



Peatland Restoration in Västerbotten, Sweden

A vegetation composition survey assessing the effects of restoration

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Peatland restoration in Västerbotten, Sweden. A vegetation composition survey assessing the effects of restoration

Torvmarks restaurering i Västerbotten, Sverige. En undersökning av vegetations sammansättningen som bedömer effekterna av restaurering

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Keywords: Peatlands, mires, swamp forests, soil drainage, peatland restoration, biodiversity, vegetation composition, species richness, species cover

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Abstract

It is estimated that approximately 1.5 million hectares of peatlands in Sweden have been drained to benefit forestry. Ditching affects the hydrology of peatlands, driving the surface peat to become drier by lowering the water table, which diminishes the provided ecosystem services and natural vegetation composition. Peatlands are crucial ecosystems for nature-based solutions to combat climate change. Boreal and subarctic peatlands cover only a small percentage of the earth's surface but store almost one-third of the earth's carbon. Peatlands are also meaningful because they give rise to ecosystem services and a diversity of life forms. Conducting ecological restoration could effectively cease the loss of biodiversity in degraded ecosystems. Restoring degraded peatlands might be one way to tackle both climate change and biodiversity loss. However, certain dynamics of peatland restorations are still unexplored. Further research is needed to improve restoration effectiveness and knowledge of how the vegetation composition is affected by restoration. This study aims to examine the early effects of peatland restoration and its impact on vegetation composition in northern Sweden on mire and swamp forest sites. Floristic inventories were collected across ten sites in Västerbotten, Sweden, from the 5th of June until the 5th of July 2024. Each site was divided into three separate treatments: restored, drained and pristine. The analysis revealed that peatland restoration in northern Sweden, at least in the short term, might increase the presence of typical wetland species and decrease the presence of forest species in mires. This is positive since the recovery of peatland ecosystems is recognised by a decline in species typical to unrestored conditions. Additionally, a difference in species richness between the treatments across swamp forests and mires was observed. Vegetation composition also differed between the majority of treatments across swamp forests and mires, whereas the investigated environmental variables had a small effect on the explained variance. Further research is needed to be done on nutrient availability and restoration success when selecting sites for restoration efforts. With more knowledge, it might be possible to improve the restoration effort and thus increase biodiversity in restored peatlands

Keywords: Peatlands, mires, swamp forests, soil drainage, peatland restoration, biodiversity, vegetation composition, species richness, species cover

Table of contents

List of tables	5
List of figures.....	7
Abbreviations	9
Introduction	10
1.1 Wetlands, peatlands and the classifications	11
1.2 Drainage of natural peatlands in Sweden	13
1.3 Peatland restoration in practice	14
1.4 Aim	16
Method.....	17
2.1 Study sites and sampling design	17
2.1.1 Deviations from sampling	21
2.1.2 Data collection	21
2.2 Data processing and species identification.....	22
2.3 Statistical analysis.....	23
Results	25
3.1 Number of species, species presence and amount of cover	25
3.2 Vegetation composition.....	32
Discussion	36
4.1 Limitations and future research.....	40
4.2 Conclusion	41
References	42
Popular science summary.....	46
Acknowledgements.....	48
Appendix 1	49
Appendix 2	50

List of tables

Table 1. All sites with the allocated letter and a brief description	17
Table 2. The Sites were classified into two subgroups, mire and swamp forest.	18
Table 3. Description of the three treatments. The assigned colour shows which colour each treatment was allocated.	19
Table 4. Every unsampled treatment area and the associated site.	21
Table 5. The accuracy of the species identification and its assigned class.	23
Table 6. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest vascular plants across mire sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	27
Table 7. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland vascular plants across mire sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	28
Table 8. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest vascular plants across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	28
Table 9. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland vascular plants across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	28
Table 10. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest mosses across mire sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	30
Table 11. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland mosses across mire sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	31

Table 12. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest mosses across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	31
Table 13. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland mosses across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'	31
Table 14. A pairwise PERMANOVA of the mire sites investigated if the vegetation composition differed significantly between treatments in Figure 11. The treatments are as follows: pristine treatment =0, ditched treatment = 1 and the restored treatment = 2.	33
Table 15. A CCA analysis to examine the influence of different environmental variables on the vegetation composition for mire sites. A permutation test with 999 iterations was conducted to assess the significance. The investigated variables are as follows: treatment, ditch, site, water and the interaction between treatment and ditch.	34
Table 16. A pairwise PERMANOVA of the swamp forest sites investigated if the vegetation composition differed significantly between treatments in Figure 12. The treatments are as follows: pristine treatment =0, ditched treatment = 1 and the restored treatment = 2.	35
Table 17. A CCA analysis to examine the influence of different environmental variables on the vegetation composition for swamp forest sites. A permutation test with 999 iterations was conducted to assess the significance. The investigated variables are as follows: treatment, ditch, site, water and the interaction between treatment and ditch.	35

List of figures

Figure 1. An illustration showing the different peatland classifications depending on hydrology and nutrient availability from Rydin and Jeglum (2013). The illustration was developed for northwestern Ontario, though it is also greatly valid in Boreal Europe.....	12
Figure 2. A visualisation of how different the peatland classifications can look from one another. A forested peatland (left) and an open mire (right). Forested peatlands tend to have forest-prone species due to shade and drier soils. Compared to open mires, which are inhabited by water-resistant mosses and vascular plants.	13
Figure 3. Picture showing a restoration effort using a dam at Rismyrbrånet to slow down water flow (left) and a restoration effort using ditch filling at Stora-Bräntjärnmyran (right). Pictures taken by the author (Nordstrand, 2024).	15
Figure 4. Picture (A) the locations of the ten selected sites in Västerbotten. Picture (B) shows the prescribed treatments 0, 1 and 2, which illustrate the corresponding types of habitats along the restoration gradient. Treatments 0 = green, 1 = orange and 2 = purple at site Rismyrbrånet (K).....	20
Figure 5. Illustration of the distribution of the 12 sampling quadrats along the transects relative to the ditch. The sampling quadrats were placed at a distance of 20 meters from each other. For treatment 0, the sampling quadrats in the centre were placed in a straight line as there was no ditch nearby.....	21
Figure 6. The modified Braun-Blanquet scoring system was used for the floristic inventories.....	22
Figure 7. Boxplot showing the number of (forest and wetland) species across treatments (0,1,2) and groups (mire and swamp forest). The treatment is as follows: pristine = 0, drained = 1 and restored =2.....	25
Figure 8. The five most dominant species are summarised based on mean cover across treatments (0,1,2) and groups (mire and swamp forest).	26
Figure 9. Boxplot exhibiting the mean cover of vascular plants (forest and wetland species) across treatments (0,1,2) for sites from the groups (mire and swamp	

forest). The median value for each treatment is presented as the central line, while the mean value is the diamond. The treatment is as follows: pristine = 0, drained = 1 and restored =2. 27

Figure 10. Boxplot exhibiting the mean cover of mosses (forest and wetland species) across treatments (0,1,2) for sites from the groups (mire and swamp forest). The median value for each treatment is presented as the central line, while the mean value is the diamond. The treatment is as follows: pristine = 0, drained = 1 and restored =2..... 30

Figure 11. An NMDS exclusively of the mire sites illustrating the vegetation community structure between sites and treatments, with a stress level of 0.175. Similarities and dissimilarities are visualised through the placement of the ellipses with a confidence of 95%, depicting the dispersion of each treatment. The points represent each individual sampling point. The labels demonstrate the calculated average position for each site within the NMDS. The treatments are as follows: pristine treatment =0, ditched treatment = 1 and the restored treatment = 2..... 33

Figure 12. An NMDS exclusively of the swamp forest sites illustrates the vegetation community structure between sites and treatments, with a stress level of 0.209. Similarities and dissimilarities are visualised through the placement of the ellipses with a confidence of 95%, depicting the dispersion of each treatment. The points represent each individual sampling point. The labels demonstrate the calculated average position for each site within the NMDS. The treatments are as follows: pristine treatment =0, ditched treatment = 1 and the restored treatment = 2..... 34

Abbreviations

CCA	Canonical-correlation analysis
GLMMs	Generalized linear mixed models
NMDS	Non-metric multidimensional scaling
NMD	National Land Cover Database
NILS	National Inventories of Landscapes in Sweden
VMI	Swedish National Wetland Inventory

Introduction

Climate change threatens the survival of species and diverse ecosystems (Hulme 2005). Because of these obstacles ahead, mankind needs to take critical measures to stop the further deterioration of our ecosystems. The loss in ecosystem services has highlighted the importance of ecological restoration and conservation of current and degraded ecosystems (Sapkota *et al.* 2018). The Habitat Directive developed by the European Union aims to restore and maintain natural habitats for flora and fauna communities in Europe (Rådet 1992). However, only 15% of Europe's habitat types have a good ecological status and 27% of all species have a promising conservation status (European Environment Agency 2023), thus making restoration an important measure to maintain the ecosystem services and biodiversity in the future. Additionally, new regulations from the European Union present the potential requirements for all the member countries to restore up to 20% of damaged ecosystems in land and sea areas (Europiska unionens råd 2024). The purpose of the new law is to stop the further deterioration of biodiversity since most habitat types in Europe are deemed to be in poor condition. Until 2030, each member country must restore habitat types such as peatlands, grasslands, rivers and lakes (Directorate-General for Environment 2024). In Sweden, many habitat types have insufficient or poor conservation status and a forecasted negative trend (Aronsson *et al.* 2020). The result from the habitat directive monitoring period from 2013-2018 showed that only 20 percent of the habitat types in Sweden have promising conservation status (Aronsson *et al.* 2020).

