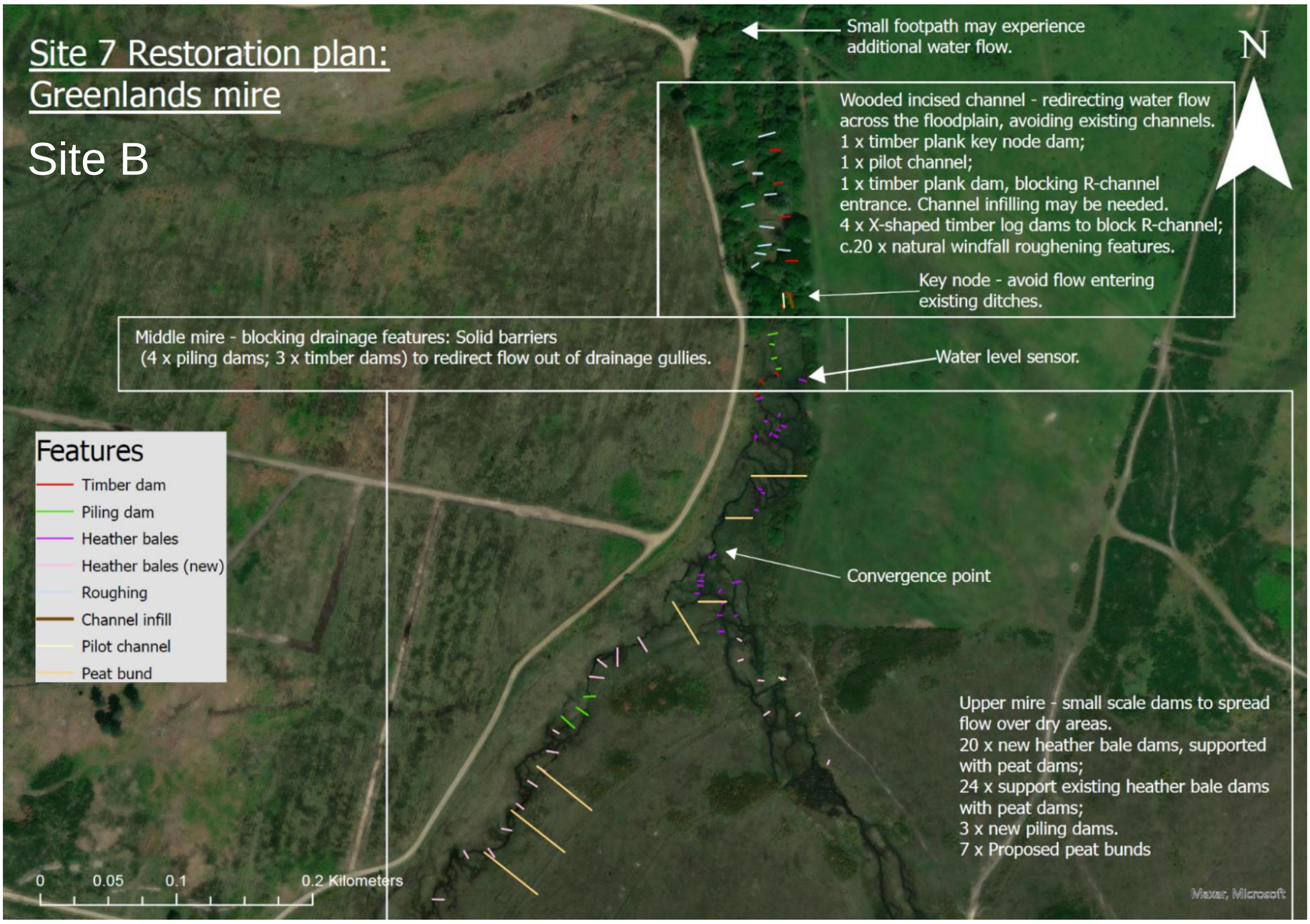
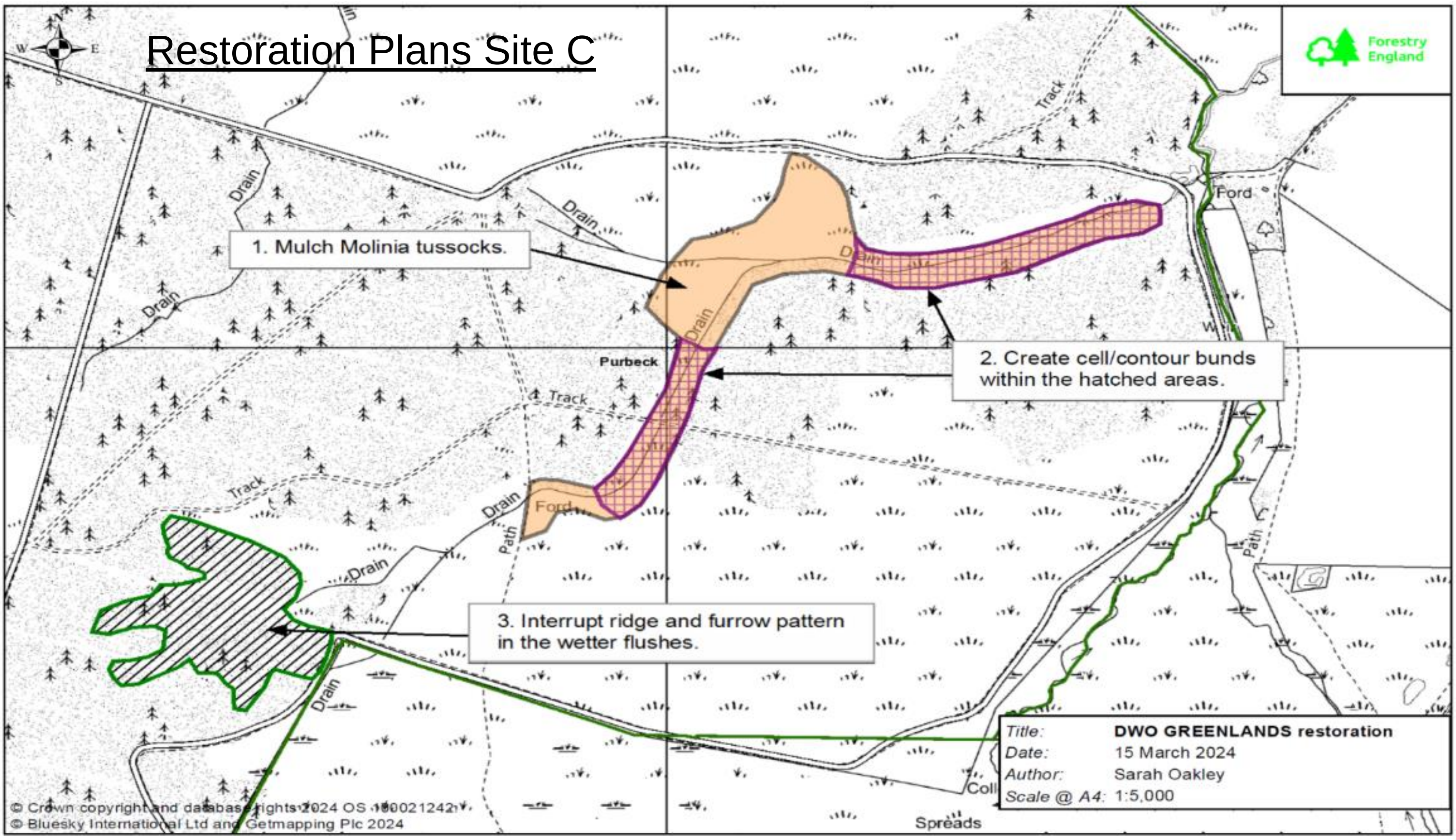


Figure 2 Map showing planned restoration work taking place in August 2024. Courtesy of Forestry England, March 2024.



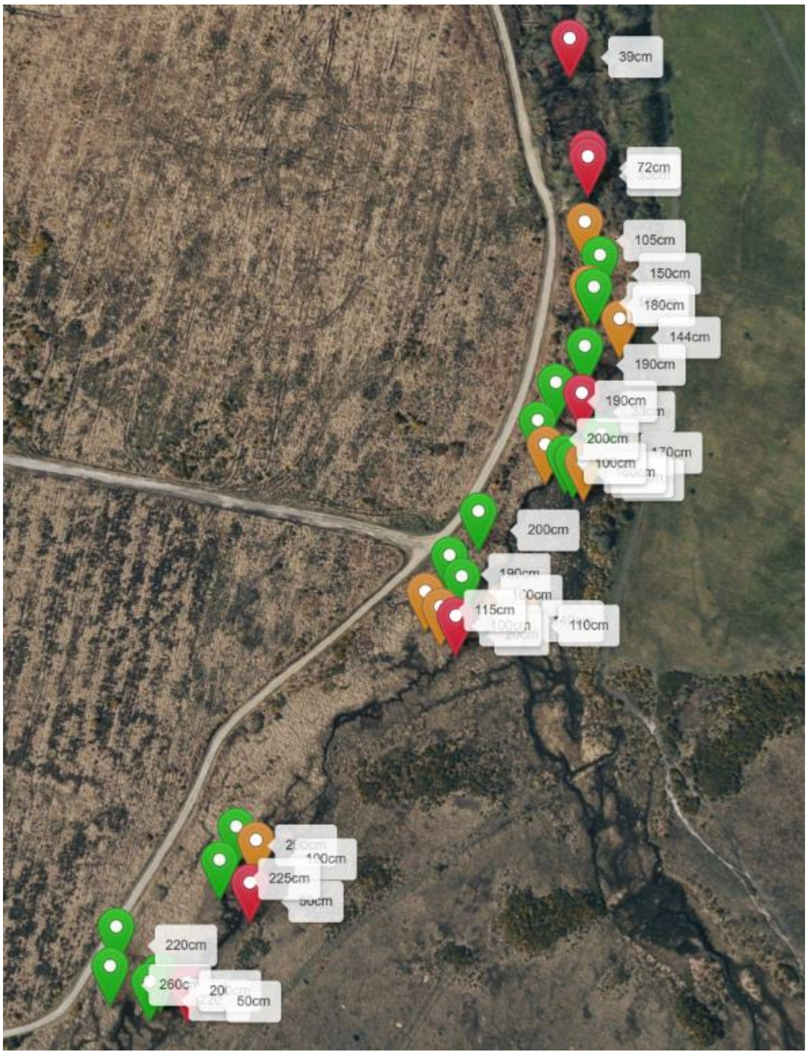
Site details are given in Table 1.

Table 1 Site details

	Area of Greenlands Mire in Pristine Condition (Site A)	Restored areas of Greenlands Mire (Site B)	Drains West of Greenlands (pre-restoration) (Site C)
Site area (ha)	5.07	5.62	9.62
Altitude (m above sea level)	19m	14m	9m
Mean Annual Rainfall (mm) *	852.68	852.68	852.68
Mean Water Depth (m)**	No data	10.9	11.2
Water Depth (m) range**	No data	10.3-11.3	10.4-11.7
Min temperature (°C) (measured while on site)	12	13	12
Max temperature (°C) (measured while on site)	18	18	15
Mean pH	5.5	5.3	5.2
Peat depth (cm)	200cm-240cm	20cm-220cm (See Figure 4)	20-80cm
Restoration dates	No restoration work being undertaken	January 2024	August 2024

*Taken from https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gbyxgmvts
**Dataloggers measured water-depth on the pre-restoration and recently restored site but no datalogger was placed on the pristine.

Figure 4 Peat depth measurements taken on Site B, 9th January 2024.



Method:

Permissions were sought from the National Trust and Forestry England with a license obtained to conduct surveys on each site for a time-limited period and risk assessments written (Appendix1,2). Preliminary observations and sampling were conducted in early June to test out the field method and make an estimation of population number. A species accumulation curve was drawn to determine the number of quadrats needed to describe the plantae community (Figure 6). The graphs show that the number of new species recorded levels off after 4-8 quadrats. However, a greater number of replications is required to ensure that the physical and biological variation of each site is sampled adequately to provide reliable results with lower confidence intervals, greater precision and statistical power. Sixty-seven quadrats were surveyed giving a percentage relative precision (PRP) of 19.6% (Figure 5) with the site quadrat allocation (Table 2) based on the species accumulation curves.

Figure 5 Formula for calculating percentage relative precision and number of quadrats required for the study as described in Barker (2001).

The formula for calculating the required number of quadrats to be measured repeatedly is:

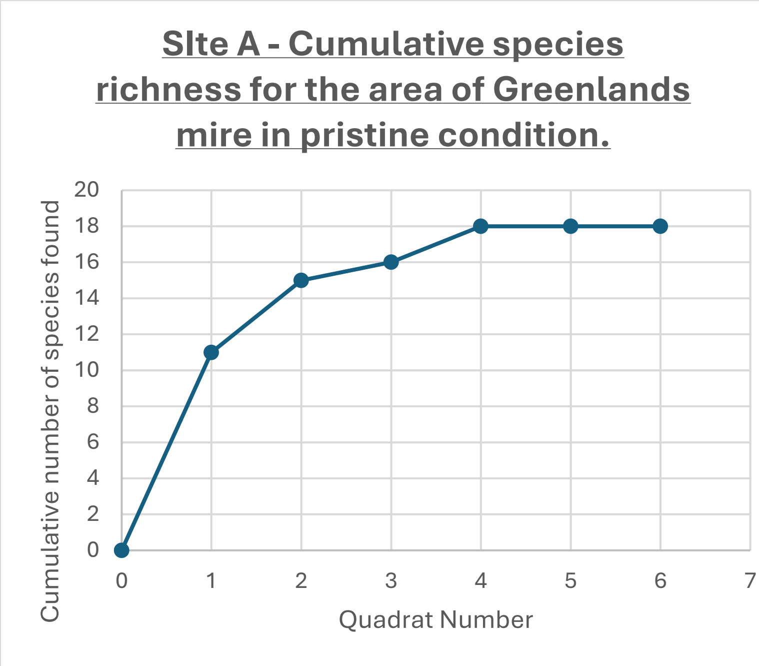
$n = SE\ s^2/d^2$

where:

n is the number of quadrats
SE = sd/sqrt n
s^2 is the variance of the sample at a particular time (the variance is the standard deviation squared)
d^2 is the squared percentage change that your sample needs to be able to detect (expressed as a difference in density). For example, if the estimated mean density is 6 individuals/quadrat and you want to detect a 10% change then d = 0.6 and d^2 = 0.36.

Table 2 Table showing the number of quadrats placed on each site.

