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SPHAGNUM RE-ESTABLISHMENT ON BARE PEAT

- an evaluation of restoration results

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Front page photo: Sphagnum growing in-between Eriophorum tussocks. Taken by author.

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Abstract

Restoration of former peat extraction sites is a rather young practice in Sweden. As part of the EU-funded project *Life to Ad(d)mire*, the County Administrative Board of Jönköping have restored a number of areas affected by peat extraction, with the purpose of achieving a favorable conservation status for the habitats and the species that depend on them. The main purpose of the current project has been to examine to what extent peat mosses, *Sphagna*, have re-established on the bare peat surfaces exposed after excavation on two of these sites. I further wanted to look into potential causes for within-site variation. *Sphagnum* coverage, species composition, thickness of the *Sphagnum* layer and relative water table position was measured in the field. The results indicate that a higher water table is preferable to a lower one in terms of thickness and coverage of *Sphagnum.* However, the species that were commonly found in the wettest areas are known to decompose faster than their hummock-living relatives more typically found in the slightly drier sites. The main purpose of the restoration project was to counteract the habitat loss due to overgrowth in order to favor birds. Poor *Sphagnum* establishment may therefore not be an urgent problem. It could, however, indicate that the water table is still too low or unstable in certain areas. If this is the case, higher vegetation could potentially re-establish and increase the need for further interventions.

Keywords: *Sphagnum*, establishment, bare peat, restoration

Sammanfattning

Restaurering av avslutade torvtäkter är en relativt ny företeelse i Sverige. Som del av det EU-finansierade projektet *Life to Ad(d)mire* har Länsstyrelsen i Jönköping restaurerat ett antal områden som påverkats av torvbrytning med syftet att uppnå god bevarandestatus för såväl habitaten som för de arter som är beroende av dem. Huvudsyftet med detta projekt har varit att undersöka till vilken grad vitmossor, *Sphagna*, har återetablerat sig på de bara torvytorna som blottades efter schaktning på två av de restaurerade områdena. Vidare ville jag undersöka eventuella orsaker bakom variation inom områdena. Täckningsgraden av *Sphagnum*, dess artsammansättning, mosslagrets tjocklek och relativ position på grundvattennivån mättes i fält. Resultaten antyder att en högre vattennivå är att föredra över en lägre, både i fråga om mosslagrets tjocklek och dess täckningsgrad. De arter som oftast återfanns i de blötaste områdena är dock kända för att brytas ner snabbare än sina tuvlevande släktingar som oftare återfanns på torrare ytor. Restaureringarnas huvudsyfte var att motverka habitatförlusten till följd av igenväxning för att främja fågellivet i områdena. Därmed är kanske en sparsam etablering av *Sphagnum* inte ett brådskande bekymmer. Det skulle dock kunna indikera att grundvattennivån ännu är för låg eller instabil i vissa områden. Om så är fallet finns det en risk att högre vegetation återkoloniserar ytorna och ökar behovet av vidare restaureringsåtgärder.

Nyckelord: *Sphagnum*, etablering, bar torv, restaurering

1 Introduction

1.1 Background

The loss and degradation of wetlands is a global problem. According to estimations, more than half of the global wetland area has been lost over the last century (Davidson, 2014). Healthy wetlands are of great importance, for a number of reasons. Not only can they store substantial amounts of carbon, they can also mediate flooding and retain nutrients and other pollutants (e.g. Joosten & Clark, 2002). They are also important habitats to a variety of species. Many open-ground birds are hesitant to breed too close to trees or other high structures where predatory birds may be on lookout (Wilson et al., 2014), and hence require the large open areas that non-forested wetlands can offer (Kaasiku et al., 2019). Furthermore, the recreational value of wetlands should not be dismissed (Bergstrom et al., 1990).

There are many types of wetlands, and their characteristics vary depending on where they are found – both within the landscape and on a larger, global scale (Rydin & Jeglum, 2006). *Peatlands* are wetlands that, due to constant waterlogging, accumulate organic material that is not fully decomposed – peat. The definition of a peatland varies, but the term commonly encompasses both land where peat is actively accumulating, like fens and bogs, but also land where the peat forming process is for some reason no longer active (see e.g. definition used by Joosten & Clark, 2002). There are several ways of further categorizing peatlands, and a common approach is to make divisions based on amount and source of nutrients and water (Rydin & Jeglum, 2006). A Swedish example would be bogs and fens, where bogs are ombrotrophic (receive nutrients solely through precipitation) while fens are minerotrophic (in contact with groundwater influenced by mineral-soil). The term *mire* is commonly used in Sweden and encompasses both fens and bogs (Rydin & Jeglum, 2006).

An active peatland has a characteristic profile (figure 1). The upper layer, or the *acrotelm*, consists of *Sphagnum* that is living or decomposing, as well as of other vegetation

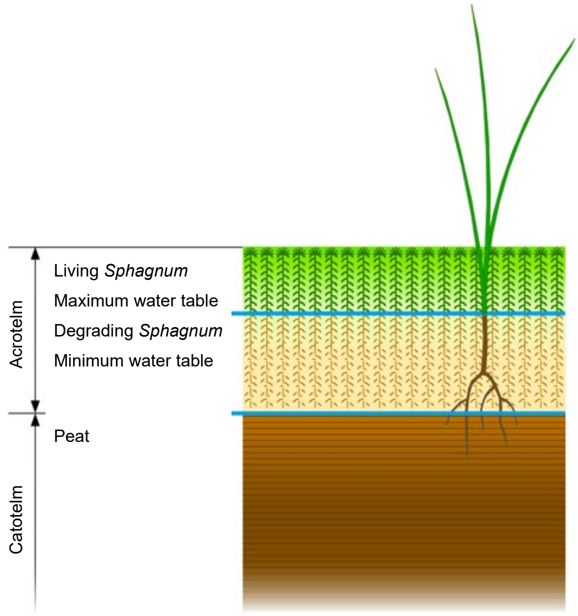

Figure 1. Illustration showing the layering of an active peatland (translated from The County Administrative Board of Jönköping, 2015)

(The County Administrative Board of Jönköping, 2015). Within this layer, the water table can fluctuate. Both the oxygen supply and the horizontal movement of water decreases with depth. Under the acrotelm lays the *catotelm*, which is constantly waterlogged and hence anoxic. The peat within the catotelm can be several meters thick (Franzén, 1985).

As previously stated, peatlands are important carbon sinks (e.g. Mitsch et al., 2013; Yu et al., 2011). There is, however, another side of the coin. The drainage of an active peatland will cause the water table to drop. As it does, portions of the peat that were once waterlogged can become oxygenated, causing a release of carbon dioxide into the atmosphere (e.g. Carlson et al., 2015). A dryer soil also allows for the establishment of trees and shrubs, which can further decrease the water table level (Laine et al., 1995; The County Administrative Board of Jämtland, 2015). Today, one of the main threats to remaining active peatlands in Sweden is overgrowth (The County Administrative Board of Jämtland, 2015). While this could be considered a natural process, it is accelerated by ditching, discontinued agricultural management as well as atmospheric deposition of nitrogen (Malmer & Wallén, 2004; SGU, 2015). Ditching has been used to drain peatlands in order to make the land more suitable for forestry and agriculture, as well as to enable extraction of peat for energy, horticulture et cetera (Rydin & Jeglum, 2006).

While peatland restoration is a relatively young practice in Sweden, the interest on an international scale has increased over the last few decades (Kimmel & Mander, 2010). As a result, a large number of studies on restoration of degraded peatlands can be found. Many of these focus on the re-establishment of peat mosses – *Sphagna* (e.g. González et al., 2013a; Karofeld et al., 2020; Smolders et al., 2003). There are more than 40 species of *Sphagnum* in Sweden, and the genus is fairly easy to recognize thanks to their characteristic appearance (Lönnell et al., 2019). The species of this genus are known for their water-holding capacity and are a main component of most Swedish peatlands. By affecting local hydrology and lowering the pH by uptake of cations, *Sphagnum* species can alter their own habitat, preventing the establishment of many other species (Clymo, 1964; Van Breemen, 1995). While common traits for all species are the need for certain wetness, a relatively low nutrient demand and tolerance for acidic conditions – more specific tolerance and habitat preferences differ between species (Lönnell et al., 2019).