Conducting ecological restoration could effectively cease the loss of biodiversity in degraded ecosystems (Elo *et al.* 2024). Increased ecosystem resilience can also be another positive outcome of ecological restoration (Wortley *et al.* 2013). Biodiversity has been shown to influence the resilience of ecosystems, which could be crucial to resist and recover from disturbances, especially during the rapid climate change (Oliver *et al.* 2015). To achieve the beneficial goals of restoration, a thorough understanding of the original state and its functions is essential when restoring deteriorated ecosystems (Rydin & Jeglum 2013; Haapalehto *et al.* 2017). Restoration is mainly performed on degraded habitats, but the reclamation of lost habitats and the creation of new ones could be equally important in the future with a changing climate (Harris *et al.* 2006). Wetlands, including peatlands, are one of the habitat types that have been negatively affected by anthropogenic degradation

and are regarded to have high ecological restoration value (Erwin 2009; Andersen et al. 2017)

1.1 Wetlands, peatlands and the classifications

The definition of a wetland, according to the Swedish Environmental Protection Agency, is as follows (Naturvårdsverket 2023b):

“Wetlands are areas where water occurs above or just below the ground surface, and at least half of the vegetation is hydrophytic. Although the water level can be difficult to see, the vegetation often helps distinguish wetlands from other land types”

There are different types of wetlands, including peatlands. Many factors contribute to the diversity of peatlands (Figure 1), such as water origin, nutrient availability, and the presence of trees (Rydin & Jeglum 2013). A peatland can range from either an open mire or a swamp forest (Figure 2). The definition of a forested peatland or swamp forest, according to the NMD, is when the canopy cover is greater than 30%, whilst an open mire is less than 30% (Löfroth 1991; Gunnarsson & Löfroth 2009). Plant and moss species found on the open peatland are usually outcompeted by forest-prone species if trees are present, creating shade and drier conditions (Korhonen et al. 2008). In Sweden, boreal swamp forests are usually dominated by Norway spruce (Hörnberg *et al.* 1998).

All peatlands are notable for their peat accumulation ability when dead organic material, often from Sphagnum, decomposes under anoxic conditions (Joosten & Clarke 2002; Erwin 2009). Peat consists of at least 30% dead organic matter, with different concentrations of Sphagnum, additional mosses, grasses and woody plants creating different peat types (Joosten & Clarke 2002; Korhonen et al. 2008). The two main peat formation processes, infilling and paludification, create peatlands. Paludification is the formation of a peatland on formerly less wet mineral soil. Infilling refers to the creation of peat in shallow lakes or slow-flowing rivers (Rydin & Jeglum 2013). Most of the world's current peatlands are estimated to have been formed in the last 15,000 years (Joosten & Clarke 2002). A necessity for an ecosystem to be classified as a peatland is the peat layer depth, which must be at a minimum of 30 cm (Rydin & Jeglum 2013; Loisel et al. 2017). Peatlands that are actively accumulating peat are classified as mires, and a widely used separation between them is being either bogs (ombrotrophic) or fens (minerotrophic). Bog mires are extended above the surrounding terrain and obtain water from rainfall exclusively. Fen mires are sunken into the ground, resulting in fens gaining access to water influenced by soil or mineral bedrock (Rydin & Jeglum 2013). Due to the characteristics of a bog, they are more nutrient-poor, while fens can be either very nutrient-rich or nutrient-poor (Chapin et al. 2004; Craft 2022). Peatlands such as

mires are distributed worldwide and cover up to 400 million hectares of the earth's surface (Murdiyarso *et al.* 2010). In Sweden, peatlands cover up to 5,23 million hectares of the total land coverage, according to estimates made by the National Inventories of Landscapes in Sweden (NILS) (Glimskär *et al.* 2008). Boreal and subarctic peatlands cover only a small percentage of the earth's surface but store almost one-third of the earth's carbon (Haapalehto *et al.* 2017). Wetlands like peatlands are meaningful because they give rise to distinct ecosystem services such as water purification, water storage, carbon storage, fire mitigation, and recreational values (Tonderski *et al.* 2002; Bonn *et al.* 2014). The diversity of peatlands is unique with a variety of life forms (Rydin & Jeglum 2013). However, anthropogenic activities have negatively affected biodiversity or entirely removed some ecosystem services provided by wetlands (Gómez-Baggethun *et al.* 2019; Kreyling *et al.* 2021).

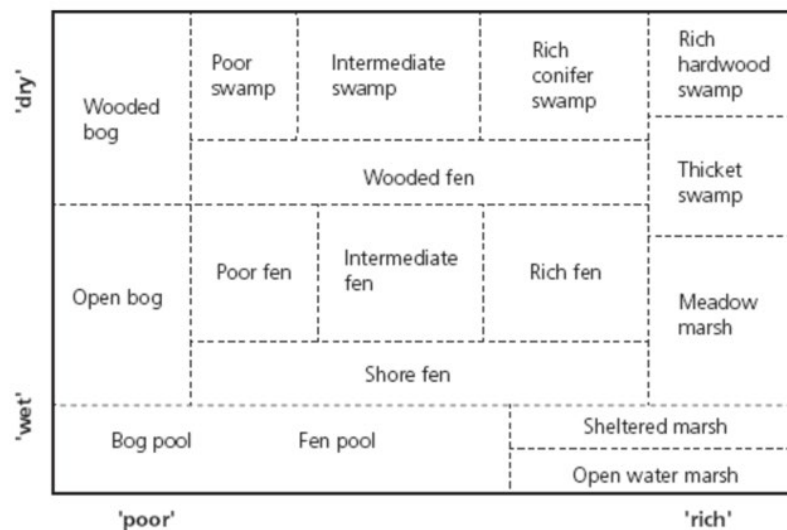


Figure 1. An illustration showing the different peatland classifications depending on hydrology and nutrient availability from Rydin and Jeglum (2013). The illustration was developed for northwestern Ontario, though it is also greatly valid in Boreal Europe.



Figure 2. A visualisation of how different the peatland classifications can look from one another. A forested peatland (left) and an open mire (right). Forested peatlands tend to have forest-prone species due to shade and drier soils. Compared to open mires, which are inhabited by water-resistant mosses and vascular plants.

1.2 Drainage of natural peatlands in Sweden

In Sweden, soil drainage is an anthropogenic activity that has greatly impacted peatlands. The creation of ditches has disfavoured the natural ecosystem of peatlands and species associated with such a habitat (Gunnarsson & Löfroth 2009; Elo *et al.* 2024). Ditching affects the hydrology of peatlands, driving the surface peat to become drier by lowering the water table, which diminishes the provided ecosystem services (Löfroth 1991; Bonn *et al.* 2014). The natural vegetation composition also shifts since the drier conditions lead to forest species succession (Jukaine *et al.* 1995). For instance, over time, *Sphagnum* mosses get replaced by other species like feather mosses, *Polytrichum* and *Dicranum* (Jukaine *et al.* 1995; Rydin & Jeglum 2013). Agricultural management has historically motivated ditching, as it can be traced back to the Middle Ages. Traditionally, ditching has been deemed a beneficial agricultural activity since more agrarian land could be attained by draining land (Jacks 2019).

Later practises of ditching are related to forestry and forest growth. According to Rydin and Jeglum (2013), the origin of peatland forestry began with the observation of trees exhibiting improved growth along the agricultural ditches. Because of this, the drainage of natural peatlands was greatly encouraged from a forest management perspective (Lundmark *et al.* 2013). Unscientific myths and beliefs about peatlands also promoted the ditching process. Examples of such beliefs were that ditching could decrease the risk of frost damage and benefit the environment (Jacks 2019). Forest drainage and cultivation through ditching became significant at the end of the 19th century in Sweden (Holmen 1964). It is estimated that approximately 1.5

million hectares in Sweden have been drained to benefit forestry, corresponding to a total length of a ditch network of roughly 1.2 million km long (Laudon *et al.* 2022; Laudon & Maher Hasselquist 2023). As a result of the forestry drainage, the extent of pristine spruce swamp forests has dramatically decreased in northern Europe (Maanavilja *et al.* 2014). However, the practice of peatland drainage has declined and almost entirely ceased today in Sweden (Hansen *et al.* 2013). The Swedish Environmental Protection Agency emphasises that establishing new ditches is nearly always prohibited in large parts of Sweden. The ban serves to preserve and protect the remaining natural wetlands (Naturvårdsverket 2023a). Peatlands are crucial ecosystems for nature-based solutions to combat climate change (Chazdon *et al.* 2021). To ensure this, formerly drained peatlands have been rewetted to restore biodiversity, which could be essential to tackle climate change (Kreyling *et al.* 2021).

1.3 Peatland restoration in practice

The goal of peatland restoration is to recover the initial state of species composition and function of habitats and ecosystems before human influence (Benayas *et al.* 2009; Rydin & Jeglum 2013). The initiative for peatland restoration started in recent years and has had a steadily increasing interest from academia and the government as well as other public groups since (Rydin & Jeglum 2013). In 2022, the EU founded the LIFE Peat Restore project, which restored over 5,300 hectares of degraded peatlands in five different countries (Life Peat Restore 2024). At the same time, there are also 319 projects scattered around Western Europe endorsed by LIFE EU to restore peatlands (Andersen *et al.* 2017). In Sweden, nearly 1500 ha of peatlands were restored in the year 2022 (Naturvårdsverket 2024). To initiate the restoration of peatlands that were drained due to forestry, it is crucial to begin rewetting the targeted area and removing shrub vegetation can also be essential (Chazdon *et al.* 2021). A report by the Swedish Forest Agency for the Grip on Life project cites different methods to execute peatland restoration in Sweden. The methods include the usage of dams and plugs or sealing the ditch with soil. Sometimes, both solutions can be implemented simultaneously depending on financial or environmental conditions (Rydin & Jeglum 2013; Lindh 2022).



Figure 3. Picture showing a restoration effort using a dam at Rismyrbrånet to slow down water flow (left) and a restoration effort using ditch filling at Stora-Bränntjärnmyran (right). Pictures taken by the author (Nordstrand, 2024).

There are challenges when constructing these solutions that must be considered, such as keeping water from flowing through the dams or plugs (Lindh 2022). The desired goal is not always achieved, and the outcome can never be fully anticipated even though the restoration was well executed (Suding 2011). Haapalehto *et al.* (2017) claim that it is easier to eliminate unwanted species than to recover characteristic species through restoration. The vegetation composition has been shown to differ immensely between restored and nearly untouched peatlands (Kreyling *et al.* 2021). Noticeable shifts in vegetation dynamics for rewetted areas have been noted, especially the drastic increase of *Eriophorum vaginatum* in rewetted fen areas (Komulainen *et al.* 1999), as seen in Figure 3. Drained forested peatlands restored to the initial water table height exhibit a restoration succession similar to a pristine *Sphagnum* accumulation within a few years (Maanavilja *et al.* 2015). Beyond rewetting, nutrient availability is also important in forming the vegetation composition at the restored sites (Komulainen *et al.* 1999). The effectiveness of peatland restoration is nonetheless varying, and there are still knowledge gaps, making it uncertain how restoration will impact these ecosystems

(Haapalehto *et al.* 2017). A functional understanding of the locally novel ecosystem is needed to enhance the planning and effectiveness of peatland restoration (Kreyling *et al.* 2021). Additional knowledge of vegetation composition and environmental conditions could provide useful insight into the consequences of restoration. Lastly, there is a geographical aspect to consider, meaning that most of the data on peatland restoration originates from Canada, Finland or the nemoral zone (Taylor *et al.* 2019; Silva *et al.* 2024). Because of this, there is very limited data available on peatland restoration in Sweden, especially in the northern parts.