Site	Number of quadrats
Drains West of Greenlands	30
Greenlands Mire Recently restored	19
Greenlands Mire Pristine Condition	18
Total:	67



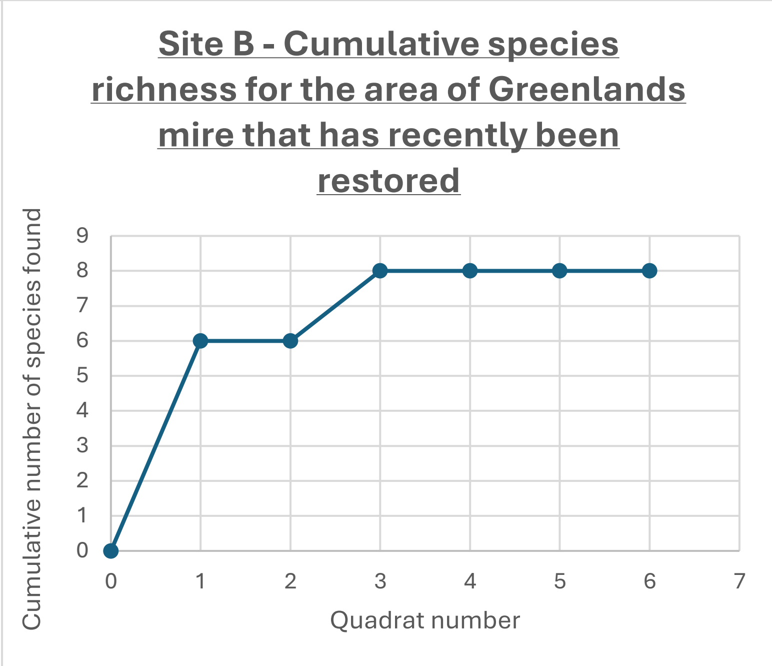
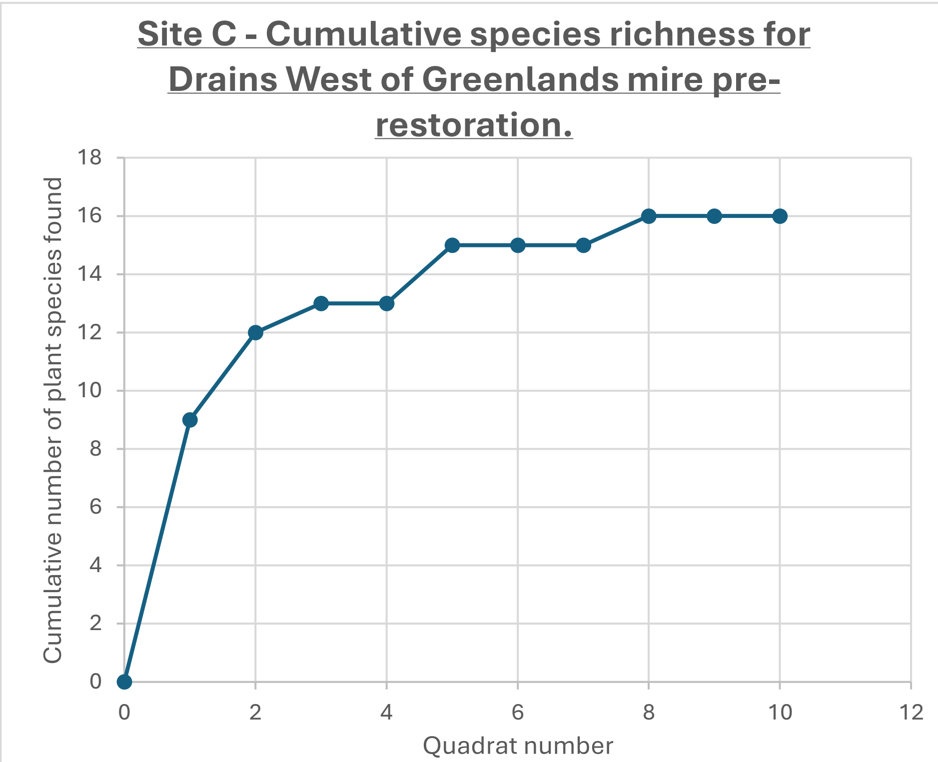


Figure 6 Species accumulation curves for each mire (Site A-Pristine, Site B-Recently restored, Site C-pre-restoration) using pre-survey data. See Site C species accumulation curve below. June 2024



Vegetation and invertebrate surveys were conducted between 13th-20th June 2024 09.00-17:00BST. Waterlogged conditions delay the development of peatland vegetation, so surveys prior to June are likely to miss species and under-record cover values (Bosanquet S. et al., 2013). A randomised block design to survey the three sites was utilised to reduce variation resulting from temporal changes (Greenwood and Robinson, 2006).

Prior to fieldwork the ArcGIS random sampling tool was used to allocate survey-points a minimum of 30m apart to ensure independence and minimise bias. ArcGIS Fieldmaps was used to navigate and mark each point visited per site (Figure 7).

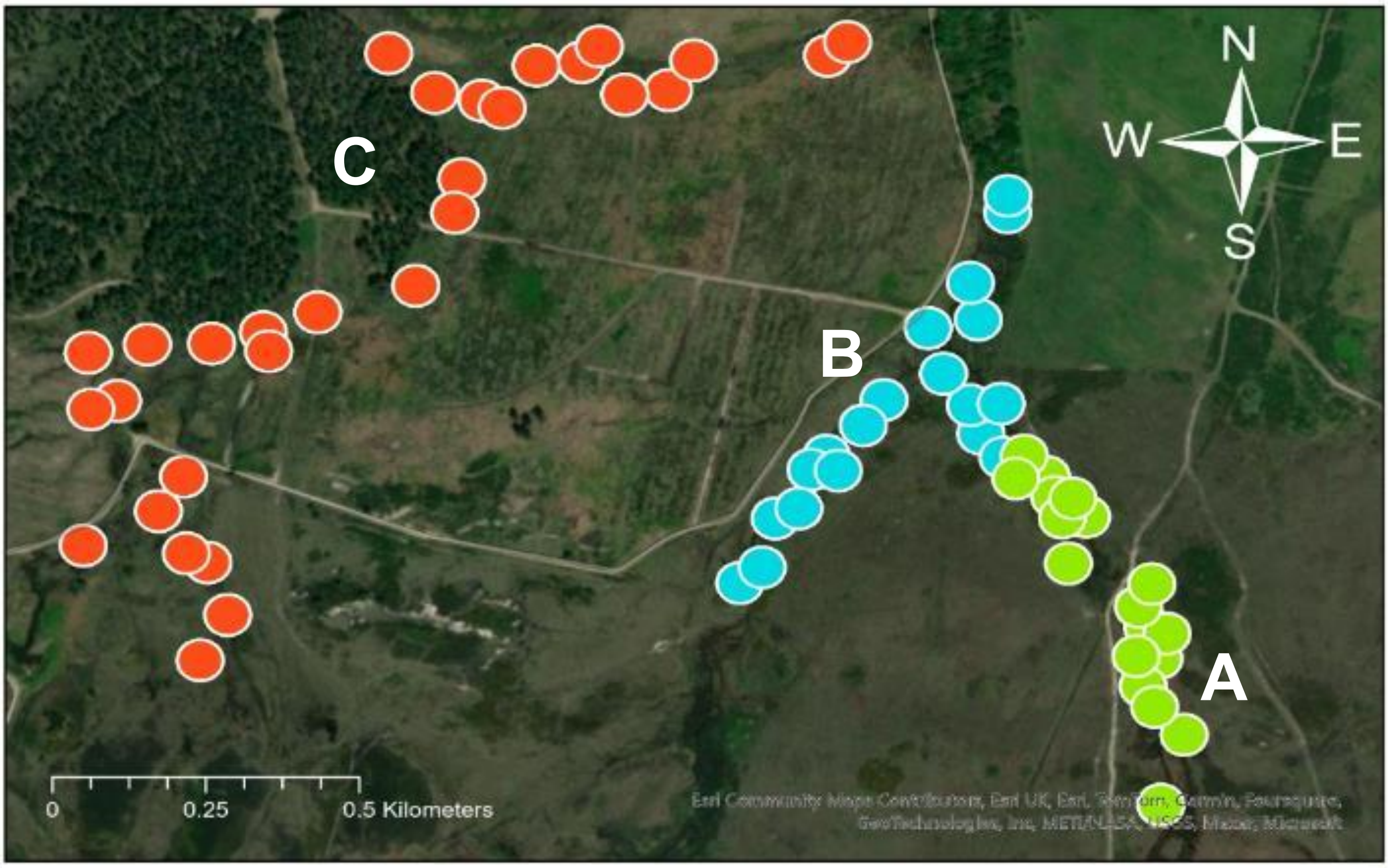


Figure 7 The above map shows the points surveyed on each site. This data was captured using the ArcGIS Fieldmaps app. The green dots are the points surveyed on the pristine part of Greenlands mire, blue dots are survey points on the restored areas of Greenlands mire and the red dots show the survey points on the pre-restoration site.

Although quadrat sizes of 0.1-1m^2 are used for bryophyte vegetation recording, quadrats of 1mx1m or smaller would not accurately represent the larger specialist vegetation found on peatlands (Peterka et al., 2020) and use of different quadrat sizes would prohibit statistical analysis requiring quadrats of equal size (Dengler et al., 2009). A Square 2mx2m quadrats recommended for wetland surveys (Bonnett, S., et al., 2009; Clarkson, B.R. et al., 2004; Rodwell, 2006) suiting the mire vegetation patterning and species (Bosanquet S. et al., 2013) were placed at each survey-point. The light plastic quadrat frame which floated, was ideally suited for use in waterlogged conditions (Figure 8). Percentage cover of vascular plants and bryophytes to species level rooted within were recorded on the prepared data-recording sheet (Appendix 4). Scores for each quadrat including bare peat and water cover often exceeded 100% due to vegetation layering. Key peatland plant species were identified

Figure 9 The string grid aided estimations of percentage cover for each vegetation type.

Figure 8 pH and ground temperature were measured in the North-eastern corner of each quadrat.

using online resources (BBS, 2024; JNCC, 2014) and reference texts (Poland et al., 2020; Streeter et al., 2016). The JNCC National Vegetation Classification Field Guide for Mires and Heaths was consulted (T. Elkington, et al., 2001). The 10-figure grid-reference along with pH and temperature within each quadrat were recorded (Figure 9). Measurements of water-depth were made using on-site dataloggers and fixed-point photography was undertaken to allow for visual comparison.

Invertebrate sampling used transparent plastic pitfall traps (10cm diameter, 10cm depth) placed in the north-eastern corner of each quadrat (Figure 10). Unbaited traps, without chemicals which attract certain species (Leather, 2005) were set flush with the surrounding substrate. Barriers were not used due to the waterlogged nature of the site and traps left uncovered as this is known to cause bias (Baars, 1979). Stones were placed in traps to reduce the impact of predation providing a refuge for smaller species (Honěk, 1988) and helped to counter upthrust due to the high-water table. Each pitfall trap was marked with red-white tape attached to a stick and labelled with the quadrat number to assist with relocation and recording (Figure 11). After 24 hours, pitfall traps were emptied into a white tray with the invertebrates counted, photographed, recorded and released (Figure 12). Identification was made based upon morphological traits (Oliver and Beattie, 1996) and reference texts (Bee et al., 2017; Brock, 2021; Sterling et al., 2012) to family/genus level. On collection a two minute-ground search was conducted within 2m of the trap to provide a representative sample of invertebrates present.


Figure 10 Pitfall traps were sunk into the peat until they were flush with the substrate using a metal trowel. The trowel was thoroughly cleaned before use to adhere to biosecurity protocols.


Figure 11 Sticks with red-white tape attached were useful in relocating pitfall traps after 24 hours.


Figure 12 The pitfall trap contents were emptied into a white tray with the invertebrate species and number recorded.

Chapter 3 - Results

Statistical Analysis:

Detrended Correspondence Analysis (DCA) using RMAVIS (Marshall et al., 2024) was employed to identify the predominant NVC communities within each site, reflecting the mires condition (Figure 13,14,15). Such analysis provides insight into successional stages of peatland restoration and similarity.

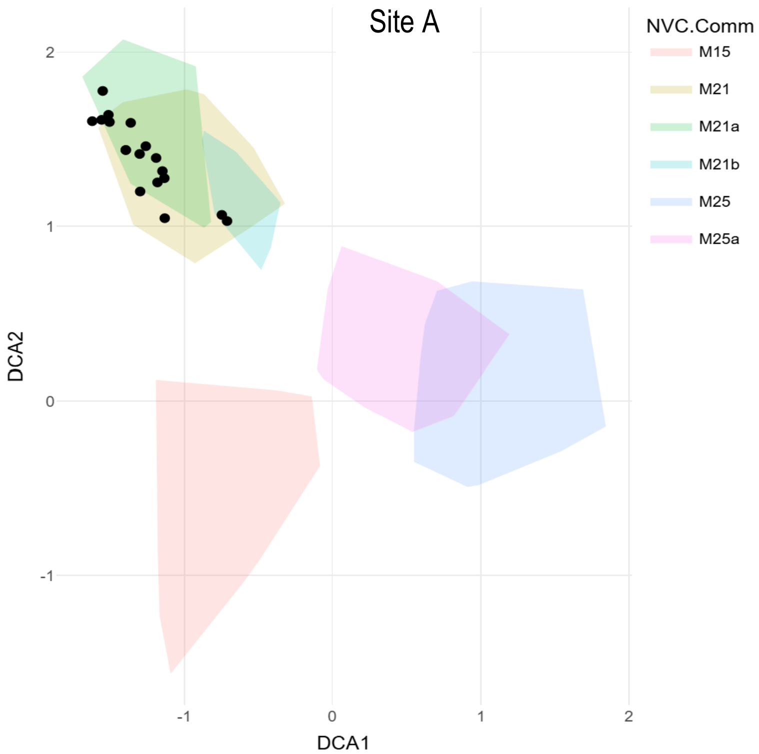


Figure 13 Detrended Correspondence Analysis (DCA) biplot for the Pristine Peatland site showing how quadrat data correlates with the National Vegetation Classification. Created using RMAVIS (Marshall et al., 2024).

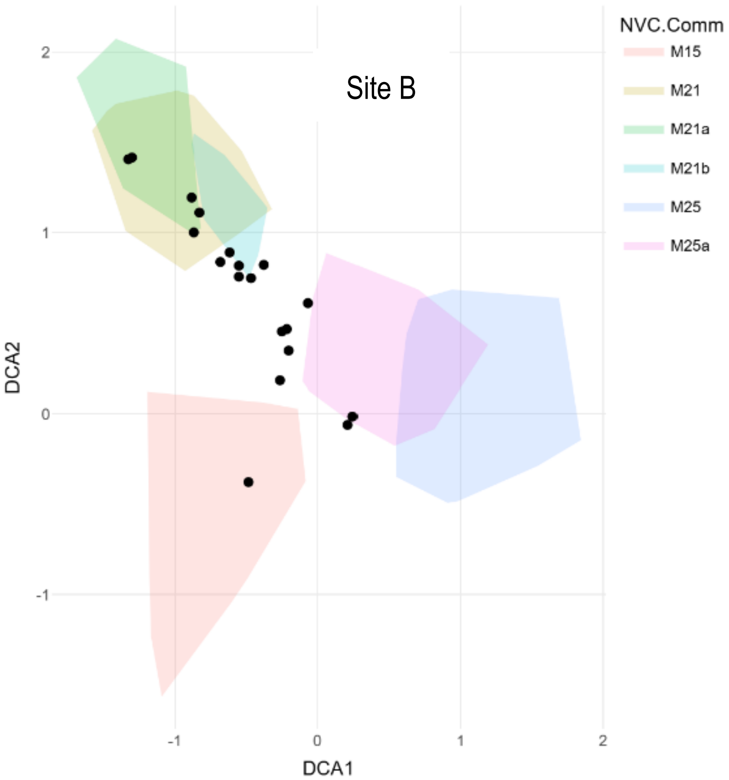


Figure 14 Detrended Correspondence Analysis (DCA) biplot for the recently restored peatland site showing how quadrat data correlates with the National Vegetation Classification Created using RMAVIS (Marshall et al., 2024).