The *Sphagnum* species typically found on bogs are commonly divided into categories according to their microtopographic preference/tolerance, which eventually mainly comes down to hydrological needs. Natural bogs most often show a characteristic pattern of hummocks (raised islands), hollows (depressions) and lawns (intermediate) (Rydin & Jeglum, 2006). Hummocks are usually dominated by *Sphagnum* mosses of the subgenera *Rigida*, *Sphagnum* and *Acutifolia* (e.g. *S. fuscum* and *S. rubellum*) while species of the subgenera *Cuspidata* and *Subsecunda* (e.g. *S. cuspidatum* and *S. fallax*) are more commonly found in hollows. In fact, *S. cuspidatum* can grow fully submerged (Lönnell et al., 2019).

Since *Sphagnum* mosses are typical to northern hemisphere peatlands and constitute one of the most important peat-forming groups, their establishment and growth is essential for the restoration efforts to be deemed successful (Rochefort, 2000). While vascular plants can obtain water through their roots, *Sphagnum* depend on capillary forces to transport water (Lönnell et al., 2019). Prior studies have proposed that the newly formed *Sphagnum* carpets of previously extracted bogs are more sensitive to hydrological variation (mainly drought) due to lower degree of connectivity between the residual peat and the newly formed acrotelm (Karofeld et al., 2020). This highlights the importance of a high and stable water table during the establishment of *Sphagnum* on cutover peat (Kozlov et al., 2016). Price and Whitehead (2001) found that a mean water table depth of -24.9 (±14.3) cm promoted *Sphagnum* establishment in an abandoned cut-over bog in Canada. Eventually, as the newly formed *Sphagnum* layer reaches a certain thickness, it can cause a positive feedback of hydrological self-regulation (Lucchese et al., 2010).

The state of the residual peat may also influence the re-vegetation outcomes (Zajac et al., 2018). Generally, the peat surface of an abandoned cut-over bog degrades over time if there is no intervention, decreasing its water holding capacity and increasing surface nutrient concentrations (Laine et al., 2013; Zajac et al., 2018). This pattern is mainly attributed to hydrological conditions like low water tables. In a survey by SGU (Geological Survey of Sweden), several peatlands in Småland and Uppland that had been surveyed in the early 1900s were revisited in 2010 and 2011 (SGU, 2015). In many of the sites, the uppermost peat layer was more humified than it had been at the time of the previous survey. The authors attribute these changes mainly to ditching for forestry and increased atmospheric nutrient deposition.

The re-establishment success of *Sphagnum* also depends on the colonization capacity of the species (Smolders et al., 2003). There are indications that colonization by hummock and lawn species (e.g. *S. papillosum* and *S. rubellum*) may be slower or less successful than that by hollow species (e.g. *S. cuspidatum* and *S. fallax*). In fact, stagnated re-vegetation dominated by species like *S. cuspidatum* following restoration is a seemingly common finding, as pointed out by Robroek et al. (2009). While *S. cuspidatum* has a high growth rate, it also decomposes at a high rate, likely making the peat accumulation slow (Johnson & Damman, 1991). The species is also more sensitive to drought than its hummock-growing relatives since it forms less dense carpets (Lönnell et al., 2019).

Dispersal is one of the prerequisites for colonization success. Sundberg et al. (2006) found that distance from the mainland was a bad predictor of *Sphagnum* species richness on land uplift islands in the Stockholm archipelago. Instead, the main explanatory variables were spore output frequency on the mainland and habitat preferences. Soro et al. (1999) also reported findings of *Sphagnum* species in peat trenches that had not previously (or rarely) been found within the region, indicating that dispersal may not be a problem.

As the hummock and lawn species are more or less essential for the development of a hydrologically self-regulating acrotelm, aided colonization (in addition to rewetting) could possibly be a way to speed up the process (e.g. Robroek et al., 2009; Smolders et al., 2003). This method has been widely used in Canada (Quinty & Rochefort, 2003), but has so far been less common in western Europe (Andersen et al., 2017).

So, how long will it take before the results are satisfactory? This of course depends on the restoration objectives. By modelling field data from the Bois-des-Bel peatland in Canada, Lucchese et al. (2010) concluded it would take 17 years for an acrotelm thick enough (19 cm) to counteract summer water table decrease, to develop. While the acrotelm thickness needed and the time it takes for it to develop varies depending on factors such as hydrology and climatic conditions, this gives us an idea of the time frame of regeneration. Pouliot et al. (2011a) found that three decades could be enough for microhabitat structures characteristic to bogs – hummocks, hollows and lawns – to develop, given that propagules were spread out as a restoration measure. Soro et al. (1999) however found that, 50 years after abandonment, the *Sphagnum* species composition in Swedish peat extraction trenches was still not characteristic for the type of habitat.

Not all restoration projects are successful (e.g. González & Rochefort, 2014). It might be valuable to be able to predict future outcomes early on in the process to be able to determine whether further interventions are needed. González et al. (2013b) assessed the potential for usage of indicator species to make early predictions of restoration success. They found that early establishment of the hummock-forming *S. rubellum* was the best predictor of a desirable trajectory.

Although most of the present literature on peatland restoration originates from other parts of the world, there have been a number of recent restorations initiatives in Sweden. The County Administrative Board of Jönköping have been working with restoration of wetlands within the EU-funded project *Life to ad(d)mire* (The County Administrative Board of Jämtland, 2015). The purpose of the Life project, as a whole, has been to counteract the habitat loss that has been accelerated due to ditching and discontinued agricultural management (grazing/mowing). The main goal has been to achieve a favorable conservation status both for the habitats themselves and for the species (mainly birds) that depend on them (The County Administrative Board of Jämtland, 2015). However, goals concerning the hydrological functioning, structure and flora of the sited are also stated (The County Administrative Board of Jönköping, 2012; 2013).

Now, there has been a desire to revisit two of the restored sites in order to estimate the degree of re-establishment of *Sphagnum* to evaluate whether peat formation has been initiated or is to be initiated anytime soon. Although many articles can be found on different aspects of peatland restoration, there is still a need to bridge the gap between research and practical management (Anderson, 2014). By following up on restoration efforts, one can not only make sure the specific sites recover in a desirable way, but also increase the knowledge about practical restoration results (Andersen et al., 2017).

1.2 Aim

The purpose of the project was to study the re-establishment of *Sphagnum* since restoration at two former peat extraction sites in southern Sweden. The main goal was to measure the thickness and coverage of the *Sphagnum* layer to assess how fast and successful the re-generation has been initially, as this will have eventually have implications for peat formation. I further wanted to examine potential causes for within-site variation. By measuring the water table depth, examining the *Sphagnum* species composition and measuring the thickness and coverage of the *Sphagnum* layer, I intended to answer the following questions:

- Does the thickness of the *Sphagnum* layer differ depending on relative water table position?

- Does the coverage of the *Sphagnum* layer differ depending on relative water table position?

- Does the *Sphagnum* species composition differ depending on water table position?

The findings were used to draw conclusions about the potential for hydrological self-regulation and eventually peat formation.

2 Material and methods

2.1 Study sites

Field sampling was conducted at two sites – the Anderstorp Stormosse nature reserve and the Store Mosse national park. The two study areas are situated roughly 20 km apart, both within the county of Jönköping in southern Sweden (figure 2). Both sites lie within mire complexes that are among the largest in the southern part of the country.

2.1.1 Anderstorp Stormosse (AS)

Anderstorp Stormosse (hereafter AS) is a nature reserve and a Natura 2000 area which covers approximately 1937 ha in total, of which the trenches where the study site is located makes up just over 18 ha (The County Administrative Board of Jönköping, 2016).