1.4 Aim

The lack of well-replicated field studies on the impacts of ecological restoration has resulted in knowledge gaps in the understanding of the extent of plant community recovery (Haapalehto *et al.* 2017). Certain dynamics of peatland restorations will be investigated further to improve the restoration's effectiveness and insight into the consequences on vegetation composition. Therefore, this study examines the early effects of peatland restoration and its impact on vegetation composition in northern Sweden. The study examines restoration projects conducted between 1 and 5 years previously. The questions that will be analysed are as follows:

- Does peatland restoration affect the cover or presence of typical wetland/forest vascular plants and mosses for mires and swamp forests, respectively?
- Do restored, undisturbed and drained peatlands affect the species richness differently?
- Does restoration affect swamp forests and open mires differently regarding vegetation composition?
- Do different environmental variables affect the vegetation composition for restored, undisturbed and drained peatlands?

Method

2.1 Study sites and sampling design

The selected areas for this project were all located in eastern Västerbotten. Ten sites in total were used in this project, and each site was divided into three treatments. The three treatments had twelve sampling locations. ArcGIS was used to determine which sites to use and assign treatments. The sampling locations were also marked on the map. Every site selected for this project was peatlands in the form of either open mires or swamp forests. Another criterion is that all these sites were previously drained areas recently restored through ditch-filling and/or blocking between 2018 and 2023. The selection of sites also required areas to be assigned as treatments drained and pristine. Information about the restorations was supplied by Naturvårdsverket and Länsstyrelsen Västerbotten, where most of the sites are either in, or closely connected to, protected areas. All 10 sites were allocated a different letter (Table 1); this was done during the preparation and site selection stage. During the site selection stage, some potential candidates were disqualified because of inaccessibility or other additional factors. The three allocated treatments with sampling locations were named 0, 1 or 2 for pristine, drained and restored, respectively (Table 3). The objective is to see differences in vegetation composition, species presence and richness between the different treatments.

Table 1. All sites with the allocated letter and a brief description

Letter	Site	Restored	Description
AG	Trollberget	2020 Ditch filling	Old-growth, multi-layered mixed forest that is adjacent to a mire.
P	Börtingtjärn	2023 Dam	Large fire-affected pines and old spruces with elements of large deciduous trees. Classified as a forested peatland.
B	Degersjön	2023 Ditch filling	Old growth spruces and indications of a rich fen.

F	Torsmyran	2021 Ditch filling	Extensive mire area with a lot of mire characteristic species.
G	Långrumpskogen	>2018 Ditch filling	Coniferous trees several hundred years old and undisturbed. Deemed to be important for protected species.
M	Stora Orrberget	2023 Dam	Dominant pine and spruce old-growth forest. Classified as a forested peatland.
N	Orrböle	2022 Dam	Calcareous spruce forest. Features of wetter areas. Classified as a forested peatland.
H	Stora-Bräntjärns myran	>2018? Ditch filling	Large zones of mire surrounded by old spruce forest and pine stumps.
A	Grössjön	2021 Ditch filling	Nature reserve inhibited by both old-growth forests and mires. Some of the mires show signs of being nutrient rich.
K	Rismyrbrånet	2022 Dam	Wet site with a mixed coniferous forest. Has signs of soil drainage in the form of ditches. Classified as a forested peatland.

Table 2. The Sites were classified into two subgroups, mire and swamp forest.

Group	Sites	Illustration
Mire	AG, B, F, G, H, A	
Swamp Forest	P, M, N, K	

A more in-depth explanation of the three treatments is as follows in Table 3:

Table 3. Description of the three treatments. The assigned colour shows which colour each treatment was allocated.

Treatment	Number	Assigned colour	Description
Restored	2	Purple	Previously drained areas which have recently been restored through the procedures of ditch filling and/or blocking of the old ditch
Drained	1	Orange	An unrestored, drained neighbouring area a few hundred meters from the restored treatment. A functioning ditch is present.
Pristine	0	Green	A neighbouring area a few hundred meters from the restored treatment. There are no signs of ditching or other drainage management.

The letters from each site in combination with the treatment number created a classification system, such as P0, P1 and P2. The size of the treatment areas was approximately 40 X 80 m for all three treatments for every site. Figure 4 illustrates the placements for the treatment areas at site K, which are placed apart to avoid pseudo replicates.

All the sampling quadrats were also mapped with coordinates. The sampling quadrats were positioned 20 meters apart on the transects along the functioning and restored ditch. For treatment 0, a virtual ditch was used in ArcGIS to position the transects. Figure 5 visualises the placement of the transects proximate to the ditch, where the black points with numbers represent the sampling quadrats.

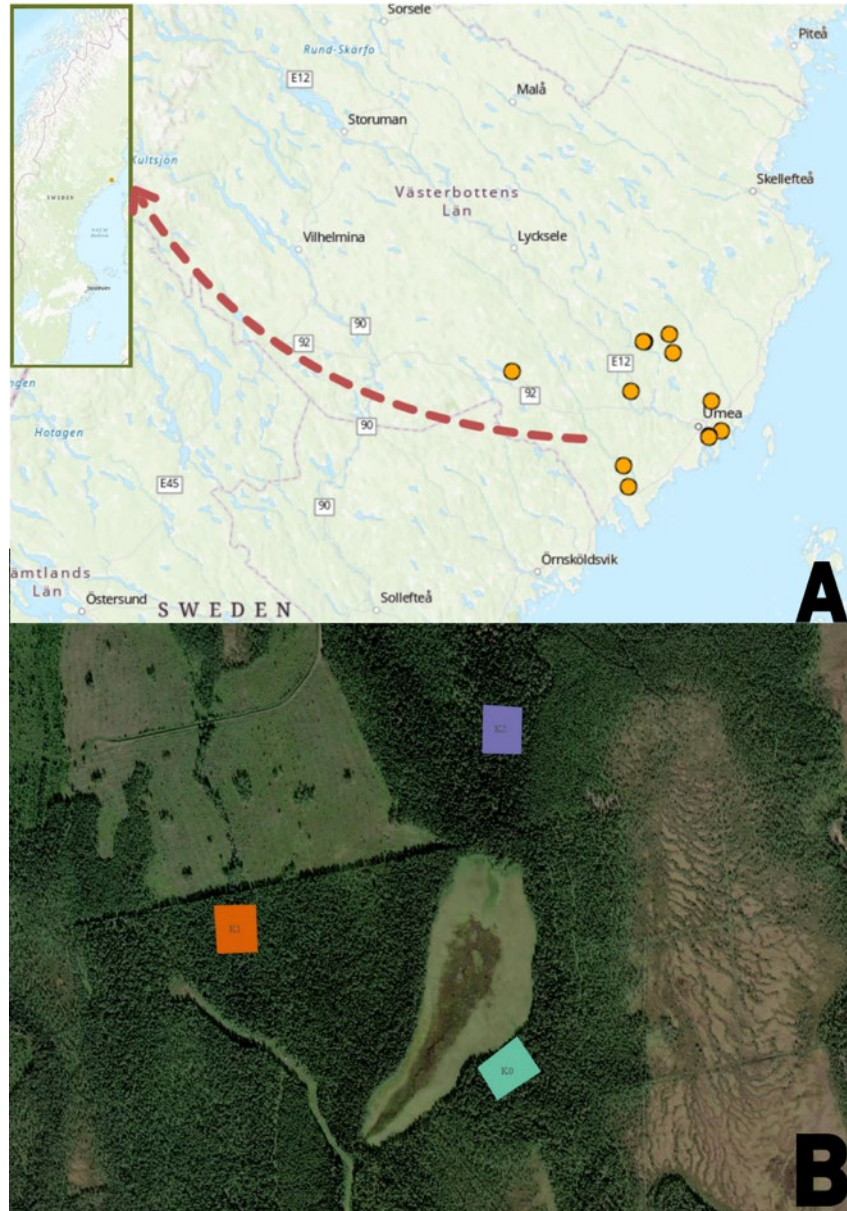


Figure 4. Picture (A) the locations of the ten selected sites in Västerbotten. Picture (B) shows the prescribed treatments 0, 1 and 2, which illustrate the corresponding types of habitats along the restoration gradient. Treatments 0 = green, 1 = orange and 2 = purple at site Rismyrbrånet (K).

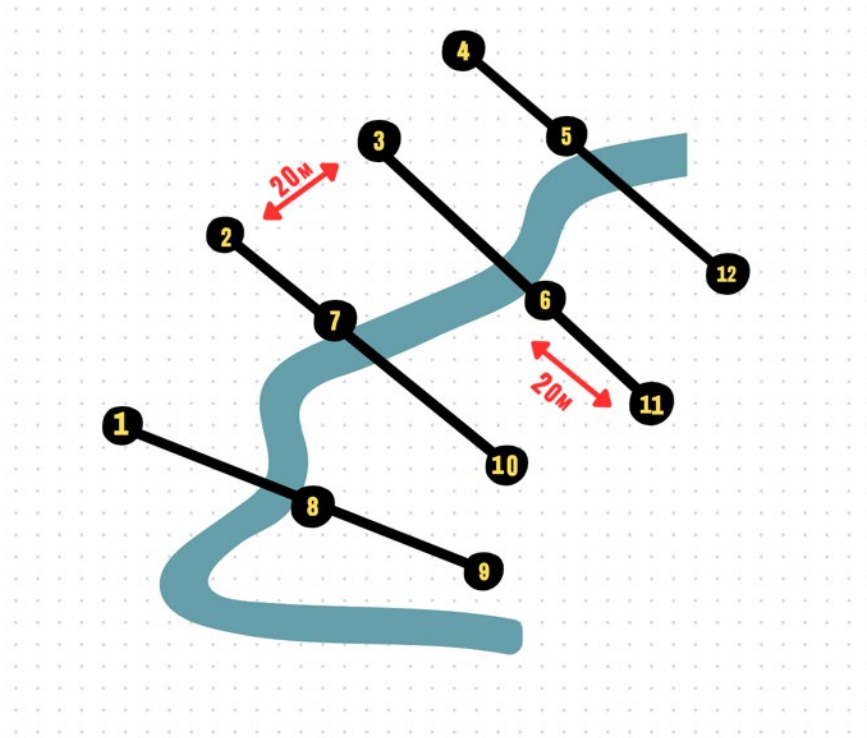


Figure 5. Illustration of the distribution of the 12 sampling quadrats along the transects relative to the ditch. The sampling quadrats were placed at a distance of 20 meters from each other. For treatment 0, the sampling quadrats in the centre were placed in a straight line as there was no ditch nearby.