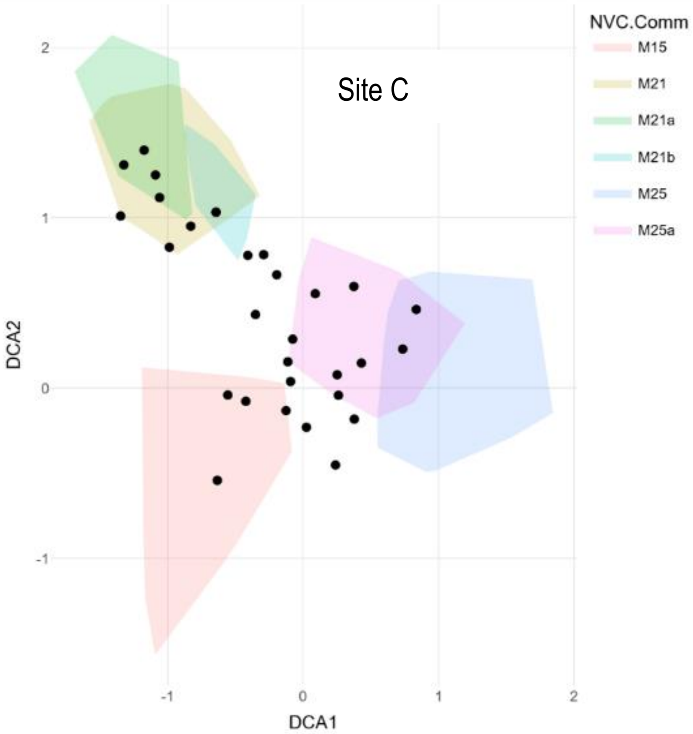
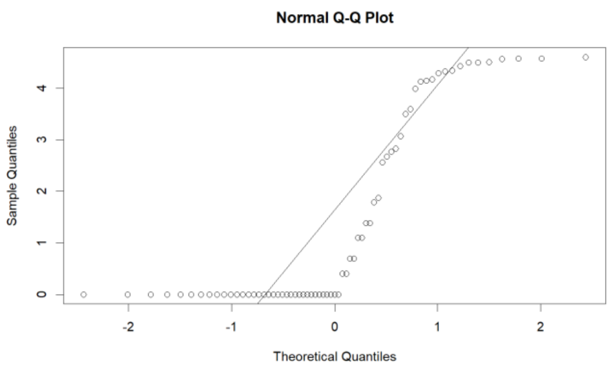
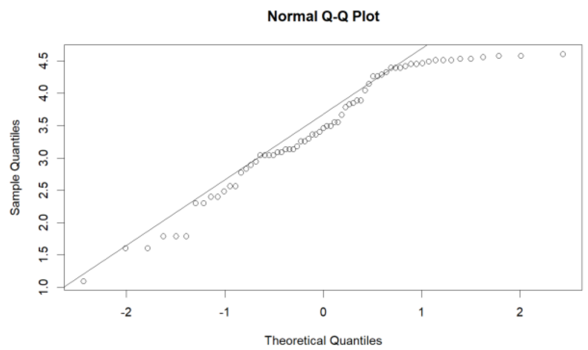


Figure 15 Detrended Correspondence Analysis (DCA) biplot for the Drains West of Greenlands (pre-restoration) peatland site showing how quadrat data correlates with the National Vegetation Classification Created using RMAVIS (Marshall et al., 2024).

Sphagnum and *Molinia caerulea* (hereafter referred to as *Molinia*) cover were compared using analysis of variance (ANOVA) (Table 3).

Table 3 Table showing conditions checked prior to conducting ANOVA.

Null hypothesis: There is no significant difference between the sphagnum cover on each site. **Null hypothesis:** There is no significant difference between the Molinia cover on each site. **Null hypothesis:** There is no interactive effect between sphagnum cover and Molinia cover on each site.	**Alternative Hypothesis:** There is a significant difference between the sphagnum cover on each site. **Alternative Hypothesis:** There is a significant difference between the Molinia cover on each site. **Alternative Hypothesis:** There is an interactive effect between sphagnum cover and Molinia cover on each site.
A **log+1 transformation** of the percentage cover data was utilised to normalise distributions.	
Sphagnum Cover: Bartlett Test of equal variance: Bartlett's K-squared = 1.8489, df = 2, p-value = 0.3968 The Sphagnum cover variance between sites is not significantly different. A **two-way ANOVA** is used.	**Molinia Cover:** Bartlett Test of equal variance: Bartlett's K-squared: 3.9764, df 2, p-value: 0.1369 The Molinia cover variances on each site are not significantly different. A **two-way ANOVA** is used.
FSQS Score variance between sites: **Site** **Variance** 1 Pre restoration 1.09 2 Pristine Peatland 0.620 3 Recently restored 1.12	**VQS Score variance for samples collected on each site.** **Site** **Variance** 1 Pre restoration 0.989 2 Pristine Peatland 0.417 3 Recently restored 0.595
	

To compare vegetation between sites a Vegetation Quality Score (VQS) based on van Duinen (2003) was calculated by summing the product of each species score and cover class and dividing this by the sum of cover classes for each site. Oertli et al. (2002) and Painter (1999) have also used similar indices.

Equation 1 Equation used to calculate the Vegetation Quality Score (VQS) based on (van Duinen et al., 2003). The cover classes, species score and criteria used to determine these can be found in Appendix 6-9.

$$VQS = \frac{\sum_{i=1}^{n} (\text{score of species}_i \ {*}\text{cover class}_i)}{\sum_{i=1}^{n} \text{cover class}_i}$$

Similarly, a Fauna Species Quality Score (FSQS) based on Foster (1989) was devised to provide a qualitative indication of peatland health, which may not be reliably obtained through biodiversity indices or calculations of abundance.

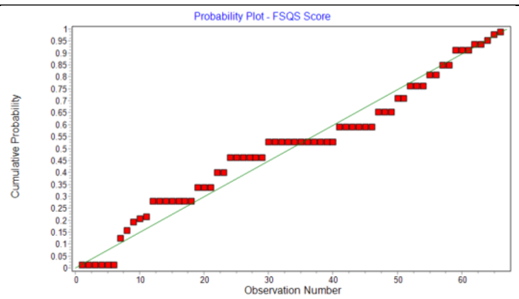
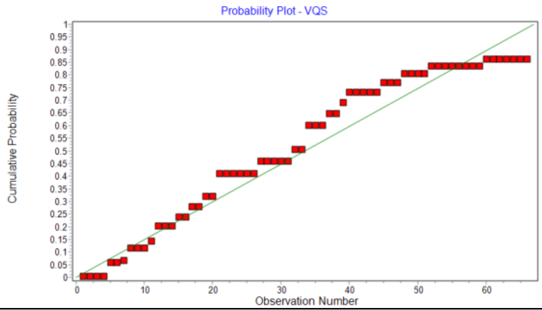
Equation 2 Equation used to calculate the Fauna Species Quality Score (FSQS) based on (van Duinen et al., 2003). The species categories and criteria used to determine these can be found in Appendix 10.

$$FSQS = \frac{\sum_{i=1}^{n} \text{score of species}_i}{\text{total number of species}}$$

Scores were assigned to plant and invertebrate species according to their affinity to lowland peatlands in pristine condition and are described in Appendix 6-10.

ANOVA was used to compare VQS and FSQS between sites. Table 4 details the checks undertaken to ensure assumptions were met.

Table 4 Table showing conditions checked prior to conducting ANOVA of mean VQS and FSQS score between sites.

Null hypothesis: There is no significant difference between the VQS and FSQS scores on each site.	**Alternative Hypothesis:** There is a significant difference between the VQS and FSQS scores on each site.
FSQS Score: Bartlett Test of equal variance: Bartlett's K-squared = 2.2756, df = 2, p-value = 0.3205 The FSQS Score variance between sites is not significantly difference. A **one-way ANOVA** is used.	**VQS Score:** Bartlett Test of equal variance: Bartlett's K-squared = 32.661, df = 2, p-value = 8.085e-08 The VQS Score variances between site is significantly different. **Welch's ANOVA** is therefore used.
Square-root (+0.5) transformations of FSQS, VQS scores were utilised to normalise distributions.	
FSQS Score variance between sites: **Site** **Variance** C Pre restoration 0.178 A Pristine Peatland 0.273 B Recently restored 0.330	**VQS Score variance for samples collected on each site.** **Site** **Variance** C Pre restoration 0.474 A Pristine Peatland 0.0215 B Recently restored 0.210
	

Pearson's correlation coefficient was utilised to determine whether presence of peatland vegetation (VQS) correlated with peatland specialist invertebrates (FSQS).

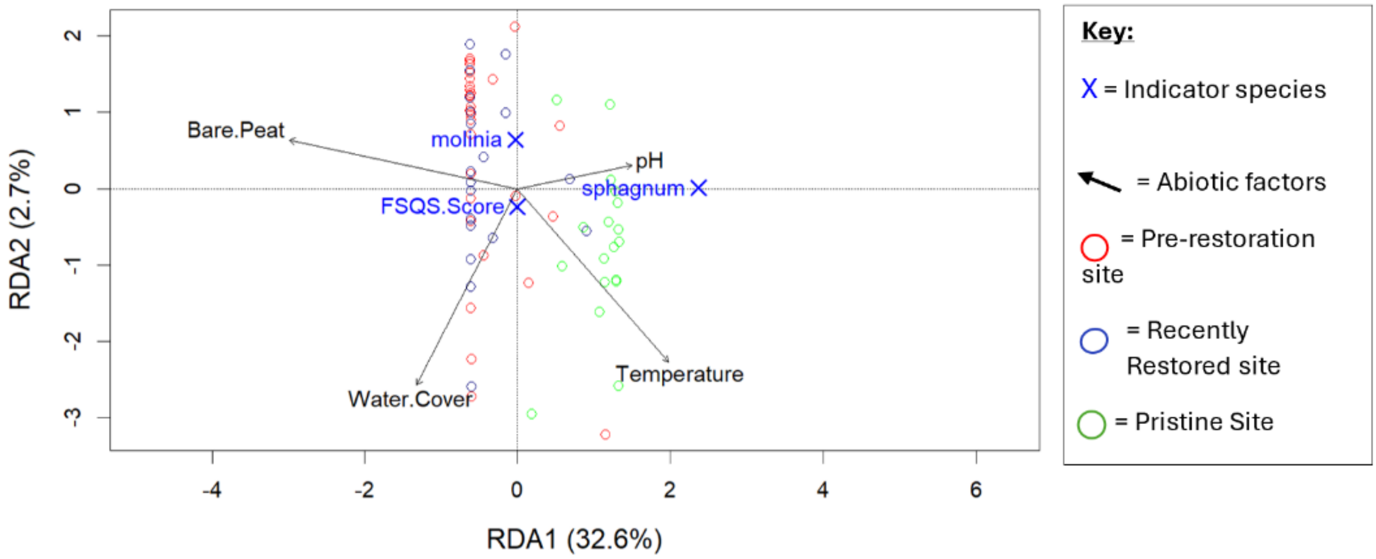
Redundancy analysis (RDA) was employed to explore the relationship between environmental variables on *Molinia*, *Sphagnum* and fauna species quality score (FSQS). The RDA model explains 35.47% of the total variance in the data (R^2_{adj}=0.3131), abiotic data and environmental variables were log-transformed prior to analysis. The overall model was highly significant (F=8.5199,p=0.001) as were all four environmental variables (Table 5).

Table 5 ANOVA was used to test the significance of each variable in the RDA.

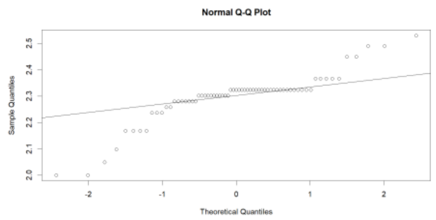
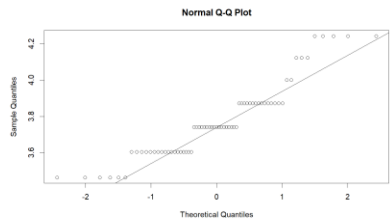
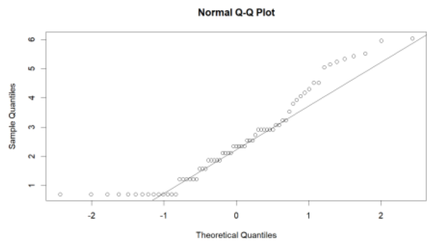
Term	Df	Variance	F	Pr(>F)
pH	1	0.28089	6.0224	0.007
Temperature	1	0.38899	8.34	0.004
Bare Peat	1	0.6195	13.2821	0.001
Water Cover	1	0.30015	6.4353	0.006
Residual	62	2.89178		

Figure 16 shows a clear divide with pristine sites having solely positive RDA1 scores and being closely associated with *sphagnum* cover and negatively associated with bare peat. Water cover was more evident on the recently restored and pre-restoration as this was recorded only when denuded of vegetation such as *Sphagnum* or *Potamogeton polygonifolius*, found in greatest abundance on the pristine site. This explains the negative correlation with *Sphagnum* and *Molinia* and does not reflect the true saturation of the ground when concealed by vegetation. Water cover is therefore not included in further analysis. pH was the least influential but closely aligned with *Sphagnum* cover.

Figure 16 An RDA was used to see how abiotic factors influenced FSQS score, Molinia caerulea and Sphagnum cover for each site.



Welch’s one-way ANOVA was used to compare abiotic factors pH, temperature and bare peat cover.

<table>
<tr><td colspan="2">Null hypothesis: There is no significant difference between the pH, temperature and bare peat cover on each site.</td><td>Alternative Hypothesis: There is a significant difference between the pH, temperature and bare peat cover on each site.</td></tr>
<tr><td>pH: Bartlett Test of equal variance: Bartlett's K-squared = 24.652, df = 2, p-value = 4.434e-06
The variance in pH between sites is not significantly difference. Welch’s ANOVA is used.</td><td>Temperature: Bartlett Test of equal variance: Bartlett's K-squared = 16.089, df = 2, p-value = 0.0003208
The temperature variances between sites is significantly different. Welch’s ANOVA is used.</td><td>Bare Peat: Bartlett Test of equal variance: Bartlett's K-squared = 15.091, df = 2, p-value = 0.0005284
The bare peat variances between sites is significantly different. Welch’s ANOVA is used.</td></tr>
<tr><td colspan="3">Square-root transformation of pH, temperature and a square-root transformation (+0.5) of bare peat were utilised to normalise distributions.</td></tr>
<tr><td>pH variance between sites:
Site Variance
C Pre restoration 0.0140
A Pristine Peatland 0.00556
B Recently restored 0.00111</td><td>Temperature variance between sites.
Site Variance
C Pre restoration 0.0120
A Pristine Peatland 0.0665
B Recently restored 0.0257</td><td>Bare peat cover variance between sites.
Site Variance
C Pre restoration 2.46
A Pristine Peatland 0.357
B Recently restored 1.49</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Results:

Vegetation:

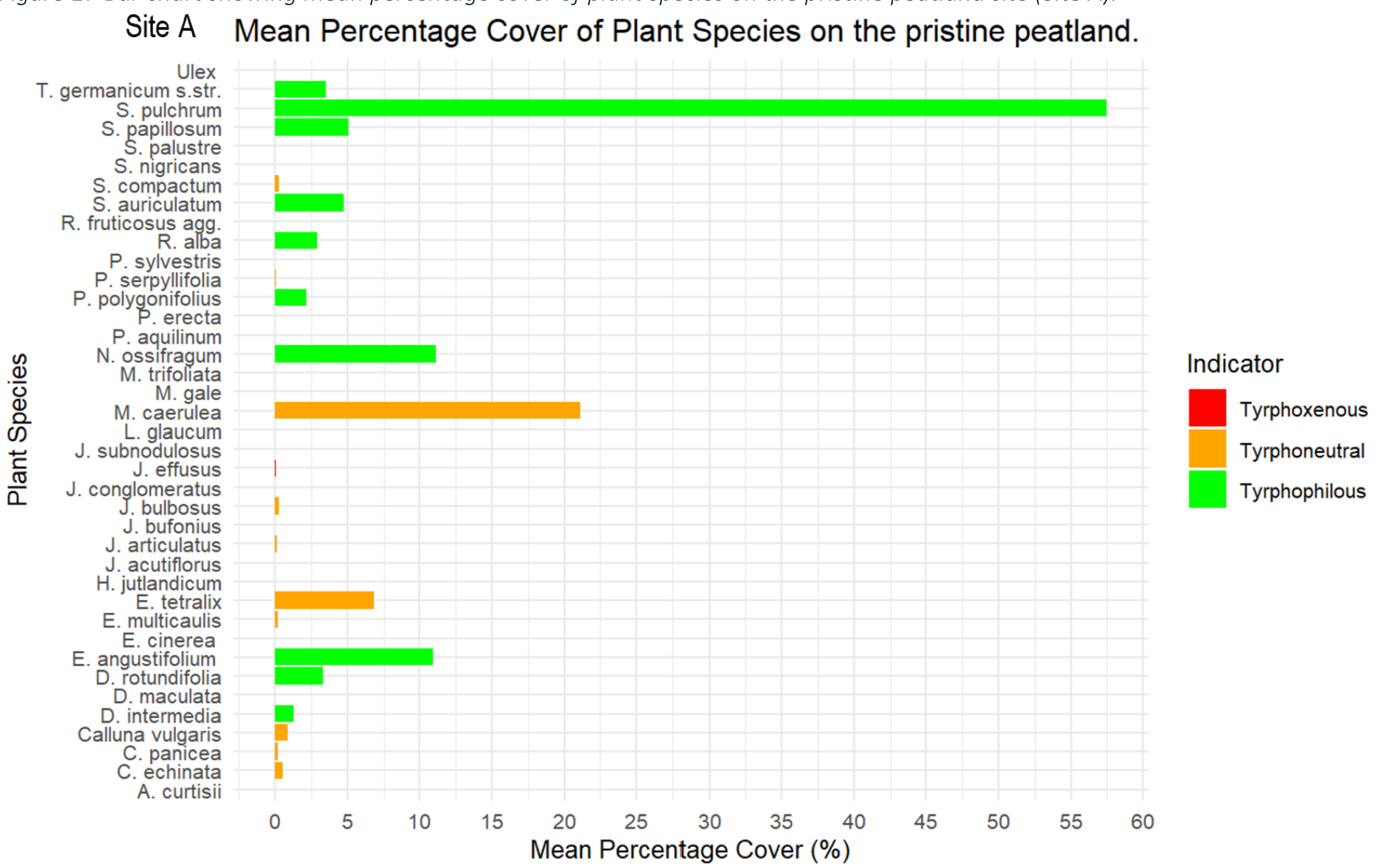
Table 6 shows the pristine peatland aligns most closely to the distinct M21 *Narthecium ossifragum-Sphagnum papillosum*-valley mire community (66% similarity score) and is illustrated in Figure 13-15 DCA plots.