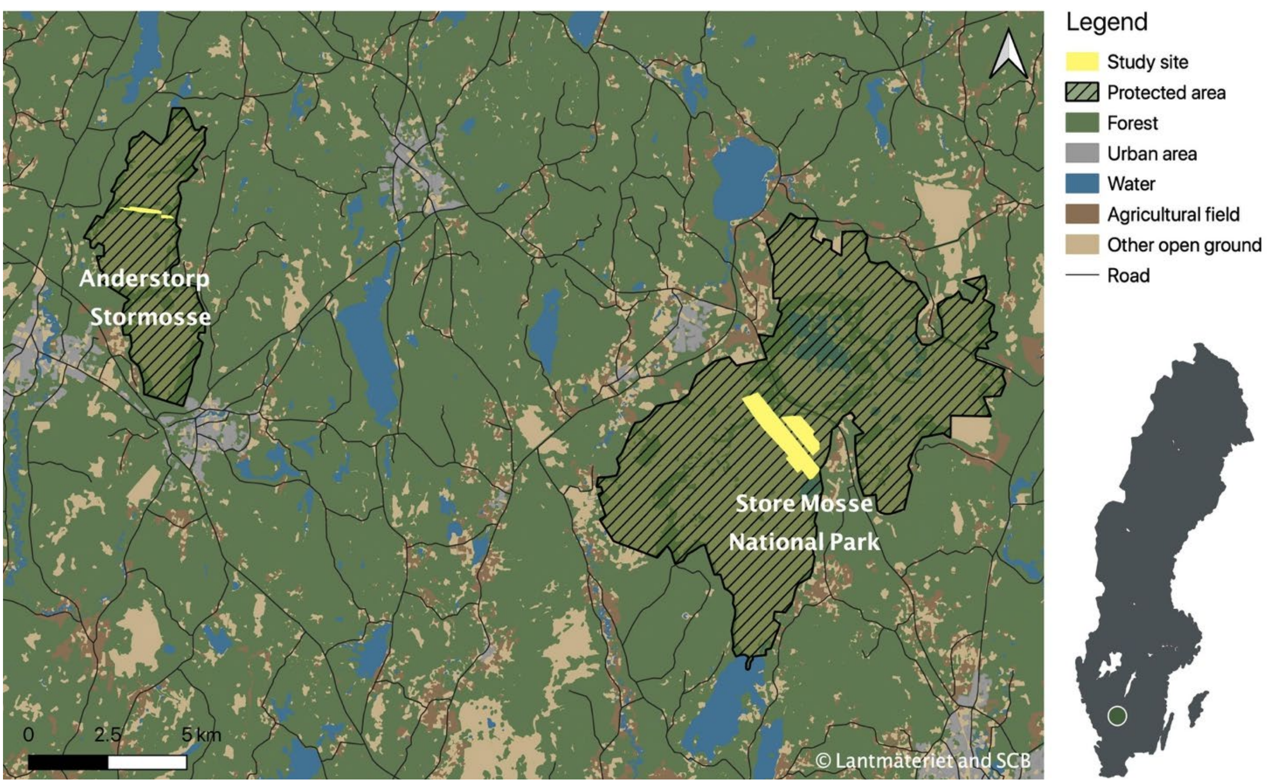

Figure 2. Map showing the localization of the two study sites.

Here, peat extraction for power generation was active between 1939 and 1949. Restoration measures included removal of higher vegetation, dam construction and excavation efforts to even out the trenches in which dry ridges/islands of intact peat had been left. Aerial photos from the site indicate that vegetation has now established in the shallower areas.

2.1.2 Store Mosse (SM)

Store Mosse (hereafter SM) is a national park and a Natura 2000 area known for its extensive open mire areas (The Swedish Environmental Protection Agency, 2015). In total, the area encompasses 7 682 ha, making it one of the greatest mire complexes in southern Sweden. Traces of peat extraction can be found in several parts of the park. The Hädinge extraction site (Hädingetäkten) is the largest - roughly 5 km long and 0.5-1 km wide, and located centrally in the park. Here, an active railway runs through the area. Peat extraction by block-cutting was active from the early 1900s up until 1966. The peat had mostly been cut in a consistent pattern of rectangular trenches of approximately 100 x 30 m.

Since the peat extraction ended and the site was abandoned, *Sphagnum* carpets had regenerated without intervention in the trenches. On the dry baulks however, higher vegetation such as trees and shrubs had established. Restoration of previously drained sites often involves raising the water table by filling in ditches and building dams (e.g. Quinty & Rochefort, 2003). However, since a higher water table could interfere with the railway running through the area and jeopardize the survival of the already well-established *Sphagnum* carpets in the trenches, it was decided that the ground level would instead be lowered. In an effort to restore the bog and favor classic peat-forming species, the trees were cut and a majority of the baulks were removed by excavation, leaving areas of exposed peat. These areas are the targets of the survey.

2.2 Field sampling

The field sampling took place between the 15th and 19th of March. A prerequisite for sampling to be possible was that the areas were free from snow and the ground was not frozen. To obtain sufficient data for the analysis, 75 plots were randomly localized at each site. For optimal randomization, plot coordinates were randomized using GIS software and located by GPS (Terrängkartan, version 3.6.2 @ 226) in the field. Due to low spatial accuracy, a dice was used for fine-scale randomization once the waypoints were reached, to ensure minimal bias in the placement of the frame. One of the corners of the frame was marked and always positioned northwards.

In Store Mosse, plot localization was limited to the baulks where traces of excavation were visible from satellite photos. In Anderstorp, localization was allowed in larger parts of the trenches, with the exception of a large baulk that had not been excavated and the western parts of the trenches, where evident wetness was assumed to make sampling difficult. The site was visited a few days before the sampling was to take place, and the size of the study area was adjusted due to extreme wetness. Regardless of the measures taken, many plots at AS were impossible to reach. Only 39 of the original 75 plots could be sampled, and an extra 10 plots were hence randomized within the reachable areas to compensate part of this loss. The final number of surveyed plots in SM and AS was 75 and 49, respectively.

A quadrat with a size of 50 x 50 cm (a grid with 25 squares of 10 x 10 cm) was used to survey the coverage and species composition of *Sphagnum* at each plot (figure 3). Using the Braun-Blanquet scale (table 1), the total coverage of *Sphagnum*, other vegetation, bare peat and water was estimated (Braun-Blanquet, 1932). Absolute coverage was also estimated for individual species of *Sphagnum*.

Table 1. The Braun-Blanquet scale used to estimate cover, with scale number and corresponding cover percentage span.

0	1	2	3	4	5
<1%	1-5%	5-25%	25-50%	50-75%	75-100%

Species that were difficult to identify in the field were collected and identified in the lab using a microscope and identification literature (Lönnell et al., 2019). Photo documentation of all plots further aided the identification. For the sake of analysis, sub-genera were used instead of species level identification. A complete species list can however be found in appendix C. Vegetation other than *Sphagnum* was documented with the purpose of providing further information about the sites and their current state.

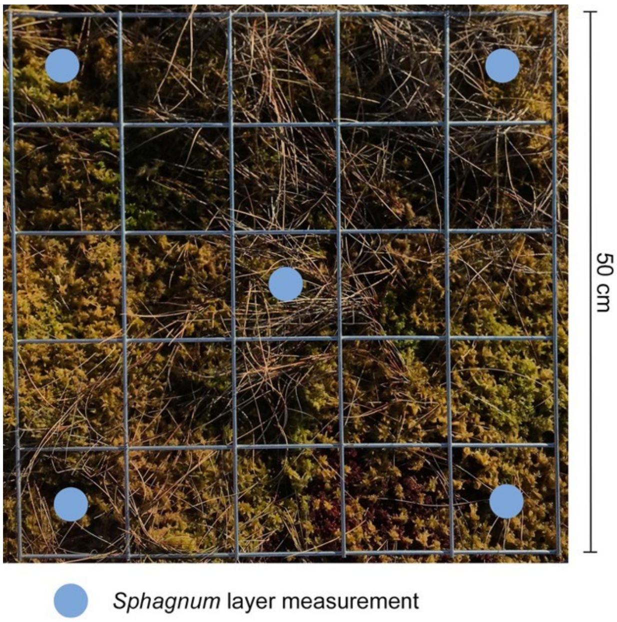

Figure 3. Quadrat sampling set-up. Blue circles show where the *Sphagnum* layer measurements were taken.

Five *Sphagnum* layer measurements were acquired in each plot (figure 3). The division between the residual peat and the newly formed moss layer was distinct. When calculating average thickness of the *Sphagnum* layer, only points where *Sphagnum* was present were used. Hence, the average was sometimes calculated using fewer than five measurements. In cases where small amounts of *Sphagnum* were present within the quadrat that failed to be captured by the measurement points, one measurement was taken in the middle of the colony (see discussion for further reasoning). The water table position was divided into one of three categories: under the residual peat layer (1), 0-10 cm above the residual peat layer (2) or >10 cm above the residual peat layer (3). Only one measurement (in the middle of the quadrat) was taken for this variable. The use of these broad categories was motivated by the difficulty in efficiently measuring water table position as a continuous variable when under the residual peat. The mean *Sphagnum* layer thickness and the plot WTD category was then used in the analyses.

During the sampling in SM, it became apparent that the establishment was better in some places than in others. To get a reference of what comparably good establishment looked like, three transects with five plots each were placed in an area with minimal amounts of bare peat. These 15 plots were not used in any statistical analyses, and hence only served the purpose of presenting an upper bound of establishment success.

2.3 Statistical analyses

Descriptive statistics were used to provide an overview of the variables studied. For calculating the average total *Sphagnum* coverage, the mid-points of the Braun-Blanquet percentage intervals were used. Given that the average *Sphagnum* cover calculations are based off of interval mid-points, they are very rough.