2.1.1 Deviations from sampling

Because of inaccessible roads, lack of landowner permission, and errors in the NMD, not all treatments could be accessed or used for each site. The unsampled locations are seen in Table 4.

Table 4. Every unsampled treatment area and the associated site.

Code	Site	Treatment
G1	Långrumpskogen	Drained (1)
N1	Orrböle	Drained (1)
N0	Orrböle	Pristine (0)
K0	Rismyrbrånet	Pristine (0)

2.1.2 Data collection

Floristic inventories and canopy measurements were done at all sampling quadrats, with the placement of TOMST loggers at some of them. The loggers will be left outside for two years to track soil moisture and temperature. The duration of the floristic inventory period occurred from the 5th of June until the 5th of July, 2024.

The inventory was performed at this time because many vascular plants in Sweden flower during these months (Mossberg & Stenberg 2021). At every sampling quadrat, a 2x2 meter square was used for the floristic inventory, where the vegetation content inside the square was noted. The square was estimated with a measuring tape and marked with pegs at every corner for each sampling point. Within the square, the percentage of plant taxa and bryophytes was estimated through a modified Braun-Blanquet score (Figure 6). Each sampling quadrat was also photographed.

Other elements, such as the percentage of standing water, were also noted to investigate environmental variables. Standing water was investigated since hydrology is a key element for peatlands and their vegetation composition (Naturvårdsverket 2023b). The remaining environmental variables include ditch, treatment, site and the interaction between treatment and ditch. These were examined to understand the influence each of these had on species composition. Previous studies have shown that the presence and distance of a ditch impact the species composition (Haapalehto *et al.* 2017; Elo *et al.* 2024).

Abundance/Dominance Indexes of Braun-Blanquet	Plant Coverage	Transformation Values of Abundance/Dominance Indexes
r	rare species in the relevés	0.01%
+	<1%	0.50%
1	1%–5%	3.00%
2	6%–25%	15.00%
3	26%–50%	37.50%
4	51%–75%	62.50%
5	76%–100%	87.50%

Figure 6. The modified Braun-Blanquet scoring system was used for the floristic inventories.

2.2 Data processing and species identification

All the collected floristic inventories with the corresponding abundance index (Figure 6) and species were compiled in Excel. Species that could not be identified in the field were either sampled or photographed to be analysed and determined later with the help of identification keys, namely Svensk flora by Krok and Almquist, and Nordens flora by Bo Mossberg and Lennart Stenberg. Further, a certainty system was implemented to score the confidence of the species identification. There are three individual classes that every individual identification was assigned to, which are as follows:

Table 5. The accuracy of the species identification and its assigned class.

Certainty class	Description	Approximate percentage
“Certain”	High accuracy	100%
“Probable”	Intermediate accuracy	90%
“Possible”	Low accuracy	50%

Artfakta by SLU was used to create Appendix 1 and Appendix 2, where the classification of typical wetland and forest species can be seen. Species biotope and landscape types found in Artfakta were used for the classification. All the species found in the floristic inventories were examined in Artfakta, during which wetland species were classified into Appendix 1 and forest species into Appendix 2.

2.3 Statistical analysis

In preparation for the analysis, only species deemed certain and probable were kept. All vascular plants were identified to species, while *Sphagnum* was identified to genus level. This was done because of time constraints and high uncertainty when identifying individual *Sphagnum* species. The plant coverage scores from the Braun-Blanquet were converted into abundances (Figure 6). Additionally, the samples from treatment 1 in site H were removed from the analysis since they did not represent a ditched area because of beavers flooding the area.

The analysis was done to investigate dissimilarities in vegetation composition between treatments and what could be the driving factor behind these differences. All analyses were done separately for the mire and swamp forest sites. RStudio version 2024.04.2+764 (Posit team 2024) was used. The mean number of typical wetland and forest species across treatments was calculated, and a list of the five species with the highest mean cover for each treatment was made. The mean cover of wetland and forest vascular plants and moss species was estimated for every site within each treatment. To investigate the effect of treatments on species presence, a generalized linear mixed model (GLMMs) was conducted using the lme4 package (Bates 2010), which also accounted for variation between sites (random effects). The GLMMs had a binomial distribution and a logit link function to model the likelihood of species presence.

An analysis of the vegetation community structure between all sampling quadrats for the three treatments was created using non-metric multidimensional scaling (NMDS). The NMDS model was run with the r-package vegan version 2.6-8 (Oksanen 2024) and is based on the Bray-Curtis dissimilarity, which calculates the differences in vegetation composition between the samples. A Permutational

Multivariate Analysis of Variance (PERMANOVA) on the Bray-Curtis dissimilarity using the function `adonis2` from the `vegan` package (Oksanen 2024) was estimated for every NMDS. If the PERMANOVA was significant, an additional pairwise comparison was made to determine which treatments differed from each other. The effects of environmental variables on composition were investigated through a canonical-correlation analysis (CCA). The environmental variables included treatment, site, water, ditch, and the interaction between treatment and ditch.

Results

3.1 Number of species, species presence and amount of cover

At mire sites, the median number of forest species was highest for treatments 1 and 2, while treatment 0 had the lowest (Figure 7). The number of wetland species was highest for treatment 1, intermediate for 0 and lowest for 2 (Figure 7). For the swamp forest sites, treatment 1 had the greatest value of forest species, while 0 and 2 were equal (Figure 7). Treatment 0 had the highest number of wetland species at the swamp forest sites (Figure 7). Overall, the swamp forest sites exhibited more forest species than the mire sites, and the number of wetland species was highest at the mire sites. When looking at species dominance, *Sphagnum sp.* had the highest mean cover across all treatments except two (Figure 8).

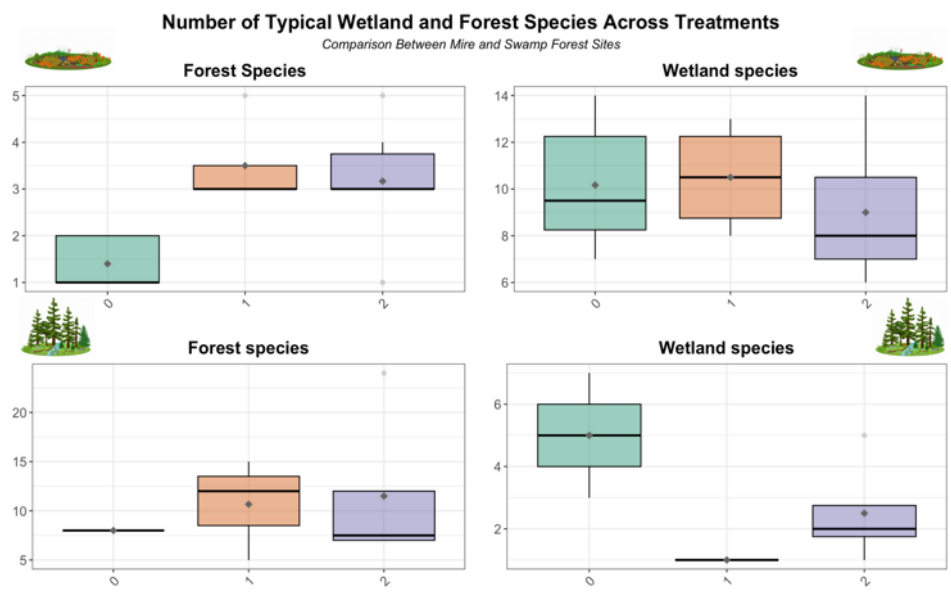


Figure 7. Boxplot showing the number of (forest and wetland) species across treatments (0,1,2) and groups (mire and swamp forest). The treatment is as follows: pristine = 0, drained = 1 and restored =2.

Species Dominance by Treatment for Mire Sites					
0		1		2	
Species	Mean Sum of Cover	Species	Mean Sum of Cover	Species	Mean Sum of Cover
<i>Sphagnum. sp</i>	74.7	<i>Sphagnum. sp</i>	36.2	<i>Sphagnum. sp</i>	48.2
<i>Carex. nigra</i>	33.5	<i>Myrica. gale</i>	34.3	<i>Trichophorum. cespitosum</i>	24.0
<i>Myrica. gale</i>	28.9	<i>Vaccinium. myrtillus</i>	23.1	<i>Carex. rostrata</i>	23.2
<i>Rhynchospora. alba</i>	26.8	<i>Trichophorum. cespitosum</i>	22.5	<i>Myrica. gale</i>	21.7
<i>Vaccinium. myrtillus</i>	25.6	<i>Rhododendron. tomentosum</i>	18.4	<i>Eriophorum. vaginatum</i>	18.0

Species Dominance by Treatment for Swamp Forest Sites					
0		1		2	
Species	Mean Sum of Cover	Species	Mean Sum of Cover	Species	Mean Sum of Cover
<i>Sphagnum. sp</i>	41.4	<i>Dryopteris. expansa</i>	26.9	<i>Carex. rostrata</i>	62.5
<i>Vaccinium. myrtillus</i>	39.1	<i>Vaccinium. myrtillus</i>	24.1	<i>Plagiomnium. sp</i>	37.5
<i>Hylocomium. splendens</i>	37.1	<i>Pleurozium. schreberi</i>	15.7	<i>Sphagnum. sp</i>	33.0
<i>Polytrichum. sp</i>	13.7	<i>Hylocomium. splendens</i>	15.7	<i>Vaccinium. myrtillus</i>	25.6
<i>Eriophorum. vaginatum</i>	13.1	<i>Sphagnum. sp</i>	15.2	<i>Hylocomium. splendens</i>	17.8

Figure 8. The five most dominant species are summarised based on mean cover across treatments (0,1,2) and groups (mire and swamp forest).