The pristine site had a high-water table with large hummocks of *Sphagnum pulchrum* (mean cover=58%) interspersed with *Sphagnum papillosum (5%). Drosera sp.(4%), Narthecium ossifragum (11%), Rhynchospora alba (3%), Eriophorum angustifolium* (11%) and *Erica tetralix* (7%). *Potamogeton polygonifolius* was present in deeper pools. Figures 17-22 clearly demonstrate the differences in tyrphophilous and tyrphoxenous vegetation cover between the sites.

Table 6 The main NVC communities identified on each site and their similarity scores using RMAVIS (Marshall et al., 2024)

	Group ↑	NVC.Code	Similarity
Site C	Pre restoration DWOG	M16a	0.56
	Pre restoration DWOG	M16	0.55
	Pre restoration DWOG	M25a	0.54
	Pre restoration DWOG	M21	0.54
	Pre restoration DWOG	M21b	0.54
Site A	Pristine	M21	0.66
	Pristine	M21a	0.63
	Pristine	M21b	0.61
	Pristine	M16c	0.52
	Pristine	M17a	0.48
Site B	Recently Restored	M21	0.57
	Recently Restored	M21b	0.55
	Recently Restored	M25a	0.54
	Recently Restored	M15	0.53
	Recently Restored	M21a	0.52

Figure 17 Bar chart showing mean percentage cover of plant species on the pristine peatland site (Site A).



The DCA plot for pre-restoration site C (Figure 15) contained the greatest variety of NVC communities with a mixture of M21, M16a *Erica-tetralix–sphagnum-compactum* wet heath and M25 *Molinia caerulea–Potentilla-erecta,* indicative of drier conditions. Although zonation is typical of valley mire the lack of key positive indicator species such as *Rhynchospora alba (<1%), Drosera sp.* (<1%), *Narthecium ossifragum* (1.8%) and *sphagnum* cover (3.5%) was evident. Tyrphoxenous species such as *Ulex*, *Rubus, Pinus sylvestris, Pteridium aquilinum* were found in 60% of quadrats. Cumulative species richness of the pre-restoration site was highest due to the range of habitat conditions, yet per quadrat the mean species richness was half that of the pristine site (Table 7).

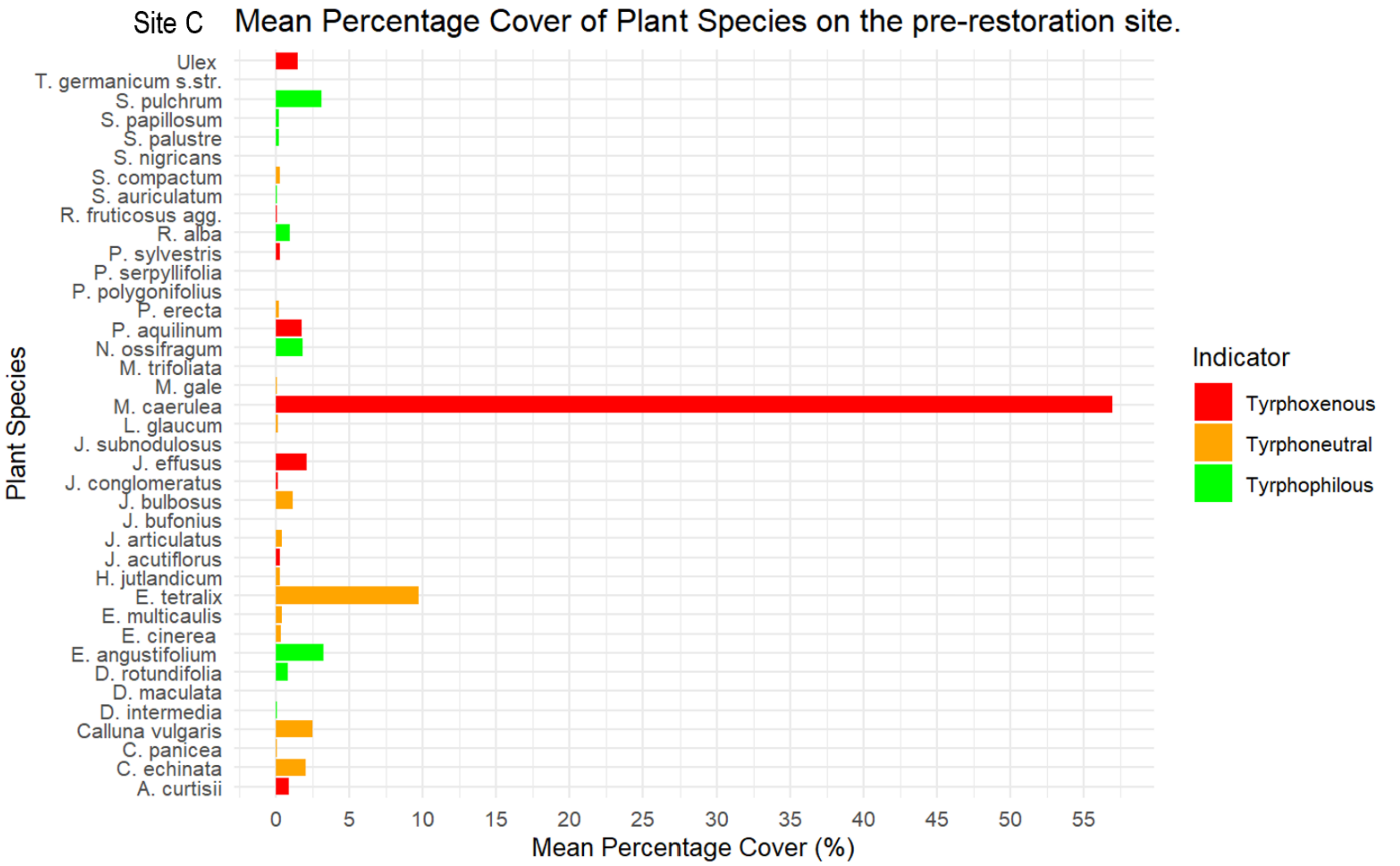
Table 7 showing mean plant species richness per site and per quadrat.

Site	Cumulative species richness on each site	Mean plant species richness per quadrat
Pristine (Site A)	21	10
Recently restored (Site B)	26	7
Pre-restoration (Site C)	31	5

Figure 18 Pristine peatland (Site A) showing the rich sphagnum carpet.

Figure 19 Negative indicator species on the pre-restoration site (Site C).

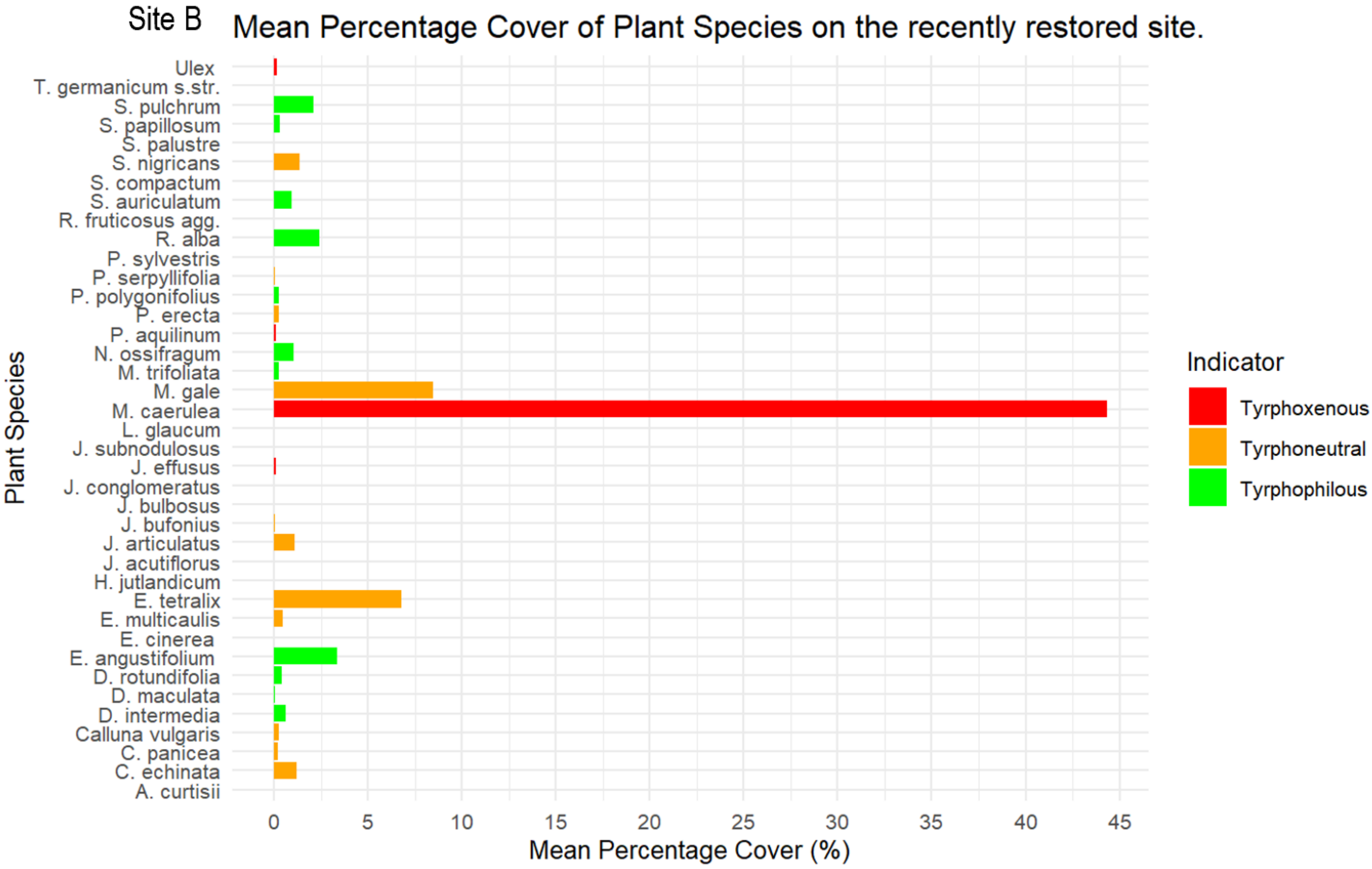
Figure 20 Bar chart showing mean percentage cover of plant species on the pre-restoration site (Site C).



The DCA plot for the recently restored site B (Figure 14) suggests a narrower corridor of communities which alongside fixed-point photography (Appendix 12) suggest restoration has impacted the vegetation present. Uniquely the recently restored site contained *Dactylorhiza maculate*, *Menyanthes trifoliata* and in the upper-eastern valley clumps of *Schoenus nigricans* forming a small *M14* NVC community. *Myrica Gale* was common on the recently restored site, present in 78% of quadrats, yet sparse on the pristine and pre-restoration site. Figure 22 shows that tyrphophilous species were emerging on the recently restored site at low cover levels (<3%) after 6 months.

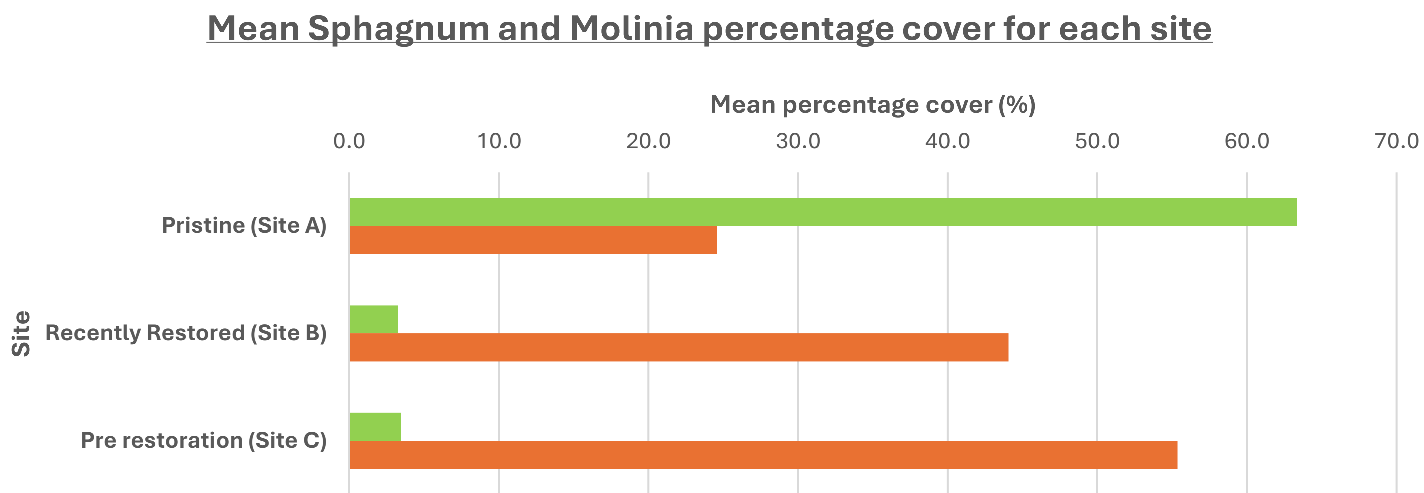
Figure 21 Recovering vegetation and bare peat on the recently restored site (Site B).

Figure 22 Bar chart showing mean percentage cover of plant species on the recently restored site (Site B).



Substantial differences in *Molinia* and *Sphagnum* cover between sites was noted (Figure 23).

Figure 23 Comparison of mean Sphagnum and Molinia caerulea cover on each site.