Since the data failed to meet all the assumptions of parametric statistical analyses, non-parametric Kruskal-Wallis tests were used to test for potential differences in thickness and coverage depending on the ordinal variable water table position. These were followed up by post-hoc tests to determine which categories that were actually significantly different. These analyses were performed in SPSS (version 28.0.1.0). Due to the low number of plots with water tables higher than 10 cm over peat surface in SM (n=3), this category was excluded for the SM site. Instead, Mann-Whitney tests were used to test for differences between the two remaining categories. An exploratory analysis of the *Sphagnum* composition was carried out in R studio (R Core Team, 2022) using the *vegan* package (Oksanen et al., 2020). Due to the ordinal nature of the data, a non-metric multidimensional scaling (NMDS) approach was used, as advised by Podani (2006).

Table 2. Summary of *Sphagnum* presence, coverage and thickness for AS, SM and the additional transect survey at SM. Average thickness was calculated excluding all plots with no establishment. (*) indicates that plots with floating *Sphagnum* were also excluded.

Site	Total number of plots (n)	Percentage of plots with *Sphagnum* (%)	Percentage of plots with *Sphagnum* coverage >50% (%)	Average thickness of *Sphagnum* layer and SD (cm)
Anderstorp Stormosse (AS)	49 (28 for thickness)	61.2	18.7	12.8 (± 8.3) *8.7 (± 5.5)**
Store Mosse (SM)	75 (22 for thickness)	57.3	26.5	6.3 (± 4.9) *5.8 (± 3.9)**
Transects, Store Mosse (TSM)	15	100.0	60.0	6.8 (± 1.8)

Clustered plotting was used to visualize any patterns using the *ggplot2* package (Wickham, 2016). For this analysis, plots without *Sphagnum* establishments were excluded.

3 Results

3.1 Overall *Sphagnum* layer thickness and coverage

The establishment of *Sphagnum* was generally patchy at both sites, with some areas with more consistent coverage.

3.1.1 Anderstorp Stormosse (AS)

30 plots (61.2%) in AS contained *Sphagnum*, and 13 plots (26.5%) had a *Sphagnum* coverage of >50%. The average total coverage of *Sphagnum* was 27.6%. The average thickness of the *Sphagnum* layer was 12.8 (± 8.3) cm, excluding plots with no establishment (n=28, 21 plots excluded) (table 2). When also excluding plots where the water table height was greater than the average thickness, indicating that the *Sphagnum* carpet was (at least to some degree) floating, the average was instead 8.7 (± 5.5) cm (n=19, 30 plots excluded). In AS, the plots were evenly distributed in terms of water table categories (figure 4).

The most represented sub-genus was *Cuspidata* (found in 42.9% of the plots),

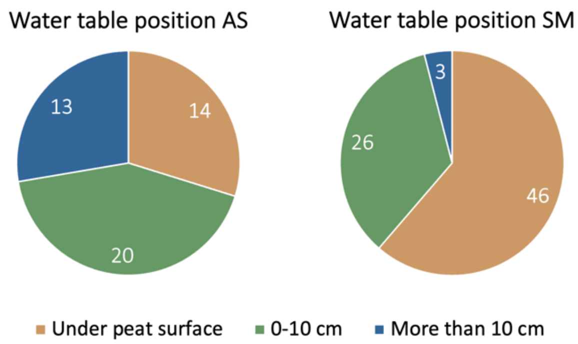

Figure 4. Distribution of plots with different water table positions in a) AS and b) SM. Labels refer to number of plots.

followed by *Sphagnum* (26.5% of the plots) and *Acutifolia* (2.0% of the plots) (figure 5).

22 out of the 47 plots containing vegetation other than *Sphagnum* were dominated by sedge vegetation (*Carex* sp.) (figure 6). Cotton-grass (*Eriophorum vaginatum)* dominated in 21 plots, and the remaining four plots were dominated by heather, (*Calluna vulgaris)*.

3.1.2 Store Mosse (SM)

The establishment of *Sphagnum* in Store Mosse varied a lot throughout the area. 43 plots (57.3%) in SM contained *Sphagnum*, and 14 plots (18.7%) had a *Sphagnum* coverage of >50%. The average total coverage of *Sphagnum* was 17.2%. The average thickness of the moss layer was 6.3 (± 4.9) cm, excluding plots with no establishment (n=41, 34 plots excluded) and 5.8 (± 3.9) also excluding plots

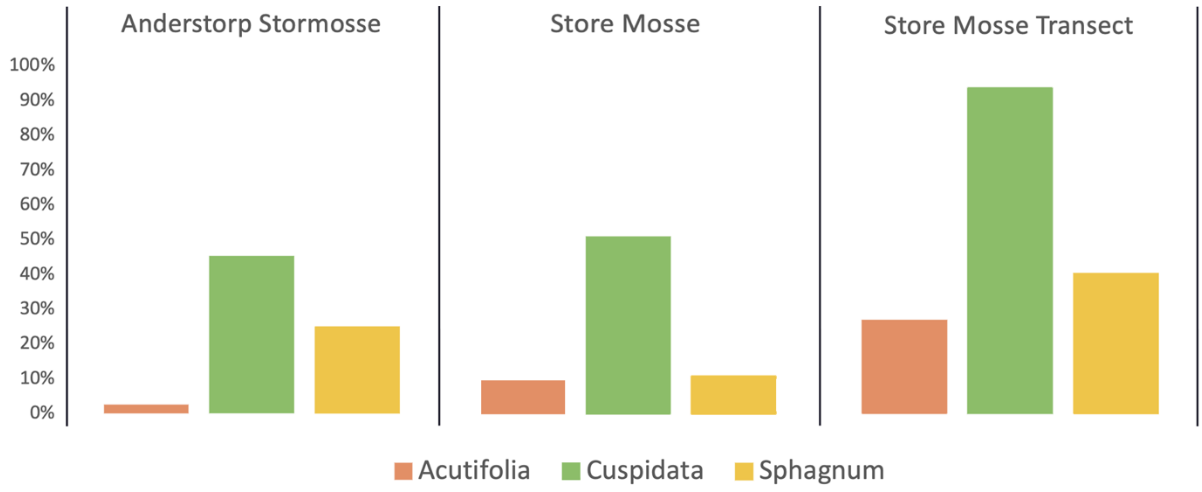

Figure 5. Percentage of plots in AS (n=49), SM (n=75) and SMT (n=15) where species from section *Acutifolia*, *Cuspidata* and *Sphagnum*, respectively, were found in any proportion.

with a floating *Sphagnum* carpet (n=35, 40 plots excluded). For the majority of the plots (64.4%), the water table was below the residual peat layer (figure 4). Only three plots (4.0%) had a water table level higher than 10 cm above the residual peat. Almost all (28 out of 32) of the plots that lacked *Sphagnum* altogether had water tables that were under the residual peat surface.

The most represented sub-genus was *Cuspidata* (found in 50.1% of the plots), followed by *Sphagnum* (13.3%) and *Acutifolia* (10.7%) (figure 5). In 68 out of the 72 plots containing vegetation other than *Sphagnum*, *Eriophorum vaginatum* dominated (figure 6). Three plots were dominated by *Calluna vulgaris*, and one by cranberry (*Vaccinium oxycoccos*).

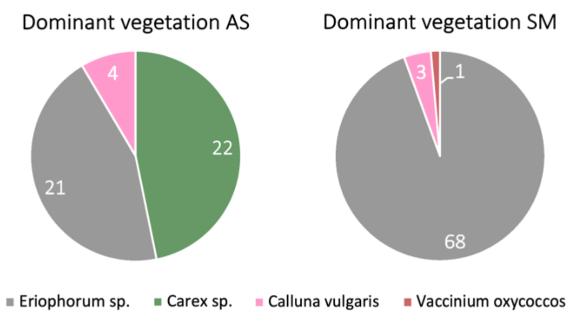

Figure 6. Distribution of plots with different dominant vegetation other than *Sphagnum* in a) AS and b) SM. Labels refer to number of plots.

3.1.3 Store Mosse Transect Survey (TSM)

For the additional transect survey in Store Mosse (hereafter TSM, as in transect SM), the establishment was more consistent. *Sphagnum* was found in all of the 15 plots (100.0%), and 9 of the plots (60.0%) had a *Sphagnum* coverage of >50%. The average *Sphagnum* coverage was 57.2%. The average thickness of the *Sphagnum* layer was 6.8 (± 1.8) cm. No plots were excluded since *Sphagnum* was found in all of them, and no floating moss carpets were present (n=15). Besides Sphagnum, *Eriophorum vaginatum* dominated in all of the plots.