Treatment 1 exhibited the highest median of forest species cover at the mire site, whereas the mean cover of forest species remained low, and the mean cover of wetland species was high (Figure 9). In swamp forest sites, forest species cover was highest in treatment 0, while 1 and 2 were equal. Wetland species cover was also highest in treatment 0 but remained low across all treatments (Figure 9).

Forest species presence on mire sites was lowest for treatment 0, while 1 and 2 had a significant increase in the presence of forest species, with treatment 1 having the greatest increase (Table 6). The random effect had a variance of 0.04071 (SD = 0.2018), implying a small variability across sites, and the model shows a good fit (Table 6). The presence of wetland species on mire sites was greatest in treatment 0, while 1 and 2 significantly reduced the presence of wetland species, with treatment 1 having the greatest decrease (Table 7). The random effect had a variance of 0.08073 (SD = 0.2841), also implying a small variability across sites and the model having a good fit (Table 7).

The presence of forest species across swamp forest sites was lowest for treatment 0, while 1 and 2 significantly increased the presence, with treatment 1 having the greatest increase (Table 8). The model had a good fit, and the random effect had a variance of 0.09323 (SD = 0.3053), suggesting some variation across sites. Wetland species presence on swamp forest sites was low for treatment 0, while treatment 2 significantly reduced the presence (Table 9). No effect from treatment 1 was exhibited, and the p-value implies no significant difference from treatment 0 (Table

9). The model has a reasonable fit, and the random effect had a variance of 0.9326 (SD = 0.9657), showing a high variability between the sites (Table 9).

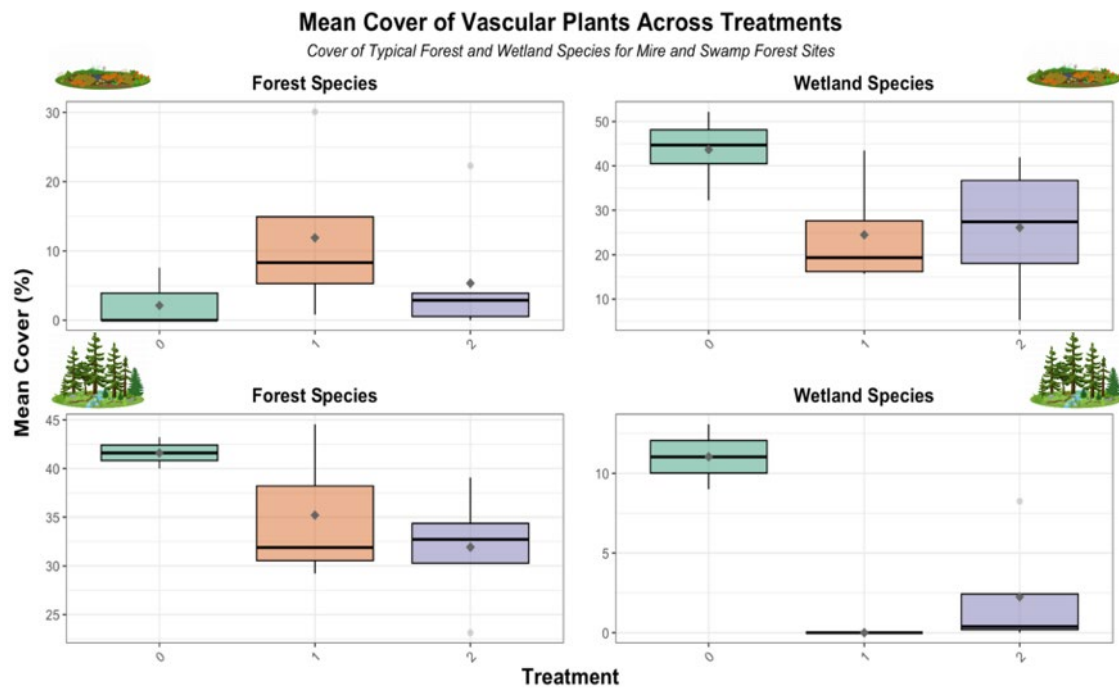


Figure 9. Boxplot exhibiting the mean cover of vascular plants (forest and wetland species) across treatments (0,1,2) for sites from the groups (mire and swamp forest). The median value for each treatment is presented as the central line, while the mean value is the diamond. The treatment is as follows: pristine = 0, drained = 1 and restored =2.

Table 6. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest vascular plants across mire sites while accounting for variability across sites. Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’.

The Presence of Typical Forest Vascular Plants Across Mire Sites
Formula: Presence ~ Treatment + (1 | Site)

Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	-4.7639	0.4188	-11.376	< 0.001	***
Treatment1	2.3379	0.4509	5.185	2.16 × 10 ⁻⁷	***
Treatment2	1.7584	0.4465	3.938	8.21 × 10 ⁻⁵	***
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
576.3	1811	-288.2	1815	6	
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.04071	0.2018		

Table 7. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland vascular plants across mire sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'.

The Presence of Typical Wetland Vascular Plants Across Mire Sites

Formula: Presence ~ Treatment + (1 | Site)



Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	0.4061	0.1399	2.902	0.00371	**
Treatment1	-0.921	0.1325	-6.949	3.67×10^{-12}	***
Treatment2	-0.689	0.1105	-6.236	4.49×10^{-10}	***
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
2434.5	1811	-1217.2	1815	6	
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.08073	0.2841		

Table 8. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest vascular plants across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'.

The Presence of Typical Forest Vascular Plants Across Swamp Forest Sites

Formula: Presence ~ Treatment + (1 | Site)



Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	-1.0719	0.2506	-4.277	1.89×10^{-5}	***
Treatment1	1.0541	0.2183	4.83	1.37×10^{-6}	***
Treatment2	0.8399	0.2504	3.354	0.000797	***
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
968.9	742	-484.5	746	4	
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.09323	0.3053		

Table 9. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland vascular plants across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'.

The Presence of Typical Wetland Vascular Plants Across Swamp Forest Sites

Formula: Presence ~ Treatment + (1 | Site)



Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	-2.271	0.7611	-2.984	0.00285	**
Treatment1	-21.6959	51.7198	-0.419	0.67486	ns
Treatment2	-1.3397	0.4918	-2.724	0.00644	**
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
267.7	742	-133.8	746	4	
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.9326	0.9657		

Treatment 1 exhibited the highest median of forest moss cover at the mire site. However, neither treatment exhibited a large amount of forest moss cover (Figure 10). Wetland mosses at the mire sites had the greatest mean cover for treatment 0, followed by 2 (Figure 10). The mean cover of forest mosses for the swamp forest sites was slightly higher for treatment 1 compared to the other treatments (Figure 10). Treatment 0 had the highest cover of wetland mosses, followed by treatment 2 (Figure 10).

Forest moss presence on the mire sites was lowest for treatment 0, while 1 and 2 had no significant effect on presence (Table 10). Treatments 1 and 2 had a positive estimate, indicating an increase in presence, but not a significant one. The random effect had a variance of 0.4806 (SD = 0.6933), implying variation between the sites and a model with a reasonable fit (Table 10). Wetland moss presence on the mire sites was highest in treatment 0, while 1 and 2 significantly decreased the presence, with treatment 1 having the greatest decrease (Table 11). The model fits well, and the random effect had a variance of 0.2913 (SD = 0.5397), implying moderate variation between sites (Table 11).

Neither treatment significantly affected forest moss presence for the swamp forest sites (Table 12). The model fit was deemed low, and the random effect had a variance of 0.0007354 (SD = 0.02712), suggesting a low variation between sites (Table 12). For wetland moss presence treatment 0 showed a significant negative estimate, indicating a low presence of wetland mosses (Table 13). Treatments 1 and 2 had no significant effect on the presence of wetland mosses compared to treatment 0. The model had a reasonable fit, and the random effect had a variance of 0.5735 (SD = 0.7573), implying a moderate variation across sites (Table 13).

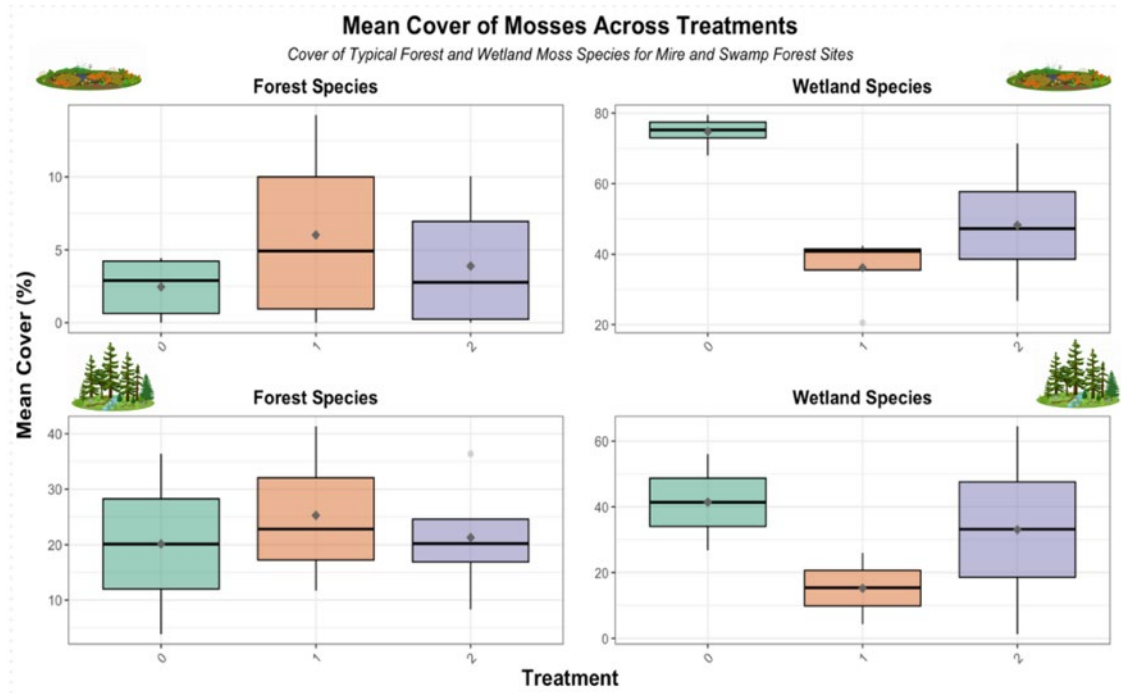


Figure 10. Boxplot exhibiting the mean cover of mosses (forest and wetland species) across treatments (0,1,2) for sites from the groups (mire and swamp forest). The median value for each treatment is presented as the central line, while the mean value is the diamond. The treatment is as follows: pristine = 0, drained = 1 and restored = 2.