	Pre restoration (Site C)	Recently Restored (Site B)	Pristine (Site A)
mean sphagnum cover	3.5	3.2	63.3
mean molinia cover	55.4	44.1	24.6

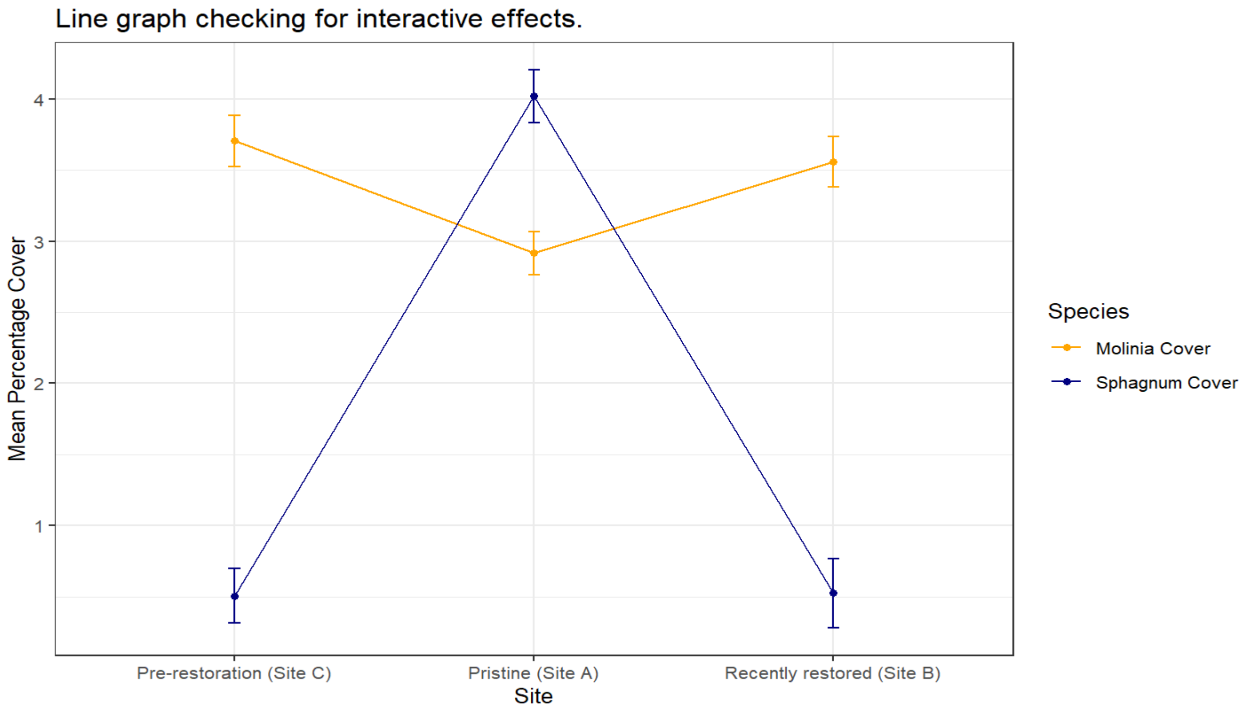
mean sphagnum cover mean molinia cover

A two-way ANOVA examined differences in *Sphagnum* and *Molinia* cover and the interaction between them. The results (Table 8) indicate that there were significant differences between sites, species and a significant interaction between them (Figure 24).

Table 8 Results of two-way ANOVA comparing Molinia caerulea and Sphagnum cover on the three study sites.

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Significance
Site	2	50.803	25.401	29.856	2.281e-11	Highly significant
Species	1	133.449	133.449	156.850	< 2.2e-16	Highly significant
Site:Species	2	118.444	59.222	69.607	< 2.2e-16	Highly significant
Residuals	128	108.903	0.851			

Figure 24 Line graph checking for interactive effects between mean Molinia caerulea and Sphagnum cover on each site using transformed



Tukey post-hoc tests (Table 9) revealed significantly higher *Sphagnum* cover on the pristine site than both the pre-restoration (+1.36,p< 0.001) and recently restored site (+1.43,p<0.001), *Sphagnum* cover between the recently restored and pre-restoration sites was not significantly different (p=0.9381).

Table 9 Tukey post-hoc test following two-way ANOVA comparing Sphagnum and Molinia caerulea cover on each site.

Comparison	Difference	Lower CI	Upper CI	p-value
Sphagnum Cover: Pristine (Site A) - Pre restoration (Site C)	1.3625	0.9014	1.8236	<0.0001
Sphagnum Cover: Recently restored (Site B) -Pre restoration	-0.0651	-0.5186	0.3884	0.9381
Sphagnum Cover: Pristine (Site A) -Recently restored (Site B)	1.4276	1.9363	0.9189	<0.0001

Ellenberg's indicator values (EIVs) utilise plant species preferences to infer the underlying environmental conditions and are useful for monitoring environmental change. Hill-Ellenberg values, developed specifically for British flora (Hill et al., 2000) were calculated to provide an indication of site conditions (Table 10).

Table 10 The weighted mean Hill-Ellenberg values for each site. RMAVIS (Marshall et al., 2024).

Weighted Mean Hill-Ellenberg Values, by Group

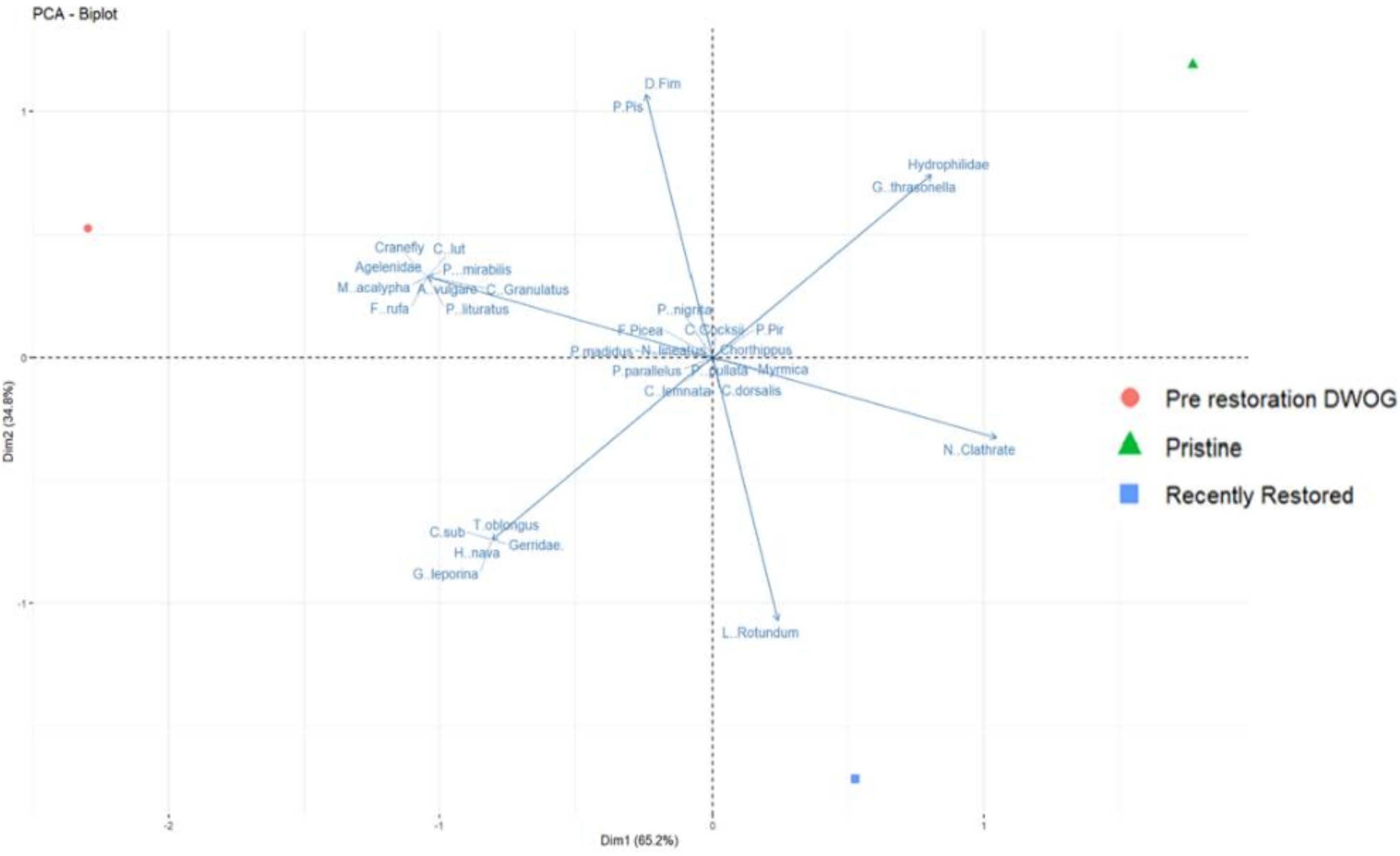
Year	Site	Group	Moisture.F	Light.L	Nitrogen.N	Reaction.R	Salinity.S
2024	C	Pre restoration…	5.67	5.15	1.31	1.99	0.00
2024	A	Pristine	9.82	8.39	1.31	2.07	0.00
2024	B	Recently Rest…	4.88	4.37	1.06	1.77	0.01

Moisture provided the largest disparity between sites emphasising the importance of a high-water table to allow vegetation associated with high quality peatland to survive. Plants present in the pristine peatland favoured higher light levels, therefore the proposed felling of the conifer plantation on the pre-restoration site may not only assist in reducing evapotranspiration but increase light levels favoured by peatland specialists. Care must be taken in interpreting site B values for moisture since the early successional stage will favour ruderal species able to withstand a range of conditions e.g. *Juncus bufonius.*

Invertebrates:

Principle Component Analysis (PCA) on invertebrate species (Figure 25) shows the presence of key peatland specialists *D.Fimbriatus*, *P.piscatorius* and to a lesser degree *P.nigrita* and *F.Picea* were closely associated, meaning conditions favouring one such species would support others with a similar environmental niche. The pre-restoration site had the greatest species diversity containing tyrphobiontic through to tyrphoxenous invertebrates (Table 11). The presence of *Hydrophilidae* were negatively correlated with *T.oblongus*, *G.leporina* and *H.nava* found on the drier tussocks of the unrestored and recently restored sites. The species centrally placed on the plot were found across all sites.

Figure 25 Principal Components Analysis (PCA) biplot showing the relationship between invertebrate species and the sites that they were found on using presence-absence data. ***Appendix 11 contains full species names.***



Species Quality Scores:

VQS and FSQS were calculated as an indication of habitat quality with higher scores for species closely associated with lowland valley mire to provide a habitat-fidelity index to assess peatland condition and compare sites (Drake, C. et al., 2007; van Duinen et al., 2003).

VQS:

Welch's ANOVA followed by a Games-Howell post-hoc test indicated a significant difference between the VQS on pre-restoration and pristine peatland with scores 1.17 points higher on the latter (estimate=1.17,95%CL[0.855, 1.49],p_{adj}=0.00000000057) (Figure 26). On the recently restored site VQS was significantly higher than that of the pre-restoration site (estimate=0.522,95%CL[0.125, 0.918],p_{adj}=0.007), with peatland specialist vegetation represented in 15 out of 19 quadrats though cover levels were low (0-25%). This is a positive finding which suggests recovery has started. Table 11 shows mean VQS scores.

Table 11 Mean VQS score per quadrat.

Site	Mean VQS Score
Pristine (Site A)	8.22
Recently restored (Site B)	4.98
Pre-restoration (Site C)	3.11

Figure 26 Estimated mean differences in VQS scores between each site using the Games-Howell post hoc test. Welch's ANOVA and Games-Howell post hoc tests were used as they do not assume equal variances between samples.

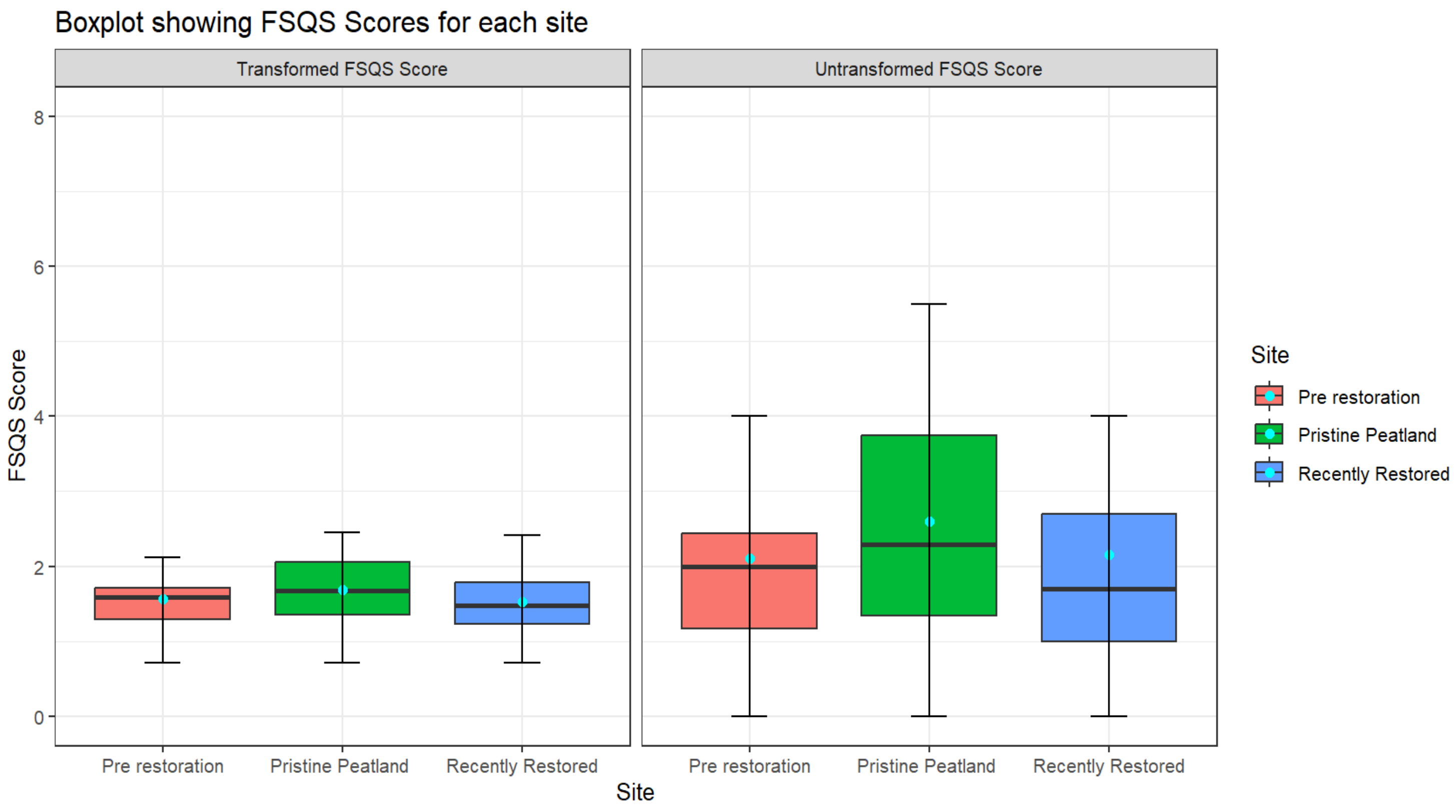
FSQS:

One-way analysis of variance (ANOVA) was used to compare FSQS scores between sites and a boxplot created (Figure 29). In this study no significant difference between sites was found ($F_{2,64}=0.5218, p=0.596$). The pristine site showed the greatest variation and the highest median value indicating that although a range of invertebrate species were present more quadrats contained tyrphobiontic invertebrates e.g. *Pirata* species (Figure 27,28)

Figure 27 Light brown Pirata sp. (Pirata piraticus)

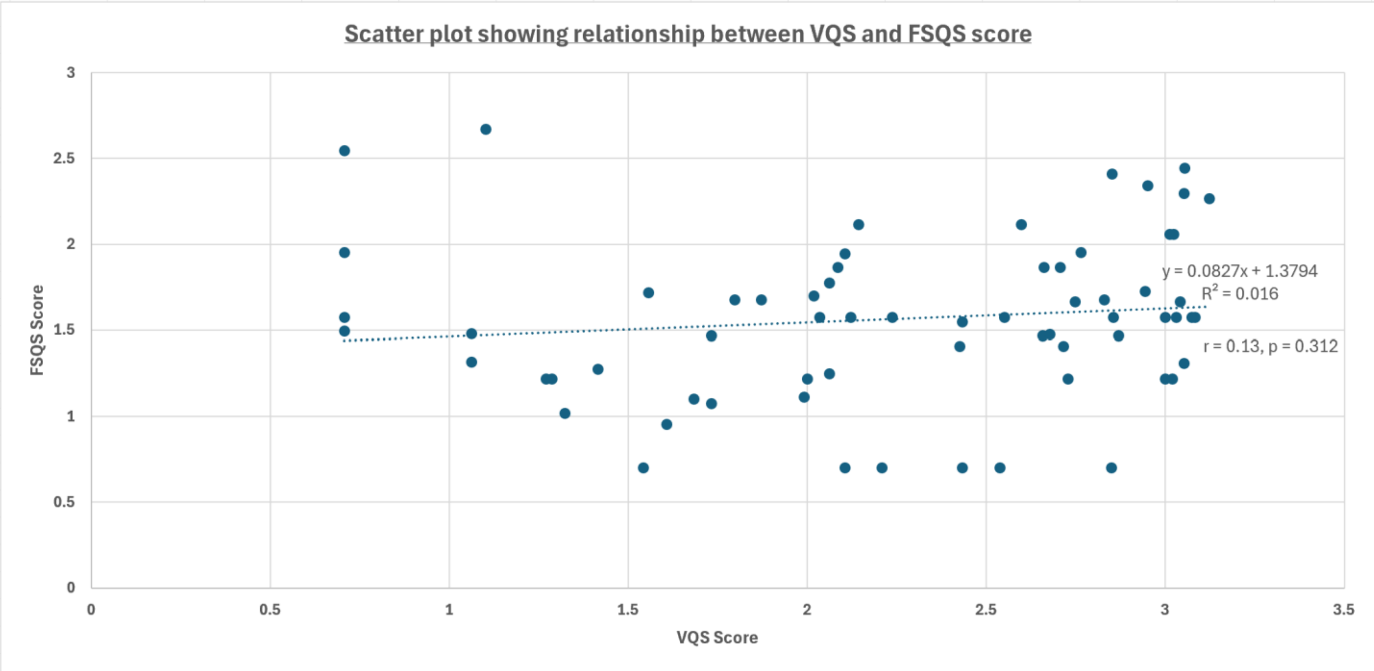
Figure 28 Dark brown Pirata sp. (Pirata piscatorius).

