Flower imprints from the history of mires and humans

A palynological study of rich fen development and periods of human land use over the last 8000 years in boreal Norway

Kristine Fjordheim

Thesis for the degree of Philosophiae Doctor (PhD)
University of Bergen, Norway
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Scientific environment

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Abstract

Cultural vegetation of boreal hay mires has been reconstructed back to the Roman Iron Age for the first time. The mowing continued to the mid-1900s in these Norwegian outfields, representing a part of 8000 years of sloping mire history. Low-intensity mowing has shaped the semi-natural form of cultural vegetation across these mires, the rich fens, characterized by a similar species composition but altered dominance of single species compared to the natural vegetation.

Previously unknown before the mid-1600s, fen mowing with scythes has been reconstructed through an interdisciplinary study. The investigation explores the development and vegetation history of two fen areas by examining pollen and spores from peat sequences. This analysis incorporates local plant-pollen relationships and comparisons with various vegetation types and land-use practices from today, employing diverse statistical techniques. The results were contextualized with archaeological, historical, and climatic data to provide a comprehensive understanding of the fens' development.

Central to the study is the investigation of plant-pollen relationships in fen vegetation to improve the interpretation of fossil pollen samples and vegetation history reconstructions. By examining mown and unmown fens in middle and northern boreal Norway, the study identifies *Thalictrum alpinum* (alpine meadow-rue) pollen as a very good indicator of local plant presence, increasing with mowing. Cyperaceae, *Eriophorum*-type, and *Pedicularis*-type (sedges, cottongrasses, and lousewort) pollen are identified as good pollen indicators of plant presence, which also increase with mowing. Poaceae species, *Molinia caerulea*, and *Succisa pratensis* (grasses, purple moor-grass, and devil's-bit scabious) are also good pollen indicators but are found to decrease with mowing. Rosaceae, *Potentilla*-type, and *Selaginella selaginoides* (the rose family, cinquefoil-type, and lesser clubmoss) are potential indicators depending on the vegetation's total species composition. This differentiation in pollen data between mowed and unmowed fens allows for more accurate reconstruction of past vegetation and investigation of mowing activity through pollen deposits.

The fen vegetation in Tågdalen, part of the farms at Dalsegg in Surnadal, dates back to 2350 BC at the investigated site, representing a part of a gradual expansion of rich fen into a continuous sloping fen by AD 980. The initiation of scything (the use of scythe to cut the hay) around AD 40 is interpreted by the vegetation composition, with increased cover of species like *Thalictrum alpinum* and *Eriophorum latifolium* (broad-leaved cottongrass), and a reduction in species like *Molinia caerulea*, in a ratio that suggests less frequent mowing than every other year. This is the earliest recorded instance of outfield scything in boreal Norway, taking place in an established farming community. Intensive mowing, mirroring historically documented scything every two years, began around AD 1135, evidenced by pollen data matching contemporary mowed areas. The mowing intensification around 1850 aligns with peak outfield exploitation in Norway, with a decline starting around 1920. The reduction in mowing intensity by 1940 is evident in the pollen records, with significant changes around 1950 marking the end of this outfield scything.

In Sølendet, part of the Brekken farms in Røros, the first identified rich fen formation began around 6585 BC, marking an early expansion phase in a sloped area, with fen coverage increasing until about 600 BC. Evidence of wild animal grazing from around 2690 BC is present until the start of scything, and probably to a limited extent further onwards. The scything started around AD 1030 as extensive mowing indicated by an increase in *Eriophorum* species. Hay collection intensified around 1415, likely by distant farmers, during a period of abandoned local farms. Scything continued as local farms were resettled from the 1650s, with traditional scything every two years evident from c. 1820 until the end of scything around 1950, mirroring the national agricultural development. The shorter history of outfield scything in Sølendet compared to Tågdalen is attributed to lower resource pressure from fewer farms prior to the scything at the end of the Viking Age in this higher-lying district.

Through the detailed analysis and integration of various data sources, the study underscores the significance of diverse statistical methods, knowledge of local pollen-plant relationships, and the critical role of precise pollen identification in reconstructing vegetation history. The ability to often, if not always, identify pollen to the genus level, as from Cyperaceae to the genera of *Carex* (true sedges) or *Eriophorum* (cottongrasses), has been crucial for improving reconstruction accuracy.

The study has revealed that humans have adapted adaptive land use strategies in response to varying pressures on resources across regions and time periods, under diverse socio-economic and climatic conditions. Over the last two millennia, human activities have shaped the boreal vegetation history in inhabited areas, with natural factors taking a secondary role. The findings underscore the importance of integrating ecological, archaeological, and historical data to understand past landscapes and regional histories, contributing to historical ecology. This study lays a foundation for informed conservation and land-use strategies in boreal ecosystems.

Samandrag

Kulturvegetasjon på boreale slåttemyrer har for første gong vorte rekonstruert tilbake til den romerske jernalderen. Slåtten på myrene heldt fram til midten av 1900-talet i norske utmarker, og representerer ein del av den 8000 år lange historia for bakkemyrer. Lågintensiv slått har forma ei semi-naturleg form for kulturvegetasjon på desse rikmyrene, kjenneteikna av tilsvarande artssamansetnad, men endra dominans mellom enkeltartar samanlikna med den naturlege vegetasjonen.

Historia til ljåslått på myrer var ukjent frå tida før midten av 1600-talet og har no vorte avdekt gjennom ein tverrfagleg studie. Undersøkinga studerer myrutviklinga og vegetasjonshistoria til to myrområde ved gransking av pollen og sporar frå torvsekvensar. Denne analysen inkluderer lokale plante-pollen-forhold og samanlikning med ulike vegetasjonstypar og landbrukspraksisar i dag, og nyttar seg av ulike statistiske teknikkar. Resultata er deretter tolka i samanheng med arkeologiske, historiske og klimatiske data for å gje ei omfattande forståing av myrene si utvikling.