Table 10. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest mosses across mire sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'.

The Presence of Typical Forest Mosses Across Mire Sites
Formula: Presence ~ Treatment + (1 | Site)

Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	-1.7144	0.3886	-4.411	1.03E-05	***
Treatment1	0.5115	0.3301	1.549	0.121	ns
Treatment2	0.4753	0.3096	1.535	0.125	ns
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
	425.2	387	-212.6	391	6
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.4806	0.6933		

Table 11. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland mosses across mire sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'.

The Presence of Typical Wetland Mosses Across Mire Sites

Formula: Presence ~ Treatment + (1 | Site)



Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	0.6222	0.2967	2.083	0.0372	*
Treatment1	-1.2741	0.2954	-4.313	1.61E-05	***
Treatment2	-0.8283	0.2584	-3.205	0.00135	**
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
508.7	387	-254.4	391	6	
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.2913	0.5397		

Table 12. A generalized linear mixed model analysing the effect of treatment on the presence of typical forest mosses across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'.

The Presence of Typical Forest Mosses Across Swamp Forest Sites

Formula: Presence ~ Treatment + (1 | Site)



Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	-0.2826	0.2434	-1.161	0.246	ns
Treatment1	0.0562	0.2952	0.19	0.849	ns
Treatment2	-0.0053	0.2867	-0.018	0.985	ns
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
532.5	385	-266.2	389	4	
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.0007354	0.02712		

Table 13. A generalized linear mixed model analysing the effect of treatment on the presence of typical wetland mosses across swamp forest sites while accounting for variability across sites. Significance codes: 0 '***' 0.001 '**' 0.01 '*'.

The Presence of Typical Wetland Mosses Across Swamp Forest Sites

Formula: Presence ~ Treatment + (1 | Site)



Fixed Effects	Estimate	Std. Error	z value	p-value	Significance
Intercept (Treatment 0)	-1.5366	0.5177	-2.968	0.003	**
Treatment1	-0.739	0.388	-1.904	0.0568	ns
Treatment2	-0.0738	0.3687	-0.2	0.8413	ns
Deviance	Residual degrees of freedom	Log-Likelihood	Number of observations	Number of Sites	
350.3	385	-175.1	389	4	
Group	Name	Variance	Std. Dev.		
Site	(Intercept)	0.5735	0.7573		

3.2 Vegetation composition

The NMDS illustrates the vegetation composition between treatments for the mire sites, where some similarities can be seen between treatments 1 and 2, while treatment 0 is more dispersed (Figure 11). The calculated stress level for the mire NMDS was 0.175, meaning that the visualisation of the distances between points closely matched the actual dissimilarities in vegetation composition. The pairwise comparison showed that the vegetation composition of all three treatments differed significantly (Table 14). Examining the influence of the environmental variables (Treatment, Ditch, Site, Water, Treatment*Ditch) effect on the composition of mire sites, was shown to be significant (Table 15). However, only a small percentage of explained variance is defined by the variables.

The swamp forest NMDS showed similarities in vegetation composition between treatments 1 and 2, whereas treatment 0 was more dispersed (Figure 12). The stress level for the swamp forest NMDS was 0.209. Thus, the visualisation of the distances between points is acceptable, but the dissimilarities in vegetation composition are not as accurate to the actual dissimilarities as for the mire NMDS. The pairwise comparison showed no significant difference between treatments 1 and 2 (Table 16). A difference was found between treatments 0-1 and 0-2 (Table 16). The influence of the environmental variables (Treatment, Ditch, Site, Water, Treatment*Ditch) on the composition of swamp forest sites is seen in Table 17. Treatment, site and ditch had a significant effect, while water and the interaction between treatment and ditch were found to not affect composition (Table 17). Nevertheless, similar to the mire analysis, the explained variance was small.

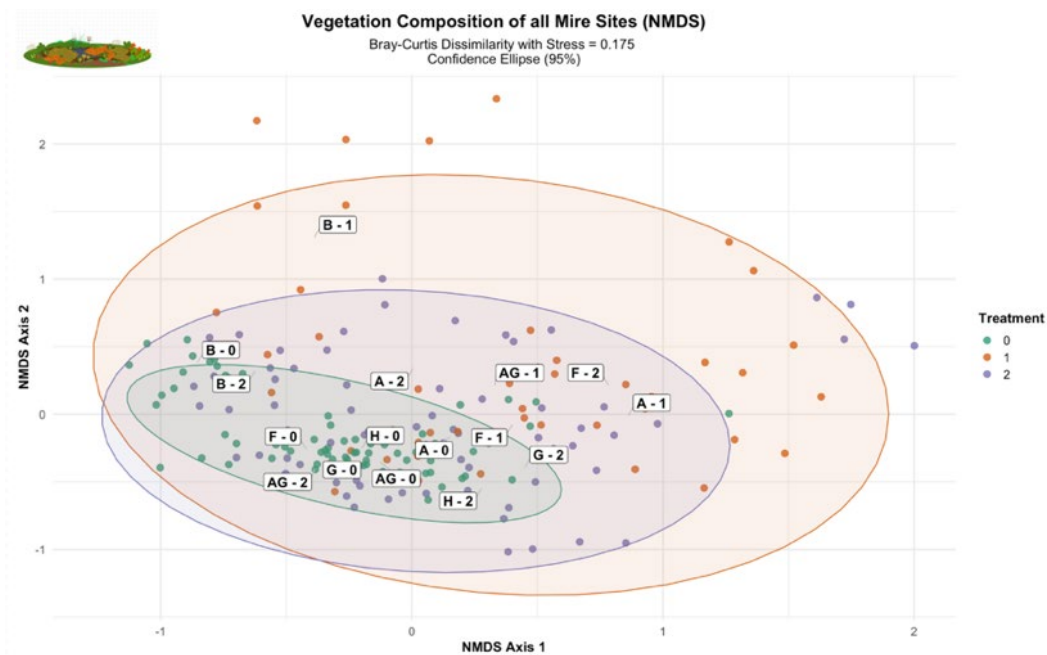


Figure 11. An NMDS exclusively of the mire sites illustrating the vegetation community structure between sites and treatments, with a stress level of 0.175. Similarities and dissimilarities are visualised through the placement of the ellipses with a confidence of 95%, depicting the dispersion of each treatment. The points represent each individual sampling point. The labels demonstrate the calculated average position for each site within the NMDS. The treatments are as follows: pristine treatment = 0, ditched treatment = 1 and the restored treatment = 2.

Table 14. A pairwise PERMANOVA of the mire sites investigated if the vegetation composition differed significantly between treatments in Figure 11. The treatments are as follows: pristine treatment = 0, ditched treatment = 1 and the restored treatment = 2.

Comparison	Df	SumOfSqs	R ²	F	Pr(>F)
0 vs 1	1	3.0401	0.11625	15.523	0.001
Residual	118	23.1108	0.88375		
Total	119	26.1509	1		
0 vs 2	1	1.5678	0.05739	8.6457	0.001
Residual	142	25.7494	0.94261		
Total	143	27.3172	1		
1 vs 2	1	1.075	0.033	4.027	0.001
Residual	118	31.51	0.967		
Total	119	32.585	1		

Table 15. A CCA analysis to examine the influence of different environmental variables on the vegetation composition for mire sites. A permutation test with 999 iterations was conducted to assess the significance. The investigated variables are as follows: treatment, ditch, site, water and the interaction between treatment and ditch.

CCA Analysis of different variables affecting Mire composition

Model: species composition ~ Treatment * Ditch + Site + Water

Factor	Df	Chi-Square	F-value	p-value	Explained Variance (%)
Treatment	2	0.1913	2.8931	0.001 ***	2.96%
Ditch	1	0.0848	2.5642	0.001 ***	1.31%
Site	5	0.5945	3.5956	0.001 ***	9.23%
Water	5	0.3587	2.1695	0.001 ***	5.57%
Treatment:Ditch	2	0.2480	3.7498	0.001 ***	3.85%
Residuals	176	5.8195			77.08%
Total		7.2967			100%

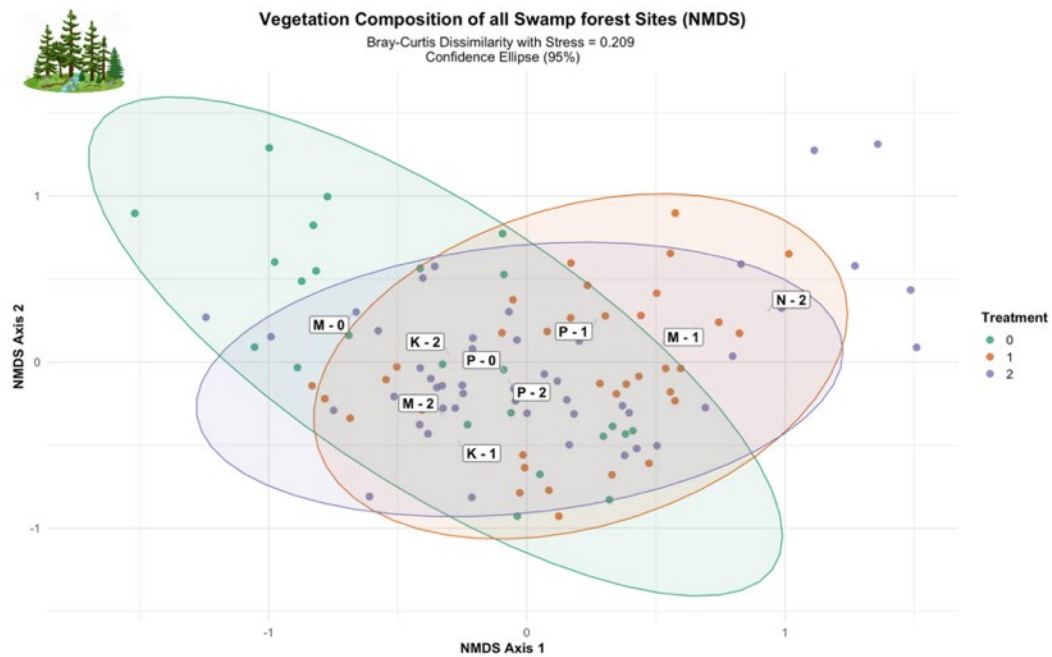


Figure 12. An NMDS exclusively of the swamp forest sites illustrates the vegetation community structure between sites and treatments, with a stress level of 0.209. Similarities and dissimilarities are visualised through the placement of the ellipses with a confidence of 95%, depicting the dispersion of each treatment. The points represent each individual sampling point. The labels demonstrate the calculated average position for each site within the NMDS. The treatments are as follows: pristine treatment = 0, ditched treatment = 1 and the restored treatment = 2.