Figure 29 A boxplot of the untransformed and transformed FSQS scores showing the interquartile range, median and mean (the cyan point) FSQS score for each site.



No significant correlation (Pearson correlation coefficient) was found between FSQS and VQS scores ($r=0.13, p=0.312$) meaning presence of peatland vegetation did not appear to influence the specialist peatland invertebrates present. One outlier was removed prior to analysis (Figure 30).

Figure 30 Scatter plot of VQS and FSQS score with trendline to show relationship between the two variables.



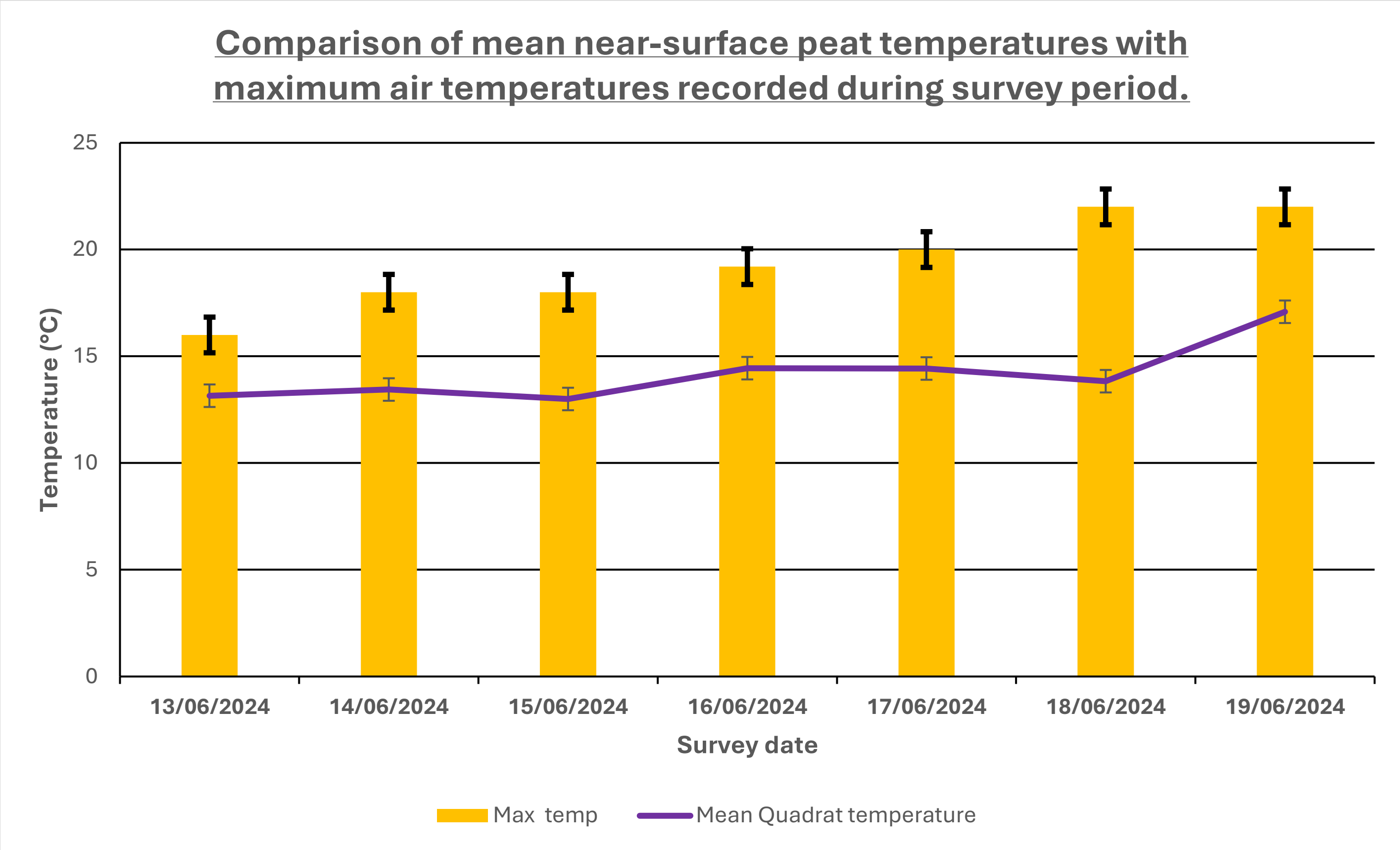
Abiotic Factors:

Using the quadrat data on pH, temperature and bare peat measured on site, Welch's ANOVA plus a Games-Howell post-hoc test revealed a modestly significant difference in pH between the pre-restoration and pristine site (p-adj=0.035,estimate=0.0717) (Table12). Bare peat cover was significantly lower on the pristine site (estimate=-2.14, $p<0.0001$) with greater vegetation cover reducing its vulnerability to oxidation and erosion visible on the pre-restoration site. Slight differences in ground temperature were recorded (estimate=0.265°C,$p< 0.001$), (estimate=0.179°C,$p < 0.001$) but site differences could be explained by daily temperatures which fluctuated throughout the survey (Figure 31).

Table 12 Games-Howell post hoc test results comparing pH and bare peat between the pre-restoration (Site C), recently restored (Site B) and pristine peatland (Site A).

pH Comparison	Estimate	95% CI (Lower)	95% CI (Upper)	p-adj	Significance
Pre-restoration vs Pristine	0.0717	0.00422	0.139	0.035	Significant
Pre-restoration vs Recently restored	0.0319	-0.0241	0.0879	0.356	Not significant
Pristine vs Recently restored	-0.0398	-0.0877	0.00820	0.117	Not significant
Bare peat Comparison	**Estimate**	**95% CI (Lower)**	**95% CI (Upper)**	**p-adj**	**Significance**
Pre-Restoration vs. Pristine	-2.14	-2.91	-1.36	1.36e-7	Highly significant
Pre-Restoration vs. Recently restored	-0.785	-1.76	0.187	1.35e-1	Not significant
Pristine vs. Recently restored	1.35	0.575	2.13	5.65e-4	Significant
Temperature Comparison	**Estimate**	**95% CI (Lower)**	**95% CI (Upper)**	**p-adj**	**Significance**
Pre-Restoration vs. Pristine	0.265	0.104	0.426	1e-3	Significant
Pre-Restoration vs. Recently restored	0.179	0.0754	0.282	5.54e-4	Significant
Pristine vs. Recently restored	-0.0860	-0.262	0.0897	4.57e-1	Not significant

Figure 31 Graph showing near-peat surface temperatures compared with daily maximum air temperatures. Data on max air temperature was taken from the nearest station weather archive- Bournemouth (meteocentre, 2024).



Chapter 4 - Discussion

Vegetation composition and cover differed significantly between the three sites and the DCA highlighted the progress of the recently restored site (B) towards NVC M21 communities typical in lowland valley mire. Rewetting has influenced the vegetation, though at an early successional stage with transitional species such as *Juncus articulatus* in 53% of quadrats. During the early stages of restoration, species like *Juncus articulatus,* adapted to the wetter, but not yet fully inundated, conditions that prevail are frequently the first to establish as the environment recovers. The Ellenberg-Hill values highlighted that peatland specialists thrive in waterlogged, open conditions and emphasise the importance of a high water-table and light intensity. There was a notable difference in *Molinia* cover between sites and restoration interventions targeting dominant *Molinia* tussocks will be important in re-establishing M21 communities. *Sphagnum* was a key feature of the pristine site with *pulchrum* and *papillosum* having cover levels of up to 96% and 20% respectively. A typical wet heath species *Sphagnum compactum* and the shade tolerant *Sphagnum palustre* commonly associated with wet woodland, ditches and flushes were found only on the unrestored site C. Restored site B had the lowest mean sphagnum cover (3.2%) though plans are in place to trial sphagnum plug planting for active regeneration. The VQS on restored site B was significantly higher than that of the pre-restoration site with peatland specialist vegetation recorded in 79% of quadrats surveyed though percentage cover was low. Future temporal surveys are necessary to confirm the establishment of k-strategist, stress-tolerant peatland specialists (high VQS) and the time interval for each successional stage post-restoration. The cumulative vegetative species richness across the pre-restoration site(C) was highest due to the extremes of conditions with areas of waterlogged bogs to drier degraded mire favouring negative indicator species such as *Pinus sylvestris*, *Pteridium aquilinum*.

Edwards (2013) documented that Greenland's mire contained some of the finest examples of lowland valley mire in Britain. These valley mires are typically open, dynamic systems requiring careful monitoring allowing for natural changes whilst being vulnerable to degradation. Degradation is often marked by dominance of few species to the exclusion of others with surface water fluctuations or nutrient enrichment suiting *Molinia* and increasing its vigour (JNCC, 2004; Meade, 2015). On the pre-restoration site C contrasting areas of M29 *Hypericum-elodes–Potamogeton polygonifolius-soakway* existed adjacent to drier M25 *Molinia caerulea-Potentilla-erecta* with *Molinia* tussocks covering up to 99% of a quadrat. Variation in conditions occurs naturally (Figure 32) however, the variability usually follows natural gradients such as valley slopes rather than anthropogenic influences e.g. drainage channels (Figure 33).

Figure 32 The following figure taken from Rodwell (1991) shows the typical zonation of vegetation communities in a valley fen.

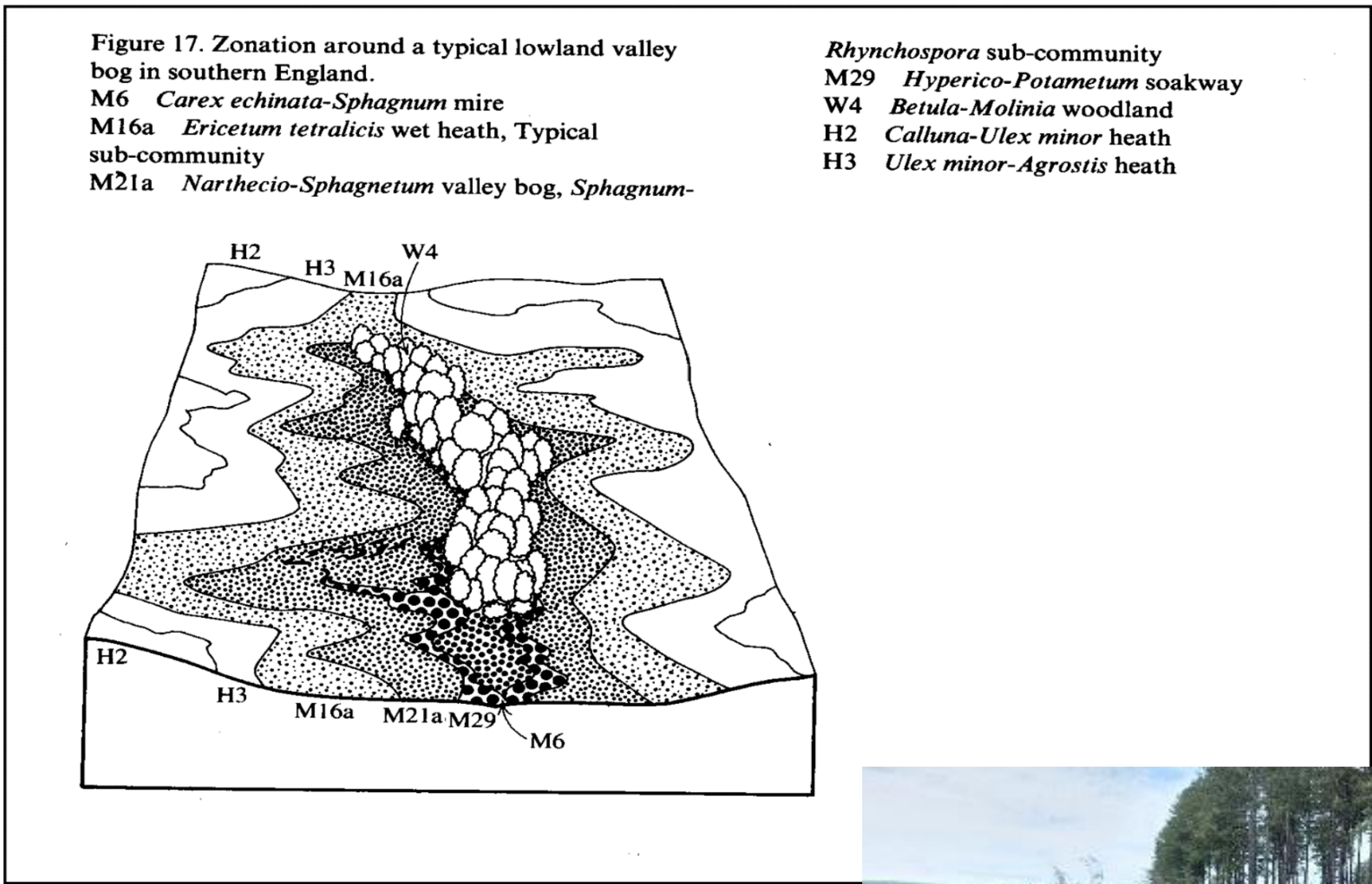


Figure 33 Drainage channels were evident across the site. Taken 18th June 2024.

Vegetation change has been used as a key indicator of peatland restoration and functionality, including carbon sequestration (Swenson et al., 2019), hydrological processes (Holden et al., 2008), peat accumulation (Clymo and Fogg, 1984) and gaseous flux (Strack et al., 2006). Time periods for restoration have been considered. Studies by Hambley et al. (2018) and Nugent et al. (2018) purport carbon sequestration occurring within 16 years of rewetting in conjunction with active revegetation. *Sphagnum* mosses sensitive to the water-table (Rydin and Jeglum, 2013b) highlight hydrodynamic changes, with studies using these as an important gauge of restoration success (Lindsay et al., 2014; Poulin et al., 2013; Rochefort, 2000). Bellamy et al. (2012) studying vegetation response to peatland drain blocking found vegetation compositions indicative of a recovering peatland only after drains were blocked for eleven years. Similarly, Anderson and Peace (2017) highlight the importance of effective damming to maintain a high-water table over the longer term and noted that vegetation composition on restored sites was initially dissimilar to the reference bog vegetation until 5-years post restoration. However, Kreyling (2021) cautions that a large number of factors influence peatland recovery with hydrology being just one factor requiring consideration. Restoration trajectories in other studies note enhanced restoration (after active revegetation) resulted in recovery of *Sphagnum* to pre-disturbance levels within 30–35 years and 20–25 years for vascular peatland species (Allan et al., 2024).