The water table position was very consistent throughout this area, with 87% of the plots being classified into the 0-10 cm category.

3.2 Differences by water table position

All of the Kruskal-Wallis tests and the Mann-Whitney tests performed on the AS and SM data, respectively, showed that there were significant differences in *Sphagnum* cover and thickness depending on water table category.

In AS, where all three water table categories were compared, the pairwise comparison revealed significant differences only between the first and third category (*under peat* and *>10 cm above peat*). This was true for both the

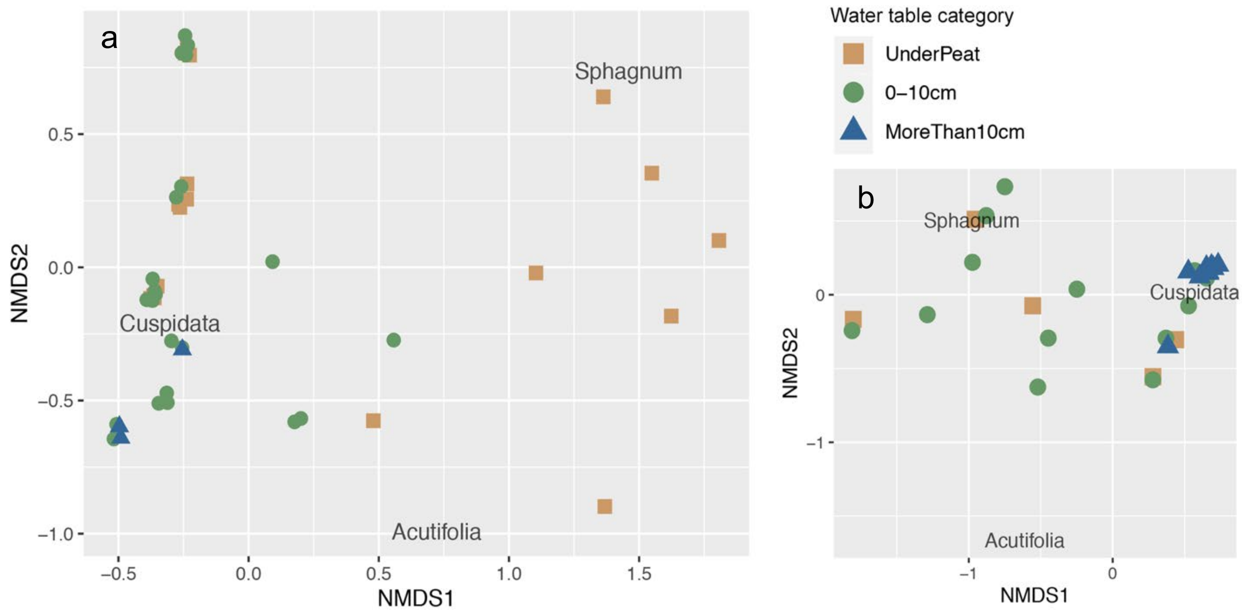

Figure 7. Plotted NMDS output for a) SM and b) AS. Each point represents one plot and its coverage of *Sphagna* from the three sections *Sphagnum*, *Cuspidata* and *Acutifolia*. Plots that group together are more compositionally similar to one another. Stress was <0.01 for AS and 0.04 for SM.

Sphagnum cover and the *Sphagnum* layer thickness (table 3). In terms of thickness, a significant difference was also found between the two wetter categories.

In Store Mosse, only two of the water table categories were compared due to too few plots with water table positions >10 cm above the peat. For both thickness (n=38) and coverage (n=72), a significant difference was found between the two categories (p=0.026 and p<0.001, respectively).

3.3 *Sphagnum* coverage and composition

The non-metric multidimensional scaling (NMDS) output was plotted in R to explore and visualize patterns in community composition for each of the sites (figure 7a-b).

In AS, the wettest sites (with a water table >10 cm above the residual peat) grouped together (figure 7b). These were associated with the section *Cuspidata*. While some of the medium-wet plots (0-10 cm) also grouped similarly, many were also spread across the plot and more associated with sect. *Sphagnum*.

A similar pattern was found in Store Mosse (figure 7a). The wetter categories (*0-10 cm above* peat and *>10 cm above peat*) showed a tendency of being more similar in terms of composition, and were mostly associated with the *Cuspidata* section. Some of the drier plots (category *under peat*) also grouped with these, while others were spread across the opposite side of the plot and more associated with sect. *Sphagnum* and *Acutifolia.*

Table 3. P-values for the pairwise comparisons in AS. Significant values are highlighted in green.

Variable	**Pairwise comparison**	**P-value***
Total *Sphagnum* cover (n=47)	Under peat I 0-10 cm above peat	0.122
	Under peat I >10 cm above peat	0.002
	0-10 cm above peat I >10 cm above peat	0.259
Sphagnum layer thickness (n=28)	Under peat I 0-10 cm above peat	0.626
	Under peat I >10 cm above peat	0.001
	0-10 cm above peat I >10 cm above peat	0.004

**p-values are adjusted by Bonferroni correction for multiple pairwise comparisons. Level of significance is* $\alpha = 0.05$.

4 Discussion

The results indicate that there are differences in both thickness and coverage of the *Sphagnum* layer for plots with different water table positions, at least between the driest and the wettest plots. The wetter plots had both a greater cover and a greater average thickness. On the other hand, the plotted NMDS output suggests that the drier plots were more prone to contain hummock-forming species of the sub-genera *Sphagnum* and *Acutifolia*.

4.1 Differences in coverage and thickness

The results show that the best establishment, both in terms of coverage and thickness, was found in plots where the water table was >10 cm above the residual peat surface and 0-10 cm above the peat surface for AS and SM, respectively.

The differences in *Sphagnum* coverage between these categories are probably much due to the many plots with no establishment in the driest category. I argue that it makes sense to include these zeros in the cover analysis, since the complete absence of *Sphagnum* is also meaningful.

For the thickness analysis, I would argue otherwise. The sampling design with five measurements per plot makes the thickness measurements cover dependent, since the probability of getting zeros increases with decreasing total cover. This flaw was thought of first when sampling was almost finished. Since I was interested in looking at the thickness of the *Sphagnum* colonies present (and not their thickness averaged out over parts of the quadrat with no establishment), I only used measurements greater than zero (>0) to calculate average thickness. I had also taken an additional measurement at all the sites where *Sphagnum* was present but not captured by the original sampling procedure. These measurements were then used in the analysis (but accompanied with a disclaimer about deviation from the sampling procedure). A better sampling approach would have been to take one measurement per square in the grid, i.e. 25 measurements per plot. By doing so, and calculating the average thickness of only the measurements >0, one would get a more objective estimate. This would, however, have increased the time spent in the field and on data handling.

For plots with very high water tables, little vegetation other than *Sphagna* from sect. *Cuspidata* was found. It could be that other vegetation has a hard time establishing in open water or that the species of *Sphagna* in question are great competitors in such an environment. Regardless, many of these plots had a *Sphagnum* cover of close to 100%, which likely also contributed to the significance.

When it comes to thickness, differences were significant for both the pairwise comparisons involving the wettest category (>10 cm above peat) in AS, but not for the comparison of the other categories (under peat and 0-10 cm above peat). In SM, where only the latter two categories were compared, they differed significantly in terms of thickness. The fact that the wettest sites stood out in AS is not a surprising, nor very useful, finding for drawing conclusions. Generally, greater inundation (>10 cm) of the peat surface was associated with high *Sphagnum* coverage. However, the species found in these plots were, as stated above, mostly from the sub-genus *Cuspidata* (primarily *S. cuspidatum* and *S. fallax*), and in many cases floating. This pattern has been reported in previous studies from restored sites (e.g. Robroek et al., 2009).

The fast-growing *S. cuspidatum* has a high decomposition rate, and forms loosely packed carpets compared to species found in hummocks (e.g. Johnson & Damman, 1991). While the floating individuals may indeed be very long, their stems are thin and branches are sparse and fine. Without the water to hold them up, they are likely to sink and lose much of their structure. By excluding all plots where the *Sphagnum* carpet was assumed to be floating, the average thickness decreased from 12.8 cm to 8.7 cm (-32%) in AS and from 6.3 cm to 5.8 cm (-8%) in SM (table 2). The floating carpets have quite a large impact on the average thickness, especially in AS where more plots with high water tables were sampled. The reasoning behind calculating the average *Sphagnum* thickness both with and without floating *Sphagnum* carpets is that these are lifted by the water and are expected to shrink considerably if the water table drops.