Table 16. A pairwise PERMANOVA of the swamp forest sites investigated if the vegetation composition differed significantly between treatments in Figure 12. The treatments are as follows: pristine treatment = 0, ditched treatment = 1 and the restored treatment = 2.

**Assessing Differences in Vegetation Composition
Between Treatment for Swamp Forest Sites**

Pairwise PERMANOVA 

Comparison	Df	SumOfSqs	R2	F	Pr(>F)
0 vs 1	1	1.201	0.072	4.532	0.002
Residual	58	15.367	0.928		
Total	59	16.568	1.000		
0 vs 2	1	0.692	0.038	2.784	0.025
Residual	70	17.408	0.962		
Total	71	18.100	1.000		
1 vs 2	1	0.478	0.022	1.804	0.085
Residual	82	21.736	0.979		
Total	83	22.215	1.00		

Table 17. A CCA analysis to examine the influence of different environmental variables on the vegetation composition for swamp forest sites. A permutation test with 999 iterations was conducted to assess the significance. The investigated variables are as follows: treatment, ditch, site, water and the interaction between treatment and ditch.

**CCA Analysis of different variables affecting
Swamp Forest composition**

Model: species composition ~ Treatment * Ditch + Site + Water 

Factor	Df	Chi-Square	F-value	p-value	Explained Variance (%)
Treatment	2	0.2658	2.1417	0.001 ***	3.74%
Ditch	1	0.1011	1.6293	0.011 *	1.42%
Site	3	0.4510	2.4226	0.001 ***	6.35%
Water	4	0.2601	1.0478	0.287	3.66%
Treatment:Ditch	2	0.1299	1.0468	0.302	1.83%
Residuals	95	5.8955			83.00%
Total		7.1034			100%

Discussion

This study investigated the early effects of peatland restoration in northern Sweden, which, as of today, is a rather unexplored subject. The results from this thesis demonstrate a shift in the vegetation composition, presence and species richness of vascular plants and mosses after restoration on mire sites. While the swamp forest sites showed some changes, they were not as prominent as those observed in the mire sites. This result suggests that peatland restoration in the short term could lead toward the goal of ceasing further deterioration of peatlands by decreasing forest species and increasing wetland species. Performing peatland restoration might, therefore, be essential for conserving or reintroducing biodiversity provided by these ecosystems, especially during these times of accelerating climate change. The following discussion explores the research questions defined in the introduction.

Does peatland restoration affect the cover or presence of typical wetland/forest vascular plants and mosses for mires and swamp forests, respectively?

The results in this thesis indicate that restoration influences the cover and presence of both forest and wetland species, especially on mire sites. The variability between sites was quite small for the mire sites, indicating that treatments impact the presence of species. I theorize that the changed hydrology caused by restoration negatively affects forest species, while wetland species are more adapted to wetter conditions and are, thus, favoured. Elo *et al.* (2024) found that the restoration of forestry-drained peatlands often succeeds in raising the water table back to its natural state. Due to the lack of results from the presence analysis of wetland species, it is hard to draw further conclusions on the effect of restoration on swamp forest sites. However, other studies have found that restoring drained swamp forest sites helps return the area to more pristine conditions (Maanavilja *et al.* 2014). Despite raising the water table, Hörnberg *et al.* (1998) advise that 300 years are needed to regain old-growth conditions in swamp forests, which are vital for many species. After analysing the forest and wetland mosses results, it is difficult to make any conclusion on how these are affected by restoration. As well as if there are any differences in the response between mire and swamp forest sites. This is probably

due to grouping all *Sphagnum sp.* together due to their extreme difficulty in determining species in the genus.

Forest species are not expected to thrive in a mire setting, the exception being the drained treatment, which should theoretically also be the driest. This is reasonable since similar patterns could be seen when observing the species richness across treatments for the mire sites. Besides that, the restored treatment had less of an impact on the presence of forest species than the drained treatment, implying that restoration might reduce the presence of forest vascular plants on mires. This is in accordance with Haapalehto et al. (2017), who state that the recovery of peatland ecosystems is recognised by a decline in species typical to unrestored conditions. The swamp forest sites exhibited higher mean cover across all treatments compared to the mire sites. This, once again, can be explained by many forest vascular plants being found within a swamp forest (Löfroth 1991; Maanavilja et al. 2014).

The pristine treatment for the swamp forests had the greatest mean cover of forest species. Due to deviations in samples between treatments and there only being four swamp forest sites, the estimation of the mean cover for the pristine treatment is only made from two sites. Therefore, the results for the swamp forest sites should be interpreted with caution. Similarly to the mire sites, the results imply that restoration reduces the presence of forest species at the swamp forest sites, although not as strong of an effect. For the wetland species, the highest mean cover was found in the pristine treatment for both the mire and swamp forest sites. These findings were not unexpected since the pristine treatment should naturally house these species. When examining the presence of wetland species across the mire sites, a significant reduction in their presence was shown for the drained and restored treatments. Similarly to before, the effect of the restored treatment was not to the same extent as that of the drained treatment. All treatments indicated a low presence of wetland vascular plants in the swamp forest sites. This result might be explained by the high variability between sites and the worse fit of the models compared to the other analyses.

The drained treatment inhabited the greatest cover of forest mosses at the mire and swamp forest sites. However, no effect from the treatments on the presence of forest mosses at the mire and swamp forest sites was found. Both models had a somewhat poor fit for the data, which could be the reason for the insufficient result. *Sphagnum sp.* was the most dominant species in cover across all treatments across the majority of sites. This is not unexpected since peat often consists of decomposed *Sphagnum* (Joosten & Clarke 2002; Erwin 2009). A relatively high coverage of wetland mosses across both the mires and swamp forest sites was observed. I propose that this could be due to *Sphagnum sp.* being the species with the highest mean coverage across the majority of sites. The drained and restored treatments, as expected,

significantly decreased the presence of the wetland mosses for the mire sites. Although the restored treatment had a higher presence than the drained treatment. The wetland mosses at the mire sites followed similar patterns as the vascular plants. This means that restoration on mire sites may, to some extent, have a positive effect on wetland mosses. Other studies show that *Sphagnum* mosses increase after the restoration of drained mires and swamp forest areas, while the common forest mosses decline (Maanavilja *et al.* 2014; Maanavilja *et al.* 2015; Elo *et al.* 2024) No insightful result was found on the presence of wetland species for the swamp forest sites. Similarly to before, the unsampled areas, as well as the low number of sites for the swamp forest comparison, could be causing this result.

Do restored, undisturbed and drained peatlands affect the species richness differently?

Overall, swamp forest sites had a much greater number of typical forest species across all treatments, whereas the mire sites did exhibit more wetland species. Many factors contribute to the differences in vegetation composition between mire and swamp forest sites, such as hydrology, nutrient availability and canopy cover (Rydin & Jeglum 2013). The difference might be explained by swamp forests having elements from wetlands as well as forests. Löfroth (1991) state that 60% of all forest vascular plants can be found in a swamp forest, which validates the findings. It has also been shown that forest-prone species in swamp forest settings outcompete wetland species (Korhonen *et al.* 2008). The same thing can be observed when the water table is lowered through ditching (Jukaine *et al.* 1995). Wetland species are, therefore, dependent on the hydrology and conditions supplied by the mire sites to be able to stay competitive. The result of swamp forest sites accommodating the greatest number of forest species, while the mire had the greatest number of wetland species, was not unexpected. Ultimately, because of the result, I conclude that the restored, undisturbed and drained peatlands affect the species richness differently. Additionally, large differences in response could also be found between the two peatland types of mires and swamp forests. It is, however, important to consider that increasing the total number of species is not the primary goal in restoration, but rather regaining original communities, as stated in Haapalehto *et al.* (2017).

The drained treatment exhibited a high number of forest and wetland vascular plants for the mire sites. However, both the pristine and restored treatments showed large variability in the number of wetland species, indicating the presence of outliers with a high number of species within these treatments. Furthermore, all *Sphagnum* species were categorised at the genus level, making the large diversity of *Sphagnum* often found in mires not represented in the results (Rydin & Jeglum 2013). The restored treatment across the mire sites exhibited few observed forest and wetland

species. I believe that a slow vegetation succession after restoration may result in few species being present after such a disturbance. One notable change in vegetation composition at the restored sites was the drastic increase in *Eriophorum vaginatum*, as seen in Figure 3. Komulainen et al. (1999) and Elo et al. (2024) also noticed this shift in vegetation favouring *E. vaginatum* after rewetting the mire sites. This species has been shown to increase the CH₄ emission from ombrotrophic peatlands in the UK, contributing to greenhouse gas accumulation (Greenup et al. 2000). Nutrient availability was not accounted for in this study, whereas it has been shown to have an immense role in the pace of vegetation succession and the total species richness (Komulainen et al. 1999; Rydin & Jeglum 2013). For the swamp forest sites, the drained treatment had the most forest species, and the pristine treatment had the most wetland species, although the number was small.

Does restoration affect swamp forests and open mires differently regarding vegetation composition?