Invertebrates are useful bioindicators providing insight into site conditions but in this study no significant difference in FSQS scores between sites were recorded. However, practical challenges of conducting invertebrate surveys on peatland using pitfall traps in a short-timescale (24 hours) must be acknowledged, particularly on the pristine site with the highest water table and *sphagnum* cover providing greater shelter. Promising finds were made on the pre-restoration site with tyrphobiontic/tyrphophilous invertebrates found e.g. *Dolomedes fimbriatus* (Figure 34) inhabiting the site prior to restoration. The fact that Site C is already able to support tyrphobiontic species is a promising sign for upcoming restoration work. The pristine site had the lowest invertebrate species richness (Table 13) though with the highest proportion of peatland specialists. The low proportion of peatland specialists on the recently disturbed areas of Site B with higher bare peat cover and openness of habitat suggests that colonisation takes time following disturbance. Indeed Beadle (2023) found that different invertebrate communities colonise in restored peatlands over time with changes to conditions such as vegetation type, food availability and bare-peat cover.

Figure 34 Dolomedes fimbriatus a tyrphobiontic spider found only on the pre-restoration site (Site C).

Table 13 Table showing invertebrate species richness and the proportion of these that were tyrphobiontic or tyrphophilous.

Site	Cumulative invertebrate species richness	Proportion of tyrphobiontic and tyrphophilous as a percentage of the total species richness
Pre-restoration (Site C)	28	12/28 = 43%
Recently restored (Site B)	15	6/15 = 40%
Pristine Peatland (Site A)	13	8/13 = 62%

Abiotic factors were considered. pH varied across quadrats within each site but mean pH on the pre-restoration site was found to be marginally lower compared with the pristine peatland (p-adj=0.035, estimate=0.0717). The high-water table and profusion of sphagnum on the pristine peatland resulted in mean cover of bare peat (1%) being significantly lower than the pre-restoration (13%) or recently restored site (7%). Surface temperature is subject to climatic conditions but known to be impacted by water-table and vegetation cover. Griffiths et al. (2019) compared chemistries of adjacent bogs and fens, finding patterns of pH and temperature were inconsistent, suggesting the causes of these differences are difficult to pinpoint.

Chapter 5 - Conclusion

In conclusion, this short-term study demonstrates significant differences in plant composition and cover between peatland in various stages of restoration, with positive indicator species being dominant on healthy pristine peatland with a high-water table, acidic soils and high light levels. Rewetting restoration interventions on Site B has resulted in the establishment of ruderal vegetation and small colonies of sphagnum species after 6 months, though future temporal surveys are needed to record subsequent successional changes periodically. There were significant differences in vegetation on the pre-restoration site C, with higher dominance of negative indicator species and *Molinia* outcompeting many other peatland specialists, alongside significant areas of bare peat. Although it sustained larger cumulative species richness due to the diversity of conditions across the site, species richness per quadrat was greatest on the pristine site where positive bioindicator cover of 10-30% was consistent and mean VQS was highest. *Sphagnum pulchrum, papillosum, Narcessium ossifragum, Rhynchospora alba, Eriophorum angustifolium Drosera sp.* were reliable indicators of peatland health. However, sites with high VQS did not necessarily have larger numbers of characteristic peatland macroinvertebrate species and no significant difference in FSQS scores between sites were found. Although marginal significant differences in abiotic factors were found between sites, it is unwise to ascertain their cause or effect with any confidence.

Few studies have focused on lowland valley mire following restoration, especially at an early stage and ongoing monitoring will be required to evaluate the long-term success of the project. As slow-developing ecosystems, a long-term approach is necessary noting that vegetation recovery following rewetting may lag-behind hydrological response (Parry et al., 2014). Further work is needed to identify the causes in variability in recovery after drain blocking and the timescale of vegetation recovery. The Ramsar Convention concedes that without intervention peatland will not naturally regenerate and peat subsidence and carbon emissions will continue (Joosten, H., 2021). Active interventions to restore the water table close to the peat surface are essential to meet net-zero carbon targets, provide unique habitat promoting biodiversity and fulfilling ecosystem services (IUCN, 2019).

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Glossary:

Tyrphobiontic- occur exclusively in bogs (Brigić et al., 2017).

Tyrphophilous- typical of bogs, but not strictly confined to them(Brigić et al., 2017).

Tyrphoneutral- distributed across different types of habitats (Brigić et al., 2017).

Tyrphoxenous- immigrants that cannot survive in bogs (Brigić et al., 2017).

Appendix:

Appendix 1: Health and Safety Risk Assessment

Health and Safety Risk Assessment created prior to conducting fieldwork.

<u>RISK ASSESSMENT:</u>

A risk assessment must be carried out in order to comply with University Safety Policy.

Please remember to consider not only possible risks to your own health and safety, but also the effect that your work may have on other people or the environment.

The competency of external agencies hosting a fieldworker must be considered. Please append copies of the hosts own risk assessment, insurance certificate and other supporting documents where relevant. If these are unavailable, arrangements and responsibilities for the fieldwork must be agreed and documented as part of the risk assessment.

HEALTH PRECAUTIONS / EMERGENCY PROCEDURES:	
Have you taken advice from the University Occupational Health Service on the health risks associated with travel to your field site (see https://occupationalhealth.admin.ox.ac.uk/travel-service)? This study takes place in Dorset. My tetanus immunisation is up to date (25/7/17 lasting 10yrs). No other immunisations or antimalarials are required.	All accidents causing injury or near miss incidents during fieldwork must be reported/logged. What procedures have you set up to ensure this is possible? Record these on notes in phone app. If phone not working record with pen and paper on clipboard.
Please provide contact details of next of kin (including name, address and telephone numbers) and state their relationship to you. For emergency use only. Mother Liz Cornish	Please provide your passport / visa numbers (overseas travel only) N/A
What first aid training have you received or what first aid is available to you? I completed a first aid course (2022) I completed a first aid course (2022)	What first aid equipment will you take to the field site? I will take a first aid kit with bandages, plasters, sterile wipes, gloves and antihistamine cream/medication. I will take a first aid kit with bandages, plasters, sterile wipes, gloves and antihistamine cream/medication.

Hazard identified (please specify) (see checklists in appendix to UPS S5/07)	Risk involved or consequence	Estimated level of risk (likelihood and impact): negligible, low, medium, high
Personal (e.g. Lone work, first aid, violence, crime, travel) Lone working in a remote location	Becoming injured/ill or stuck without anyone to assist	Medium – phone available. Inform colleague before site visit and anticipated return time.
Physical (e.g. Extreme weather, caves, marshes, tides) Extreme weather Cold – hypothermia Marsh environment	Becoming cold/wet Struck by lightning Turning/twisting an ankle or becoming injured from falling due to the uneven peatland environment.	Medium - phone available. Inform colleague before site visit and anticipated return time.
Hazardous substances (e.g. Dust, chemicals, allergens) Ingestion of mire water Waterborne disease	Becoming unwell/sick Disease due to contaminated water.	Low - Avoid eating/drinking on site and ensure hands are washed thoroughly after contact with bog. Keep head well away from water surface. Ensure cuts are cleaned and covered.
Equipment (e.g. Electrical) Leaking equipment	Risk of cold/hypothermia and damp conditions	Low - Wear suitable clothing to mitigate risk of cold/hypothermia and damp conditions. Have several layers of clothing, check wellington boots do not leak before going on site and use waterproof gloves (have a spare pair to put on)

Environmental (e.g. Pollution, waste)	E. Coli in the soil.	Wash hands thoroughly after contact with the peatland water and soil.
Biological (e.g. Animals) Animals	Animals – such as reptiles may be in the water - bitten by fauna while working on the peatland site Ticks – lyme disease	Medium Wear appropriate clothing – wellington boots, waterproof trousers, top gloves. Ensure whole body is covered. Check for tick on legs/arms Be aware of symptoms.
Other (e.g. Manual handling, work at height) Manual handling	Injury due to carrying equipment – heavy/awkward to carry.	Low – if necessary use wheelbarrow or other device to help with carrying equipment required.

*See attached notes of estimation of level of risk.

Where the level of risk involved is considered to be any more than low or negligible you need to document the measures that have been taken to control it. Your first choice should be to avoid the hazard if at all possible: If you cannot do this, you need to take steps to reduce the risk to an acceptable level.

Risk	Control measure(s)
Medium - Lone working in a remote location	Let others know where you are and how long you intend to be. Where possible make site visits with another person. Have phone with you so that you can be contacted or you can contact others.
Medium - Extreme weather Cold – hypothermia Uneven marsh environment causing injury	To avoid being caught out in extreme weather e.g. thunder/lightning check forecast and if thunder and lightning storm starts stop field work. Ensure properly clothed with waterproofs and warm layers Avoid rushing, taking care with each step. Plan route across the mire carefully. Ideally have another person to go with to help if injury does occur but have phone with you so can contact someone to let them know if you are injured or to phone emergency services.

Medium - Animals	Ensure whole body is covered and wellies worn. Check site carefully and plan route avoiding any clear signs of animal activity. Avoid rushing, taking time to move through tussocks.

8/ DECLARATIONS:

- Risks associated with this Project have been acknowledged. I have read and understood the University of Oxford **University Policy Statement S5/07 'Safety in Fieldwork'** https://safety.admin.ox.ac.uk/travel-and-fieldwork and have followed guidance therein.
- Appropriate controls are in place/documented to manage any risks/foreseeable hazards
- The information given on this form is correct to the best of my knowledge

Signed (Student):	**Date: 01/03/2024**

Appendix 2: Survey Permissions

Survey Permissions from Forestry England and the National Trust Purbeck.

Forestry England

South England Forest District
The King's House, Lyndhurst
Hampshire, SO43 7NH

Tel: 0300 067 4601

Jonathan Cornish
Amen Cottage
Gussage All Saints
Wimborne
Dorset
BH21 5ET

Date: 25/03/2024

PERMIT NUMBER **025474/2024** FILE REF Rec. **12/28**

THIRD PARTY ECOLOGY SURVEY PERMISSION

1. THE PARTIES

Forestry Commission, acting through Forestry England South England Forest District, King's House, Lyndhurst, Hants SO43 7NH hereinafter referred to as Forestry England.

The Permit Holder Jonathan Cornish, Amen Cottage, Gussage All Saints, , Wimborne Dorset, BH21 5ET hereinafter referred to as the Permit Holder

2. THE RIGHTS GRANTED

Permission is given to the Permit Holder to Ecology Survey: Vegetation and invertebrate transect line survey on Forestry England land, subject to the following conditions:

Please message Mark Warn (Wildlife Ranger & Landscape Recovery Manager) Mark.Warn@forestryengland.uk or on 07881 502221 in advance before arriving on site.

3. THE SITE

The area over which the rights are granted is shown below:-

Drains West of Greenlands Ponds

4. THE DURATION

From 10/06/2024 To 20/06/2024

Hi Jonny,
You can take this email as permission to carry out your research and surveys on National Trust land in the manner, locations and timeframes described below.
I will look for some data from previous vegetation surveys in that area for you.
Kind regards,
Darren

Appendix 3: Equipment Checklist

First Aid kit

Waders or Wellies

All weather gear – long sleeved top/coat, waterproof trousers

Voucher specimen containers

A collapsable 2mx2m quadrat with 100 grid squares to aid calculation of percentage cover

Reference textbooks - (Bee et al., 2017; Brock, 2021; Poland et al., 2020; Sterling et al., 2012; Streeter et al., 2016)

Hand lens

Trowel

Pint sized plastic cups

pH meter

Rubber gloves

Red and white marking tape

Sticks with red-white tape attached to mark location for re-collection and a sticky label to denote quadrat number

Mobile phone loaded with GIS maps to note locations and grid reference finder to note grid reference (alternatively use GPS device)

All weather clipboard

Pen/pencil

Vegetation Data recording sheet

Invertebrate Data recording sheet

Bag

Pack lunch/snack

Water bottle

Suncream

Hat

Sunglasses

Appendix 4: Vegetation Data recording sheet

Surveyor: Jonathan Cornish	**Date:**	**Climatic conditions:**	**Region:** Studland and Godlingston Heaths NNR
Time:	**Site:**		

Species name (*Genus Species*)	**Percentage Cover**									
	Quadrat 11	**Quadrat 12**	**Quadrat 13**	**Quadrat 14**	**Quadrat 15**	**Quadrat 16**	**Quadrat 17**	**Quadrat 18**	**Quadrat 19**	**Quadrat 20**
Grid reference:										
Ph/temp										
Bare peat cover										
Water cover										
Bryophyte species										
1.										
2.										
3.										
4.										
5.										
Positive indicator species										
6. *Eriophorum angustifolium*- Common cottongrass										
7. *Drosera rotundifolia* - Round-*leaved sundew*										
8. *Drosera intermedia – Narrow-leaved sundew*										
9. Myrica gale – Bog myrtle										
10. Narthecium ossifragum - Bog *asphodel*										
11. Potentilla erecta – Tormentil										
12. Rhynchospora alba- white beaked sedge										
13. Rhynchospora fusca- brown beaked sedge										
14. Schoenus nigricans- black *bog-rush*										
15. Trichophorum cespitosum- deergrass										
16.										
17.										
18.										
Negative indicator species										
19. Ulex sp. - Gorse										
20. Molinia caerulea – Purple moor grass										
21. Betula sp.- birch										
22. Pinus Sylvestris – Scot's pine										
23. Rubus fucticosa - bramble										
24. Pteridium aquilinum- bracken										
25.										
26.										
27.										
*28. **Neutral/Other Species***										
29. Erica tetralix- Cross-leaved										
30. Calluna vulgaris- Common/Ling heather										
31. Erica cinerea- Bell heather										
32. Juncus effusus – Soft rush										
33. Juncus introflexus- Hard rush										
34. Juncus articulatus- Jointed rush										
35. Juncus subnodulosus- Blunt-flowered rush										
36. Juncus acutiflorus- Sharp flowered rush										
37. Eleocharis multicaulis- Many-Stemmed Spike Rush										
38. Carex echinata – star sedge										
39.										
40.										
41.										

Appendix 5: Invertebrate Data recording sheet

Surveyor: Jonathan Cornish	**Date:**	**Time:**	**Site:**
Climatic conditions:	**Grid Reference:**		**Region:** Studland and Godlingston Heaths NNR

Species /Morphospecies	**Abundance/Number in pitfall trap**									
	Quadrat 1	**Quadrat 2**	**Quadrat 3**	**Quadrat 4**	**Quadrat 5**	**Quadrat 6**	**Quadrat 7**	**Quadrat 8**	**Quadrat 9**	**Quadrat 10**
1.										
2.										
3.										
4.										
5.										
6.										
7.										
8.										
9.										
10.										

Surveyor: Jonathan Cornish	**Date:**	**Time:**	**Site:**
Climatic conditions:	**Grid Reference:**		**Region:** Studland and Godlingston Heaths NNR

Species /Morphospecies	**Abundance/Number in pitfall trap**									
	Quadrat 11	**Quadrat 12**	**Quadrat 13**	**Quadrat 14**	**Quadrat 15**	**Quadrat 16**	**Quadrat 17**	**Quadrat 18**	**Quadrat 19**	**Quadrat 20**
1.										
2.										
3.										
4.										
5.										
6.										
7.										
8.										
9.										
10.										