The same reasoning should be applied when evaluating the results of the Kruskal-Wallis analysis. While the rank-based nature of this analysis dampers the effect of the often rather extreme thicknesses of the floating carpets, it might still give an exaggerated idea of their importance by ranking them the highest. That being said, their existence does not lack value. It has, for example, been proposed that floating carpets of e.g. *S. cuspidatum* could help facilitate the establishment of other *Sphagnum* species by providing them with a growing-ground (Money and Wheeler, 1999). Grosvernier et al. (1997) also discusses the importance of *S. fallax* as an early colonizer which can potentially initiate further succession of *Sphagna*.

4.2 Species composition

Although not statistically proven, there seems to be differences in *Sphagnum* species composition based on water table position. To no surprise, wetter sites seem to contain species of the sub-genus *Cuspidata* to a greater degree while species of the sub-genera *Sphagnum* and *Acutifolia* are more commonly found in drier sites. This is in line with the preference/tolerance presented in the literature (Lönnell et al., 2019) and findings from other studies (e.g. Soro et al., 1999).

An important reminder is that only sites with *Sphagnum* establishment were included in this analysis. Hence, the visualization alone cannot fully describe the establishment patterns. In fact, the driest plots were strongly overrepresented among the plots with no *Sphagnum* establishment at all.

The composition analysis gives us somewhat of another perspective on the establishment situation. Since the species of sect. *Sphagnum* and *Acutifolia* have been shown not to decompose as readily as those of sect. *Cuspidata* (and hence potentially contribute to peat formation to a greater degree), these might be the ones we want to favor the most (Bengtsson et al., 2016). So, while the wetter sites had the greatest establishment in terms of thickness and coverage of *Sphagnum*, a (relatively) lower water table position could arguably be considered to be beneficial in terms of composition.

4.3 Evaluating success

To evaluate the success of a restoration project, one must first define success. Several definitions of peatland restoration success are to be found in the literature. Some articles argue that a hydrologically functional and self-regulating acrotelm is a prerequisite for a project to be deemed successful (Lucchese et al., 2010). This is often attributed to the thickness of the newly formed layer of peat-forming species. Rochefort (2000) defines the goals of peatland restoration as *"1) a plant cover dominated by Sphagna or brown mosses, depending on the status of the residual peat and 2) the diplotelmic hydrological layers that characterize intact 'active' peatlands"*. She further adds that long term ecosystem functionality traits such as nutrient cycling, peat accumulation, microhabitat development and productivity should be part of the goals.

The main purpose of the EU-funded Life project has been to counteract the loss of wetland habitat due to ditching and discontinued agricultural management (grazing/mowing). The goals stated for the project relate to obtaining and maintaining a favorable conservation status for the open mire habitats and birds that depend on them (The County Administrative Board of Jämtland, 2015). Early follow-ups, (Gustafsson, 2015a; 2015b) found that (when comparing bird inventories from 2010 and 2015) typical forest bird species decreased both in AS and SM, and more waterfowls were observed in AS where a lot of open water surfaces were created. For other wetland species, no distinct pattern was observed. While the differences are small and the sampling occasions are few, the County Administrative Board still argues that these results may indicate that the areas are on the right path. Alsila et al. (2020) reported similar results following peatland restorations in

Finland, where non-specialist bird territories decreased while those of peatland specialists remained rather unchanged within the timeframe of 6-8 years. Further follow-ups are needed to evaluate whether the restoration goals have been met in terms of the bird fauna.

In the hydrological reports, it is further stated that the restoration sites shall be hydrologically intact and structurally similar to pristine raised bogs within 50 years (The County Administrative Board of Jönköping, 2012; 2013). The flora should consist of species typical to raised bogs, without traces of overgrowth.

So what does this mean? Hydrological functioning is, at least partly, linked the diplotelmic structure of an active peatland. As the new *Sphagnum* layer grows thicker, its capacity to raise and withhold the water table increases. While the thickness needed for a newly developed acrotelm to be functional varies with site conditions, Lucchese et al. (2010) modeled that 17 years would be enough for the development of an acrotelm with the thickness of 19 cm. In 8 years, the newly formed layer had become 13.6 ± 6.5 cm thick in the studied Bois-des-Bel peatland. Compared to this, even the optimistic estimates (including floating *Sphagnum* that might not contribute as much to peat formation and hydrological functioning) of the present study are lower (12.8 (± 8.3) and 6.3 (± 4.9) for AS and SM, respectively). Further, the moss cover in the Bois-des-Bel peatland was, as described by Lucchese et al. (2010), complete and dominated by *S. rubellum* of sect. *Acutifolia* (worth noting is that *Sphagnum* fragments were spread out as part of the restoration effort). The average coverage in AS and SM was 27.6% and 17.2%, respectively. It seems as if a fully functional acrotelm will not be achieved anytime soon. When, or if, is hard to predict since development is not necessarily linear.

Sphagnum species composition has only been compared between restored surfaces with different water table positions. To properly evaluate how similar the species composition is to that of an intact bog, surveying reference plots outside of the degraded areas would have been of interest. The reasoning behind not doing a full vegetation survey (i.e. noting down the absolute cover or presence/absence of every single species found in each plot) was mainly the timing of the sampling. *Sphagna* are, even though they might look washed-out after emerging from snow, evergreen. The timing of sampling is therefore not as crucial as it is with many vascular plants, where noticeability and cover may change a lot throughout the season. A complete vegetation study may become increasingly relevant as more time passes. What can be said however, is that several species that are considered typical or characteristic to raised bogs were found (The Swedish Environmental Protection Agency, 2011).

Are these results unusually bad then? Probably not. In a field study spanning over 15 years, Kozlov et al. (2016) followed up on the vegetation dynamics in two rewetted peat extraction sites in Sweden. Prior to the rewetting, both sites were characterized by bare peat. In one of the sites - the Porla wetland (degraded bog), the authors documented vegetation changes similar to those seen in Store Mosse. Within the first few years after rewetting, re-vegetation was poor and there was a lot of bare peat. Six years after the rewetting, the average plot vegetation cover was approximately 40%, of which 35% was *Eriophorum spp*. A *Sphagnum* cover of 12% was documented in 2012 (12 years after the restoration), and had almost doubled the following year. This shows that establishment can progress rather fast. No recent documentation from the Porla site has been found. It would be interesting to get an update of the vegetation development of the site.

Another study providing coverage references is Soro et al. (1999). They compared peat trenches that had been abandoned for 50 years to an intact bog in terms of e.g. species composition and species niche breadth. The total *Sphagnum* cover in the revegetated trenches was 54%, as compared to 74% on the non-degraded bog. It is not unthinkable that the *Sphagnum* cover in AS and SM will be comparable to these numbers by the time 50 years have passed as long as conditions are favorable. In fact, some areas already have establishment of this degree (see 3.1.3).

4.4 Limitations of the study

A common problem in ecological observational studies is that it is difficult to confidently claim that an observed pattern, that is seemingly attributed to a certain variable/set of variables, is not a result of other, unstudied variables. This is perhaps most important when considering the linkage between other vegetation and *Sphagnum* establishment. It is possible, and even likely, that water table level is influencing both the establishment of *Sphagnum* and that of other types of vegetation. As an example, cotton-grass (*Eriophorum vaginatum*) is a common early colonizer on cut-over peat (e.g. Lavoie et al. 2003; Kozlov et al. 2016). Studies have proposed that it could help facilitate the establishment of typical wetland species such as *Sphagna*, by offering microhabitats with increased shade and stability (e.g. Tuittila et al., 2000; Pouliot et al., 2011b). Lavoie et al. (2005) however question this theory. In their study, the moss establishment was more closely associated with the hydrological characteristics of the sites than with the presence of *Eriophorum*. The *Eriophorum* cover was also correlated with hydrological variables, and a higher water table led to greater presence of tussocks. Disentangling of these interactions is beyond the scope of this project and hence, no such analysis was performed.

Worth noting is also that examining the water table position at only one point in time only gives us a snapshot of this hydrological variable. This is a rough measurement of a more complex and dynamic variable. In a hydrological investigation carried out prior to the restoration in Store Mosse, the maximum water table difference recorded by a water table logger during the period of measurement (from February 11th to August 12th, 2013) was 24 cm, with the highest level occurring in May and the lowest in August (The County Administrative Board of Jönköping, 2013). No such data have been recorded in AS, and no recent investigation of the hydrology is to be found for any of the sites. It can be expected that the summer water tables at both sites will be lower than what was observed during the field sampling.