The results suggest that the vegetation composition for swamp forests and mires responds differently to restoration. The pairwise comparison for the swamp forest sites showed no significant difference in composition between the drained treatment and the restored treatment, while a significant difference was found for the mires site. This result indicates that the restored treatment only had an effect at the mire sites, creating a distinct composition from both the pristine and drained treatments. Whereas the restored composition at the swamp forest sites was not significantly different to the drained one. The swamp forest NMDS similarly showed some overlap between the drained and restored treatment, however, due to the stress value (0.209), one should be cautious when interpreting the visuals. The mire NMDS also visually showed how they differed between treatments, indicating some overlap between treatments. Haapalehto et al. (2017) suggest that restoration at first drives the community composition in a different direction from the goal of pristine composition. Komulainen et al. (1999) also found an evident change in vegetation composition after restoring drained peatlands, but the shift appeared to be subject to nutrient availability.

Do different environmental variables affect the vegetation composition for restored, undisturbed and drained peatlands?

The environmental variables were chosen to assess the potential impact on vegetation composition assembly. Site and treatment were investigated to see if geographical or environmental conditions could provide insight into differences in composition. Whereas water and ditch were included because of their connection to hydrology. Lastly, the interaction between treatment and ditch was accounted for

since the ditch differed among treatments. The pristine treatment lacks a ditch entirely, while the drained treatment has a functional ditch, and the restored treatment has a restored ditch.

Treatment only had a small proportion of the explained variance. It is difficult to know if the vegetation composition differs mainly because of the restoration or because of other factors. Additionally, when investigating what could drive the differences in composition, the environmental variables were shown to all have an influential effect. Site was the variable with the highest explained variance, meaning that treatment had a lower effect on species composition across the mire sites. Water was the variable with the second-highest explained variance, highlighting the importance of hydrology on vegetation composition in these ecosystems. The presence of a ditch was thought to have a large impact but only accounted for a small percentage of the explained variance. This was unexpected since the distance from the ditch has previously been shown to impact the vegetation composition (Haapalehto *et al.* 2017; Elo *et al.* 2024). It is important to note that all the environmental variables only explained a small percentage of the vegetation composition. Implying that differences in the composition are likely due to other environmental factors that need to be investigated. It has been found that the C/N ratio, pH level and concentration of certain minerals are elements that influence the species composition of peatlands, but these were not included in this study (Andersen *et al.* 2011). Furthermore, other studies conducted across oligotrophic peatlands in North America also show that shade and water table depth also matter for species composition (Graham *et al.* 2016).

Site was the environmental variable for the swamp forests with the highest explanatory variance, followed by treatment. The variables that had a significant effect on vegetation composition for the swamp forest sites were only treatment, site and ditch. Unlike the mire sites, where all variables were significant, water had a greater effect on vegetation composition. I believe that the reason for this is that swamp forests have drier conditions due to inhabiting large trees compared to the mire sites. Moreover, a complete change in species composition should not be expected in a restored swamp forest due to forest species naturally residing there (Maanavilja *et al.* 2014). Similarly to before, all the environmental variables only explained a small portion of the variance, implying once again that other variables explain the differences in vegetation composition.

4.1 Limitations and future research

The largest limitation of this study is the fact that no vegetation surveys were conducted at the restored sites before the restoration. If that had been done, one

could see how the present vegetation composition is impacted by restoration, removing uncertainties created by comparing different sites. Elo *et al.* (2024) state that only 23% of the biological intervention studies used before-impact sampling. Furthermore, this study is based on restoration efforts conducted 1-5 years prior, making time a limitation when examining the effects of restoration. It is still important to investigate the short-term effects of restoration. However, studies have shown that there is a risk of drawing hasty conclusions on restoration with only short-term monitoring (Haapalehto *et al.* 2017). Long-term monitoring is therefore needed to determine the efficiency of the restoration since a lot of previous studies have been conducted with short-term monitoring. Further research should, therefore, be done to assess the long-term effects of peatland restoration in northern Sweden, as well as to decide which sites to prioritise when conducting restoration. For this study, it would also be interesting to further investigate which environmental variables affected species composition. Another limitation to account for is that the number of swamp forest sites was too few to be a suitable comparison group to the mire sites. Lastly, since all *Sphagnum* species were only identified to genus level, the number of wetland moss species was much lower in the analysis than it otherwise would have. Therefore, the variety of *Sphagnum* species often found at mire sites is not captured and accounted for in this analysis.

4.2 Conclusion

Restoration can stop further degradation of drained boreal peatlands ecosystems. This thesis indicates that peatland restoration in northern Sweden, at least in the short term, might increase the presence of typical wetland species and decrease the presence of forest species on mire sites. In addition, differences in species richness between the treatments across swamp forests and mires were observed. Vegetation composition also differed between the majority of treatments across swamp forests and mires, whereas the investigated environmental variables had a small effect on the explained variance. This study is, however, limited by a short monitoring period, as well as a few sampling sites for swamp forests. Further research is needed to be done on nutrient availability and restoration success when selecting sites for restoration efforts. With more knowledge, it might be possible to improve the restoration effort and thus increase biodiversity in restored peatlands.

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Popular science summary

Climate change has become an increasing threat to species' survival and diversity. Because of these challenges, restoring habitats damaged from human activities has become more and more important. Wetlands, including peatlands, are one example of habitat types which has been damaged by humans through soil drainage. In Sweden alone, close to 1.5 million hectares of peatlands have been drained to benefit forestry. Ditching changes the hydrology of peatlands, causing the surface peat to get dryer by lowering the water table. This removes the provided ecosystem services and natural vegetation composition. Peatlands are viewed to have high ecological restoration value due to their beneficial abilities, such as water and carbon storage. The carbon-storing ability has been mentioned in academia to work as a nature-based solution to fight climate change. Performing restoration could also be important for stopping further loss of biodiversity in drained peatlands and help mankind with tackling climate change. However, despite all the positive things, there are still elements of peatland restoration that are still unexplored. Further research is needed to understand how the composition of different plant species is affected by restoration and how restoration can be improved. This study, therefore, sought to investigate the early effects of peatland restoration on mires and swamp forests in northern Sweden as well as how the vegetation compositions are impacted by it. Vegetation inventories were collected across ten sites in Västerbotten, Sweden, from June until July 2024. Every site was divided into three separate treatments: restored, drained and pristine to be able to examine the differences between them. The result showed that short-term peatland restoration in northern Sweden sometimes increases the presence of wetland species and decreases forest species, at least on mires. This outcome is viewed as positive since the recovery of peatlands is recognised by such a change in vegetation composition. This study also found a difference in the number of species between the treatments in both the mire and swamp forest sites. On top of that, the vegetation composition also differed between the majority of treatments across all sites. The effect of environmental variables on vegetation composition was made clear and showed that almost all investigated variables had a meaningful but small effect on the plant community composition. This study suggests that more research is needed on nutrient availability and understanding what contributes to restoration success when selecting sites for restoration. More knowledge of peatland restoration could

improve the effectiveness of restoration and in return increase biodiversity in restored peatlands.

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Appendix 1

Typical wetland species

Swedish name	Scientific name
Rosling	Andromeda polifolia
Vattenklöver	Menyanthes trifoliata
Flaskstarr	Carex rostrata
Dvärgbjörk	Betula nana
Tranbär	Vaccinium Oxycoccus
Trådstarr	Carex lasiocarpa
Sjöfräken	Equisetum fluviatile
Tuvull	Eriophorum vaginatum
Ängsull	Eriophorum angustifolium
Hjortron	Rubus chamaemorus
Dystarr	Carex limosa
Rundsilesår	Drosera rotundifolia
Storsilesår	Drosera anglica
Dvärgtranbär	Vaccinium microcarpum
Vitag	Rhynchospora alba
Kärrviol	Viola palustris
Taggstarr	Carex pauciflora
Sumpstarr	Carex magellanica
Hundstarr	Carex nigra
Strängstarr	Carex chordorrhiza
Snip	Trichophorum alpinum
Kärrsilja	Peucedanum palustre
Dybläddra	Utricularia intermedia
Vitmossor	Sphagnum

Appendix 1. List of vascular plant and moss species from the floristic field inventory that is classified by Artdatabanken SLU as typical (wetland), (wetland/alpine) and (wetland/freshwater) species.

Appendix 2

Typical forest species

Swedish name	Scientific name
Gran	<i>Picea abies</i>
Asp	<i>Populus tremula</i>
Vårtbjörk	<i>Betula pendula</i>
En	<i>Juniperus communis</i>
Rönn	<i>Sorbus aucuparia</i>
Contortatall	<i>Pinus contorta</i>
Hallon	<i>Rubus idaeus</i>
Smultron	<i>Fragaria vesca</i>
Blåbär	<i>Vaccinium myrtillus</i>
Skogsstjärna	<i>Lysimachia europaea</i>
Linnea	<i>Linnaea borealis</i>
Majveronika	<i>Veronica serpyllifolia</i>
Harsyra	<i>Oxalis acetosella</i>
Ekorrbär	<i>Maianthemum bifolium</i>
Ormbär	<i>Paris quadrifolia</i>
Mjölke	<i>Chamaenerion angustifolium</i>
Gullris	<i>Solidago virgaurea</i>
Midsommarblomster	<i>Geranium sylvaticum</i>
Skogskovall	<i>Melampyrum sylvaticum</i>
Ängskovall	<i>Melampyrum pratense</i>
Nattviol	<i>Platanthera bifolia</i>
Klotpyrola	<i>Pyrola minor</i>
Ögonpyrola	<i>Moneses uniflora</i>
Vårfryle	<i>Luzula pilosa</i>
Bergsslok	<i>Melica nutans</i>
Kruståtel	<i>Avenella flexuosa</i>
Hässlebrodd	<i>Milium effusum</i>
Skogsfräken	<i>Equisetum sylvaticum</i>
Skogsbräken	<i>Dryopteris carthusiana</i>
Ekbräken	<i>Gymnocarpium dryopteris</i>

Hultbräken	Phegopteris connectilis
Nordbräken	Dryopteris expansa
Majbräken	Athyrium filix-femina
Lumrar	Lycopodium sp
Husmossa	Hylocomium splendens
Enbjörnmossa	Polytrichum juniperinum
Skogsbjörnmossa	Polytrichum formosum
Väggmossa	Pleurozium schreberi
Stor kvastmossa	Dicranum majus
Kammossa	Ptilium crista-castrensis
Späd krypmossa	Amblystegium serpens

Appendix 2. List of vascular plant and moss species from the floristic field inventory that is classified by Artdatabanken SLU as typical forest species.

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