Surveyor: Jonathan Cornish	**Date:**	**Time:**	**Site:**
Climatic conditions:	**Grid Reference:**		**Region:** Studland and Godlingston Heaths NNR

Species /Morphospecies	**Abundance/Number in pitfall trap**									
	Quadrat 21	**Quadrat 22**	**Quadrat 23**	**Quadrat 24**	**Quadrat 25**	**Quadrat 26**	**Quadrat 27**	**Quadrat 28**	**Quadrat 29**	**Quadrat 30**
1.										
2.										
3.										
4.										
5.										
6.										
7.										
8.										
9.										
10.										

Appendix 6: Vegetation Quality Score (VQS) Plant indicator criteria

Table explaining the criteria by which the positive/negative indicator and tyrphoneutral plants were chosen to calculate the VQS score.

Positive indicator species – that are tyrphobiontic/tyrphophilous
Positive indicator plant species were chosen based upon their affinity to lowland valley mire and fen, being key components of the M21a *Narthecium ossifragum – Sphagnum papillosum* valley mire, M1 *Sphagnum auriculatum and M3 Eriophorum angustifolium bog pool* phytosociological community. All peatland specialist sphagnum species, vascular plants closely associated or found exclusively in peatlands or areas with a high-water table. Rare wetland species are also placed within this category.
Tyrphoneutral plants- found in mires but not confined to them
Common wetland species, general peatland specialists and vegetation associated with mires and heaths. Vegetation that commonly occurs in areas (zonation) surrounding M21a valley mire (see Figure) – where gradation of wet heath and mire communities occurs. Indicative of wetland habitat and associated phytosociological communities.
Negative indicator species- Tyrphoxenous species not typical of mire/wetland habitats
Species not commonly associated with peatlands, mire or heathland but survive due to modifications such as drainage of peatland sites and hence are indicative of drier conditions. Species that have an adverse effect on peatlands e.g. trees which increase water loss through higher levels of evapotranspiration and result in drying of the peat substrate. Invasive species and those that dominate, outcompeting species commonly found in peatland areas.

Appendix 7: Cover scale used to calculate VQS score.

Seven grade cover class based on *Braun–Blanquet* scales for visual estimates of cover	Range of Cover (%)
0	<1
1	1-5
2	5-10
3	10-25
4	25-50
5	50-75
6	75-100

Appendix 8: VQS Scoring System

Scores used in the Vegetation Quality Scoring (VQS) system based on their affinity to a lowland valley mire vegetation community (NVC M21a).

Positive indicator species – that are tyrphobiontic/tyrphophilous	*Score*
Sphagnum papillosum	*10*
Sphagnum pulchrum	*10*
Sphagnum auriculatum	*10*
Eriophorum angustifolium- Common cottongrass	*10*
Drosera rotundifolia - Round-*leaved sundew*	*10*
Drosera intermedia – Narrow-leaved sundew	*10*
Narthecium ossifragum - Bog asphodel	*10*
Rhynchospora alba- White beaked sedge	*10*
Trichophorum germanicum- deergrass	*10*
Dactylorhiza maculate- Heath Spotted-orchid	*10*
Menyanthes trifoliata- Bog bean	*10*
Potamogeton polygonifolius- Bog pondweed	*10*
Tyrphoneutral plants- found in mires but not confined to them	
Sphagnum compactum	*5*
Leucobryum glaucum	*5*
Hypnum cupressiforme sp.	*5*
Hypnum jutlandicum	*5*
Erica tetralix- Cross-leaved heath	*5*
Calluna vulgaris- Common/Ling heather	*5*
Erica cinerea- Bell heather	*5*
Schoenus nigricans- Black bog-rush	*5*
Carex echinata – Star sedge	*5*
Carex panicea – Carnation sedge	*5*
Juncus articulatus- Jointed rush	*5*
Juncus bulbosus- Bulbous Rush	*5*
Eleocharis multicaulis- Many-Stemmed Spike Rush	*5*
Potentilla erecta – Tormentil	*5*
Myrica gale – Bog myrtle	*5*
Juncus bufonius - Toad rush	*5*
Polygala serpyllifolia - Heath Milkwort	*5*
**Molinia caerulea – Purple moor grass (when <25% cover less than 6 on the Domin scale)*	*5*
Negative indicator species- Tyrphoxenous species that are not typical of mire habitats	
Ulex sp. - Gorse	*0*
**Molinia caerulea – Purple moor grass (when >25% cover- more than 6 on the Domin scale) scores 0*	*0*
Betula sp.- birch	*0*
Pinus Sylvestris – Scot's pine	*0*
Rubus fucticosa - bramble	*0*
Pteridium aquilinum- bracken	*0*
Juncus effusus – Soft rush	*0*
Juncus acutiflorus- Sharp flowered rush	*0*
Juncus subnodulosus- Blunt-flowered rush	*0*
Juncus conglomearatus- Compact rush	*0*
Agrostis curtisii	*0*

**Molinia caerulea* is described in the National Vegetation Classification M21a *Narthecium ossifragum–Sphagnum papillosum* valley mire (T. Elkington, et al., 2001) as being typical of the community but as being 'weak and not tussock-forming' and following guidance in the Conference Paper 'Managing Molinia' (Meade, 2015).

Appendix 9: Resources consulted to decide indicators used in this study.

Positive and negative plant indicators of the UK Priority Habitat Fen: H7150 Depressions on peat substrates of the Rhynchosporion as published by (DAERA, 2018).

Positive Indicators:

Alisma-plantago aquatica	Water-plantain
Anagallis tenella	Bog Pimpernel
Angelica sylvestris	Wild Angelica
Caltha palustris	Marsh Marigold
small *Carex* sp.	small *Carex* sp.
medium *Carex* sp.	medium *Carex* sp.
bulky *Carex* sp.	bulky *Carex* sp.
Cicuta virosa	Cowbane
Crepis paludosa	Marsh Hawk's-beard
Dactylorhiza sp.	Marsh Orchid
Epilobium palustre	Marsh Willowherb
Equisetum fluviatile	Water Horsetail
Equisetum palustre	Marsh Horsetail
Eriophorum angustifolium	Common Cottongrass
Galium palustre	Common Marsh-bedstraw
Hydrocotyle vulgaris	Marsh Pennywort
Juncus articulatus	Jointed Rush
Lotus pedunculatus	Greater Bird's-foot-trefoil
Lysimachia nummularia	Creeping Jenny
Lysimachia vulgaris	Yellow Loosestrife
Lythrum salicaria	Purple-Loosestrife
Mentha aquatica	Water Mint
Menyanthes trifoliata	Bogbean
Parnassia palustris	Grass of Parnassus
Pedicularis palustris	Marsh Lousewort
Pinguicula vulgaris	Common Butterwort
Polytrichum commune	Common Haircap Moss
Potamogeton spp.	Pondweed
Potentilla erecta	Tormentil
Potentilla palustris	Marsh Cinquefoil
Ranunculus flammula	Lesser Spearwort
Sagina nodosa	Knotted Pearlwort
Selaginella selaginoides	Lesser Clubmoss
Silene flos-cuculi	Ragged Robin
Sphagnum sp	Peat Moss
Succisa pratensis	Devil's-bit Scabious
Triglochin palustre	Marsh Arrowgrass
Valeriana officinalis	Common Valerian
Veronica scutellata	Marsh Speedwell
Viola palustris	Marsh Violet

Negative Indicators:

Agrostis stolonifera	Creeping Bent
Arrhenatherum elatius	False oat-grass
Brachypodium sylvaticum	False-brome
Deschampsia caespitosa	Tufted Hair-grass
Epilobium hirsutum	Great Willowherb
Glyceria fluitans	Flote-grass
Glyceria maxima	Reed Sweet-grass
Juncus acutiflorus	Sharp-flowered Rush
Juncus conglomeratus	Compact Rush
Juncus effusus	Soft Rush
Juncus inflexus	Hard Rush
Juncus subnodulosus	Blunt-flowered Rush
Lolium perenne	Perennial Rye-grass
Molinia caerulea	Purple Moor-grass
Phalaris arundinacea	Reed Canary-grass
Phragmites australis	Common Reed
Poa trivialis	Rough Meadow-grass
Sparganium erectum	Branched Bur-reed
Typha latifolia	Bulrush
Urtica dioica	Stinging Nettle

Positive and negative indicator species as designated by the National Plant Monitoring

Acidic fens, flushes, mires and springs

Name	Common name	WF	Indicator	Page No.
Anagallis tenella	Bog Pimpernel	✿	+	66
Carex rostrata	Bottle Sedge		+	144
Chrysosplenium oppositifolium	Opposite-leaved Golden-saxifrage	✿	+	108
Cirsium palustre	Marsh Thistle	✿	+	89
Comarum palustre (Potentilla palustris)	Marsh Cinquefoil	✿	+	89
Deschampsia cespitosa	Tufted Hair-grass	✿	-	133
Deschampsia flexuosa	Wavy Hair-grass		+	134
Drosera rotundifolia	Round-leaved Sundew	✿	+	12
Epilobium hirsutum	Great Willowherb	✿	+	71
Hypericum elodes	Marsh St John's-wort		+	40
Impatiens glandulifera	Himalayan Balsam	✿	-	73
Juncus inflexus / effusus / conglomeratus	Hard Rush / Soft Rush / Compact Rush	✿	-	138/139
Lathyrus pratensis	Meadow Vetchling	✿	+	44
Lotus pedunculatus	Greater Bird's-foot-trefoil	✿	+	45
Lycopus europaeus	Gypsywort	✿	+	19
Mentha aquatica	Water Mint	✿	+	94
Menyanthes trifoliata	Bogbean	✿	+	20
Montia fontana	Blinks		+	22
Myrica gale	Bog-myrtle		+	111
Nardus stricta	Mat-grass		+	136
Narthecium ossifragum	Bog Asphodel	✿	+	47
Osmunda regalis	Royal Fern	✿	+	129
Pinguicula lusitanica	Pale Butterwort		+	96
Potamogeton polygonifolius	Bog Pondweed	✿	+	123
Rhynchospora alba	White Beak-sedge		+	146
Rumex crispus / obtusifolius	Curled Dock / Broad-leaved Dock	✿	-	113/114
Scutellaria galericulata	Skullcap		+	99
Senecio aquaticus	Marsh Ragwort		+	55
Urtica dioica	Common Nettle	✿	-	117
Valeriana officinalis	Common Valerian	✿	+	82

Appendix 10: FSQS Invertebrate bioindicator categories and associated species scores

The invertebrate scoring system was developed based on the categories described by (Brigić et al., 2017) and the habitat descriptions of the invertebrates present on the sites found in the *Britain's Insects Field Guide* (Brock, 2021), *Britain's Spiders Field Guide* (Bee et al., 2017) and *Field Guide to Micro-moths* (Sterling et al., 2012) and online resources *(BAS, 2024), (UKBR, 2024) (Bantock and Botting, 2018)*.

Tyrphobiontic — invertebrates strongly affiliated to mire habitats	Score:
Light brown Pirata sp. (Pirata piraticus)	8
Dark brown Pirata sp. (Pirata piscatorius)	8
Raft spider - Dolomedes fimbriatum	8
Formica picea- Black bog ant	8
Shore bug- Hemiptera: Saldidae Chartoscirta cocksii	8
Hydrophilidae- Water scavenger beetle	8
Bronze micromoth with markings Glyphipterix thrasonella	8
Tyrphophilous — typical of mires, but not strictly confined to them	
Small white micromoth - Crambidae family - Cataclysta lemnata	4
Cranefly larvae	4
Pterostichus sp. (nigrita/rhaeticus)	4
Conocephalus sp. (dorsalis)- Cricket	4
Gerridae – Pondskater (Gerris lacustris)	4
Tyrphoneutral — invertebrates distributed across different types of habitats	
Caribus granulatus	2
Tibellus sp. (oblongus) - Straw coloured oblong running spider	2
Gnaphosa sp. (Gnaphosa leporina)	2
Myrmica sp. (red ant)	2
Chorthippus sp. (field grasshopper)	2
Wolf spider - Pardosa sp. pullata	2
Black-white marbled spider Neriene sp. (clathrate)	2
Harvestman spider (Opiliones) Leiobunum sp. Rotundum	2
Tyrphoxenous — invertebrates that are not usually found/cannot usually survive in mires	
Pterostichus madidus	1
Mangora acalypha - Round orb spider	1
Hahnia sp. (Hahnia nava)	1
Clubiona sp. (Clubiona lutescens) Wasp-like spider	1
Funnel web spider Agelenidae sp. labyrinthica	1
Straw coloured spider - Pisaura sp. mirabilis	1
Formica rufa - Wood ant	1
Pseudochorthippus sp.- parallelus (meadow grasshopper)	1
Woodlouse - Armadillidium vulgare	1
Neophilaneus lineatus - froghopper	1
Piezodorus lituratus- Gorse Shield bug	1

Appendix 11: Full species names alongside the abbreviated version used in PCA biplot.

Shortened version used in PCA biplot graph.	Species
P.Pir	*Pirata piraticus*
P.Pis	*Pirata piscatorius*
D.Fim	*Dolomedes fimbriatus*
F.Picea	*Formica picea*
C.Cocksii	*Saldidae*
Hydrophilidae	*Hydrophilidae*
G. thrasonella	*Glyphipterix thrasonella*
C. lemnata	*Cataclysta lemnata*
Cranefly	*Cranefly*
P. nigrita	*Pterostichus nigrita/rhaeticus*
C.dorsalis	*Conocephalus dorsalis*
Gerridae.	*Gerridae*
C. Granulatus	*Caribus granulatus*
P. pullata	*Pardosa pullata*
T.oblongus	*Tibellus oblongus*
G. leporina	*Gnaphosa leporina*
Myrmica	*Myrmica*
Chorthippus	*Chorthippus*
L. Rotundum	*Leiobunum rotundum*
N. Clathrate	*Metellina merianae / Neriene clathrate*
P.madidus	*Pterostichus madidus*
M. acalypha	*Mangora acalypha*
H. nava	*Hahnia nava*
C. lut	*Clubiona lutescens*
Agelenidae	*Agelenidae labyrinthica*
P. mirabilis	*Pisaura mirabilis*
F. rufa	*Formica rufa*
P.parallelus	*Pseudochorthippus parallelus*
A. vulgare	*Armadillidium vulgare*
N. lineatus	*Neophilaneus lineatus*
P. lituratus	*Piezodorus lituratus*
C .Sub	*Unconfirmed spider id*

Appendix 12: Fixed Point Photography on the Recently Restored site showing the interventions taken and the vegetation on-site 1-month and 5-months post-restoration.


Fixed point photography of Site B (recently restored site) showing the tail-end of the central valley on the 1-month and 5-months post restoration. Taken on the 20th February 2024 and 20th June 2024 by Jonathan Cornish.


Photos showing the plastic and timber dams used in the restoration project (Site B-recently restored site) to block the incised channels draining the mire. Taken post-restoration on the 20th February 2024.


Peat bunds and heather bale dams were created to slow the flow of water through the valley mire (Site B-recently restored site).

Appendix 13: Photos of invertebrate specimens collected.

M1 *Pterostichus nigrita/rhaeticus*

M2 *Pterostichus madidus*

M3 *Caribus granulatus*

M4 *Shore bug - Chartoscirta cocksii*

M5 Pseudochorthippus- (meadow grasshopper)

M6 Chorthippus (field grasshopper)

M7 *Conocephalus fuscus- Long-winged conehead cricket*

M12 *Piezodorus litturatus- Gorse Shield bug*

M15 *Dark brown Pirata sp. (Pirata uliginosus/piscatorius)*

M16 *Light brown Pirata sp. (Pirata piraticus)*

M18 Raft spider - *Dolomedes fimbriatus*

M20 *Clubiona species (Clubiona lutescens)* -Wasp spider

M21 *Mangora acalypha* (Round orb spider)

M23 Funnel web spider *Agelenidae sp. (Agelenidae labyrinthica)*

M25 Wolf spider - *Pardosa pullata*

M30 *Metellina merianae*- Black white marbled spider (*Neriene sp. clathrate)*

M31 *Harvestman spider (Opiliones) Leiobunum sp. Rotundum*