The water table category *under peat* encompasses all plots where the water table did not exceed the peat surface. No distinction was made based on the wetness/dryness below this level due to inability to do so in a non-biased and/or time-efficient way. Some of the plots were remarkably dry. It would hence have been interesting to try and distinguish between plots where the water table was just below the peat surface and ones where the water table was far below the surface. This could be done by installing wells for monitoring, either using automated loggers or measuring the water level manually.

Further studies or follow-ups of the restored sites could focus on determining whether the water table actually is the main driver of the observed differences in establishment success. By specifically targeting areas with different degrees of establishment and following up on site conditions throughout the year (perhaps including further variables such as peat characteristics, pH etc.), one could potentially further disentangle the processes behind the observed patterns.

Species from section *Cuspidata* were the most frequently found at both study sites (figure 5). This could be due to wetness or effective dispersal. Another potential explanation is that these fast-growing species are favored by an increased nutrient supply (Limpens et al., 2003). Looking into nutrient concentrations at the sites may hence also be of interest. If the peat surface or the water is, for whatever reason, more rich in nutrients than what would be expected from a raised bog, this could make it less likely that a flora typical to that of such bogs will establish in the near future.

Worth remembering is also that peat is likely to change as it is exposed and allowed to degrade (Zajac et al., 2018). As it becomes more humidified, its capacity to successfully host *Sphagna* may decrease. Distinct stratification in peat color could be observed at the study sites (figure B1, appendix B). The bare peat surfaces may also be susceptible to frost heaving (Quinty & Rochefort, 2003). In fact, potential signs of frost heaving could be observed at both sites (figure B2, appendix B).

These factors may also be interesting to look into.

4.5 Implications for further management

The leakage of carbon dioxide from drained peatlands is a hot topic in Sweden (and globally) at the moment. This gained interest may contribute to continued financial support for peatland restoration projects. Swenson et al. (2019) highlight the importance of regeneration of *Sphagnum* in restored peatlands as a climate change mitigation strategy, due to it being negatively correlated with the global warming potential.

The results from the current study show that, in these specific cases, there is a significant difference between the *Sphagnum* establishment in plots with different water table positions. The best establishment, both in terms of coverage and thickness, was found in plots where the water table was high. Generally, it seems as if surface inundation (at least for part of the year) increases the chances of any *Sphagnum* establishment. Too deep inundation however seemingly results in *S. cuspidatum* monocultures.

In AS, large parts of the old trenches are greatly inundated. As previously stated, it allows for establishment of hollow-living species like *S. cuspidatum* (unless establishment is impeded by wave action) that can potentially, in the long run, facilitate the establishment of other *Sphagnum* species by providing a suitable surface (Money and Wheeler, 1999). Surface inundation could also add habitat complexity and favor birds (Ma et al., 2009). That being said, it may also have some drawbacks. When the peat is rewetted and oxygen supply decreases, carbon dioxide emissions generally decrease. However, the emissions of methane increase (e.g. Moore and Dalva, 1993; Mitsch et al., 2013). Methane is a more potent greenhouse gas, but it is also more short-lived in the atmosphere than carbon dioxide (Canadell et al., 2021). Mitsch et al. (2013) argue that the carbon sequestration of restored peatlands generally outweighs the methane emissions on greater time scales and that rewetting should not be hindered by the fear of increasing methane emissions.

While the establishment was generally patchy and less extensive than desirable, there were areas where establishment was good. This suggests that dispersal is probably not the main issue. Judging by this study alone, it seems more likely that some environmental factors limit the establishment success of propagules. Whether these factors are mainly hydrological or not remains unproven.

Is it urgent then? And what can actually be done? It all comes down to costs and benefits. *Sphagnum* establishment (and eventually peat formation) is beneficial for many reasons, including carbon sequestration (Swenson et al., 2019). Even after establishment has been properly initiated, it will take quite some time before the hydrological functioning is comparable to that of a pristine bog (e.g. Lucchese et al., 2010). This could be an argument for trying to initiate the establishment process as soon as possible. In Canadian peatland restoration, a common practice is to actively transplant propagules of hummock species as part of the restoration efforts (Quinty and Rochefort, 2003). Robroek et al., (2009) argues that facilitated spreading of diaspores can speed up the process of *Sphagnum* establishment (and eventually peat formation and carbon sequestration).

Poor establishment could also indicate that parts of the restored sites are still too dry, at least for some part of the year, to host *Sphagna*. If this is the case, overgrowth may yet again become a problem within a foreseeable future. Further investigations and, if needed, further interventions with the purpose of raising/stabilizing the water table could be considered.

While the results should not be used to draw any absolute conclusions about restoration of peat extraction sites in general due to few actual replicates, they can be used to predict the future of the sites studied. With some caution, they could also help guide future restoration projects by adding to the reference library of restoration outcomes.

5 Conclusion

About nine years have now passed since the restoration efforts. The best *Sphagnum* establishment, both in terms of thickness and coverage, was found in plots that were relatively wet at the time of sampling. While some areas indeed have a decent *Sphagnum* cover, it seems as if a self-regulating acrotelm and peat formation is not to be achieved anytime soon in most areas.

Given that the main objective of the restoration was to counteract overgrowth in order to favor the open wetland habitats and the birds that depend on them, fast *Sphagnum* establishment in itself may not be crucial. The reasons behind the poor establishment should however be further looked into. If the water table is still too low or unstable, there is a risk that trees and shrubs will re-establish in certain areas, perhaps creating the need for further restoration efforts. While adaptive management should not be underrated, I believe we should strive to avoid keeping our restored areas on life-support. Hence, looking for early indications may be very valuable. While this study does not capture the whole picture, it can hopefully provide some insight into the *Sphagnum* establishment situation at the two restored sites.

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Appendix A. Popular science summary

Peatland mosses won't return overnight – but don't let it bog you down!

Are we capable of healing the wounds that past human activities have left in the landscape? And if so – how long will it take? With snow-shoes on my feet as an insurance against involuntary dips, I made my way across two restored peat extraction sites in early spring to see how well peat mosses, Sphagnum, had established on the bare peat after restoration.

What is restoration?

While *restoring* something means bringing it back to its former state, the term is often used a bit more loosely when talking about ecosystem restoration. What a restoration encompasses depends on the type of ecosystem, but could for example involve promoting species typically found in an area before exploitation or recreating physical structures in the environment.

Sphagnum – the peatland engineer

Peat mosses, or *Sphagna*, are sometimes considered ecosystem engineers due to their ability to alter their own habitat. By forming dense carpets, they can efficiently suck up and withhold water, raising the water table. They also make their surroundings more acidic by exchange of ions. Many other organisms do not thrive in these conditions, giving the peat mosses competitive advantages.

Why restore wetlands?

Healthy wetlands can have many important functions. They can, for example, prevent nutrients and other pollutants from reaching downstream waters and offer important living-grounds for many birds and other organisms. A specific type of wetlands are called *peatlands*. This is because they accumulate plant material that is not fully decomposed – *peat*. Healthy peatlands can store substantial amounts of carbon. This also means that the energy content of peat is quite high, and extraction of peat for energy generation has taken place both in Sweden and elsewhere for many decades. When extracting peat, the water table must first be lowered by ditching. As the peat dries and comes in contact with oxygen, it starts to decompose faster which releases carbon dioxide, contributing to global warming. This leakage is one of the reasons to restore peatlands. Other reasons include favoring wetland species and counteracting overgrowth by trees and shrubs.

Does it work?

Restoration of peatlands often include raising the water table to ground level by filling in ditches and building dams. When that is not possible, like in the Store Mosse National Park in Jönköping, an alternative could be to lower the ground level to water level by excavation. This specific site is one of two that I've followed up upon in my project. By looking at the percentage of the ground covered by *Sphagnum*, the thickness of the moss layer and the composition of different *Sphagnum* species, I was interested in evaluating the success of the *Sphagnum* re-establishment. Knowing that wetness is a highly important factor affecting this, I wanted to compare areas with different degrees of wetness. I found that the wetter sites generally had thicker and more extensive moss carpets. But, and here's the catch: the wettest sites were dominated by a floating, fast-growing *Sphagnum* species. This species has a high decomposition rate and will not contribute as much to the peat formation as some of its' relatives.

What does it mean?

Almost 10 years after the restoration, the portion of the ground in Store Mosse covered by *Sphagnum* was, on average, 17%. In terms of peat formation, it seems as if we'll have to wait. Some areas however, had a more extensive cover of peat-forming species, indicating that the conditions were better in these areas than in others. Since the main purpose of the restoration was to favor the open wetland habitats and the birds that depend on them, slow re-establishment may not be a problem. It could, however, indicate that parts of the restored areas are still too dry, or that the water table is not stable enough throughout the year. If this is the case, there is also a risk that higher vegetation will establish again, creating a need for further restoration measures.

Appendix B. Study site pictures

Figure B1. Picture from Store Mosse showing the difference between the uppermost peat layer (dark) and that beneath (light).

Figure B2. Picture from Store Mosse showing bare peat with potential signs of frost heaving.

Appendix C. Species lists

Specimens that could not be identified to species level have only been assigned to their respective sub-genus. Note that there has been no expert confirmation of the identifications.

Table C1. *Sphagnum* species identified at Anderstorp Stormosse. C is short for coverage and refers to the Braun-Blanquet scale.

Plot	Sphagnum species 1	C	Sphagnum species 2	C	Sphagnum species 3	C	Sphagnum species 4	C
A31	*Sphagnum cuspidatum*	5						
A32	*Sphagnum cuspidatum*	5						
A33	*Sphagnum cuspidatum*	5						
A34								
A35								
A36								
A37	*Sphagnum cuspidatum*	1	*Sphagnum papillosum*	1				
A38	*Sphagnum cuspidatum*	5						
A39	*Sphagnum palustre*	0						
A40	*Sphagnum papillosum*	5						
A41	*Sphagnum palustre*	0						
A42	Unidentified (sect. *Acutifolia*)	0	*Sphagnum fimbriatum*	1	*Sphagnum divinum*	1	*Sphagnum cuspidatum*	1
A43	*Sphagnum papillosum*	2	*Sphagnum divinum*	2				
A44								
A45	*Sphagnum papillosum*	3						
A46	*Sphagnum papillosum*	1						
A47								
A48								
A49	Unidentified (sect. *Cuspidata*)	2						
A50	*Sphagnum medium*	1	*Sphagnum divinum*	1	*Sphagnum palustre*	3		
A51								
A52								
A53	*Sphagnum papillosum*	1						
A54								
A55								
A56	*Sphagnum cuspidatum*	1						
A57								
A58								
A59								
A60								
A61								
A68	*Sphagnum cuspidatum*	5						
A69	*Sphagnum cuspidatum*	4						
A70	*Sphagnum cuspidatum*	5						
A71	*Sphagnum cuspidatum*	5						
A72	*Sphagnum cuspidatum*	2						
A73	*Sphagnum cuspidatum*	4						
A74	*Sphagnum cuspidatum*	5						
A75								
Ex1	*Sphagnum palustre*	2	*Sphagnum cuspidatum*	1				
Ex2	*Sphagnum cuspidatum*	3						
Ex3	*Sphagnum papillosum*	1						
Ex4								
Ex5								
Ex6	*Sphagnum fallax*	2	*Sphagnum papillosum*	2				
Ex7	*Sphagnum fallax*	4						
Ex8								
Ex9	*Sphagnum cuspidatum*	5						
Ex10	*Sphagnum cuspidatum*	2						

Table C2. *Sphagnum* species identified at Store Mosse. C is short for coverage and refers to the Braun-Blanquet scale.

Plot	Sphagnum species 1	C	Sphagnum species 2	C	Sphagnum species 3	C	Sphagnum species 4	C
S1								
S2								
S3	*Sphagnum fallax*	1						
S4	*Sphagnum cuspidatum*	2						
S5								
S6	Unidentified (sect. *Cuspidata*)	0	*Sphagnum cuspidatum*	0				
S7								
S8								
S9	*Sphagnum fimbriatum*	1	Unidentified (sect. *Cuspidata*)	0	*Sphagnum rubellum*	0	Unidentified (sect. *Sphagnum*)	0
S10	Unidentified (sect. *Cuspidata*)	0						
S11	*Sphagnum fallax*	1						
S12	*Sphagnum cuspidatum*	4						
S13	*Sphagnum papillosum*	2						
S14								
S15								
S16								
S17	Unidentified (sect. *Cuspidata*)	2						
S18	Unidentified (sect. *Sphagnum*)	4						
S19	*Sphagnum cuspidatum*	1						
S20	*Sphagnum fallax*	4						
S21	*Sphagnum cuspidatum*	3	Unidentified (sect. *Cuspidata*)	1				
S22	*Sphagnum cuspidatum*	5	Potentially another (sect. *Cuspidata*)	2				
S23	*Sphagnum fallax*	2	*Sphagnum fallax*	2	*Sphagnum fimbriatum*	3		
S24	Unidentified (sect. *Cuspidata*)	2						
S25	*Sphagnum cuspidatum*	4						
S26	*Sphagnum cuspidatum*	2						
S27								
S28								
S29	*Sphagnum papillosum*	1						
S30	*Sphagnum fallax*	1						
S31	Unidentified (sect. *Cuspidata*)	0						
S32	*Sphagnum cuspidatum*	2						
S33	*Sphagnum cuspidatum*	3	*Sphagnum rubellum*	2				
S34	*Sphagnum cuspidatum*	1						
S35	*Sphagnum cuspidatum*	0						
S36	Unidentified (sect. *Cuspidata*)	2	Unidentified (sect. *Sphagnum*)	0				
S37	*Sphagnum cuspidatum*	2	*Sphagnum medium*	3				
S38								
S39								
S40	*Sphagnum cuspidatum*	0						
S41	*Sphagnum cuspidatum*	3	*Sphagnum rubellum*	2				
S42								
S43	*Sphagnum cuspidatum*	4						
S44	*Sphagnum papillosum*	2	*Sphagnum rubellum*	0	*Sphagnum cuspidatum*	0		
S45								
S46	*Sphagnum cuspidatum*	3	*Sphagnum medium*	2	*Sphagnum medium*	2	*Sphagnum rubellum*	0
S47	*Sphagnum cuspidatum*	5	Unidentified (sect. *Sphagnum*)					
S48	*Sphagnum fallax*	0						
S49	*Sphagnum cuspidatum*	5						
S50	*Sphagnum papillosum*	1	*Sphagnum fimbriatum*	0				
S51								
S52								
S53	*Sphagnum cuspidatum*	1	*Sphagnum rubellum*	2				
S54	*Sphagnum cuspidatum*	5						
S55								
S56	Unidentified (sect. *Cuspidata*)	0						
S57								
S58								
S59								
S60								
S61								
S62								
S63								
S64								
S65								

(continued on the following page)

(Table C2, continued from previous page)

S66								
S67								
S68	*Sphagnum cuspidatum*	3	*Sphagnum cuspidatum*	1				
S69	*Sphagnum cuspidatum*	2						
S70								
S71								
S72	Unidentified (sect. *Cuspidata*)	1						
S73								
S74	*Sphagnum cuspidatum*	2						
S75								

Table C3. *Sphagnum* species identified by the additional transect survey at Store Mosse. C is short for coverage and refers to the Braun-Blanquet scale.

Plot	Sphagnum species 1	C	Sphagnum species 2	C	Sphagnum species 3	C	Sphagnum species 4	C
T1	Unidentified (sect. *Cuspidata*)	4	*Sphagnum medium*	1	Unidentified	0		
T2	*Sphagnum cuspidatum*	1						
T3	*Sphagnum fallax*	4	*Sphagnum medium*	2				
T4	*Sphagnum fallax* and *S. cuspidatum*	5						
T5	*Sphagnum fallax*	4						
T6	*Sphagnum capillifolium*	2	*Sphagnum fallax*	2	*Sphagnum cuspidatum*	0		
T7	*Sphagnum fallax*	3	*Sphagnum cuspidatum*	1	*Sphagnum rubellum*	2	*Sphagnum medium*	0
T8	*Sphagnum fallax*	3						
T9	*Sphagnum fallax*	4	*Sphagnum capillifolium*	1	*Sphagnum fallax*	2		
T10	*Sphagnum fallax*	5	*Sphagnum fallax*	1				
T11	*Sphagnum fallax*	2	*Sphagnum medium*	1				
T12	*Sphagnum fallax*	2	*Sphagnum medium*	1	*Sphagnum fallax*	0		
T13	*Sphagnum fallax*	4	*Sphagnum papillosum*	2	*Sphagnum papillosum*	0	*Sphagnum fallax*	1
T14	*Sphagnum fallax*	2	Unidentified (sect. *Cuspidata*)	1				
T15	Unidentified (sect. *Sphagnum*)	3	Unidentified (sect. *Cuspidata*)	2				