Sentralt i studien er undersøking av plante-pollen-forholdet i myrvegetasjon for å forbetra tolking av fossile pollenprøvar og rekonstruksjonar av vegetasjonshistoria. Ved å undersøka slåttemyrer og uslåtte myrområde i mellom- og nordboreale Noreg, identifiserer undersøkingane pollen frå *Thalictrum alpinum* (fjellfrøstjerne) som ein svært god indikator på lokal førekomst av planten, som aukar med slått. Pollen frå Cyperaceae, *Eriophorum*-type og *Pedicularis*-type (storr, myrull og myrklegg) er identifisert som gode indikatorar på førekomst av desse plantane, som òg aukar ved slåtteaktivitet. Poaceae, *Molinia caerulea* og *Succisa pratensis* (gras, blåtopp og blåknapp) er gode pollenindikatorar, men vert redusert ved slått. Rosaceae, *Potentilla*-type og *Selaginella selaginoides* (rosefamilien, mure og dvergjamne) er potensielle indikatorar avhengig av den totale artssamansetnaden i vegetasjonen. Denne differensieringa i pollendata mellom slåttemyrer og uslåtte myrer mogleggjer meir presise rekonstruksjonar av fortida sin vegetasjon og undersøking av slåtteaktivitet ut frå historiske pollenavsetnader.

Myrvegetasjonen i Tågdalen, ein del av gardane på Dalsegg i Surnadal, kan sporast tilbake til 2350 f.Kr. ved den undersøkte staden, og representerer ein del av ei gradvis utviding av rikmyr i eit hellande landskap til eit samanhengande hellande myrområde rundt år 980 e.Kr. Oppstart av slått rundt år 40 e.Kr. er tolka ut frå vegetasjonssamansetnaden, med auka dekning av artar som *Thalictrum alpinum* og *Eriophorum latifolium* (breiull), og ein reduksjon i artar som *Molinia caerulea*, i eit forhold som tyder på mindre hyppig slått enn annakvart år. Dette er den tidlegast dokumenterte førekomsten av utmarksslått i boreale Noreg, noko som fann stad i eit etablert jordbrukssamfunn. Intensiv slått, som speglar den historisk dokumenterte frekvensen av slått annakvart år, starta rundt år 1135, som bevist ut frå pollendata som samsvarar med moderne slåtteområde. Intensivering av slått rundt 1850 samsvarer med den høgaste utnyttingsgrada av utmarksressursar i Noreg, og seinare ein nedgang som starta rundt 1920. Reduksjonen i slåtteintensiteten rundt 1940 er tydeleg i pollendata, med klåre endringar rundt 1950 som markerer slutten på denne utmarksslåtten.

Ved Sølendet, ein del av gardane i Brekken i Røros, starta den første identifiserte rikmyrsdanninga rundt 6585 f.Kr., og markerte ein tidleg utvidingsfase av myr i eit slakt hellande område, med myrdekning som auka til omtrent 600 f.Kr. Spor etter beite frå ville dyr frå rundt 2690 f.Kr. heldt fram

til oppstarten av slåttetradisjonen og sannsynlegvis i avgrensa grad framover i tid. Slåtten starta rundt år 1030 e.Kr., med ekstensiv slått, indikert av ein auke i *Eriophorum*-artar. Høysankinga vart intensivert rundt 1415, sannsynlegvis av bønder som heldt til eit stykke unna, i ein periode med fråflytta lokale gardar. Slåtten heldt fram etter at busetnaden på lokale gardar vart tatt opp igjen frå 1650-talet, med tradisjonell slått annakvart år frå rundt 1820 til det vart slutt på myrslåtten rundt 1950, ei utvikling som speglar den nasjonale jordbruksutviklinga. Den relativt seine starten på utmarksslått ved Sølendet samanlikna med Tågdalen vert tilskrive lågare ressurspress frå færre gardar fram til slutten av vikingtida i dette høgareliggande distriktet.

Gjennom si detaljerte analyse og integrering av ulike datakjelder understrekar denne studien verdien av ulike statistiske metodar, kunnskap om lokale plante-pollen-forhold, og den avgjerande rolla til presis pollenidentifikasjon i rekonstruksjon av vegetasjonshistoria. Evna til ofte, om ikkje alltid, å identifisera pollen til slektsnivå, som frå Cyperaceae til slekter som *Carex* (storr) eller *Eriophorum* (myrull), har vore avgjerande for å forbetra presisjonen i rekonstruksjonane.

Studien har vist at menneska har nytta tilpassa landbruksstrategiar som respons på varierande ressurspress i regionar og tidsperiodar, under ulike sosioøkonomiske og klimatiske forhold. Over dei siste to tusenåra har menneskelege aktivitetar forma den boreale vegetasjonshistoria i dei busette områda, der naturlege faktorar spelar ei sekundær rolle. Funna understrekar kor viktig det er å integrera økologiske, arkeologiske og historiske data for å forstå tidlegare landskap og regionale historier, og bidrar vidare til feltet historisk økologi. Denne studien legg eit grunnlag for kunnskapsbasert bevaring og landbruksstrategiar i boreale økosystem.

List of publications

This PhD thesis is based on the following individual papers:

I Fjordheim K., Moen A, Hjelle K. L., Bjune A. E. & Birks H. H. (2018). Modern pollen–vegetation relationships in traditionally mown and unmanaged boreal rich-fen communities in central Norway. *Review of Palaeobotany and Palynology* 251, 14–27.

II Fjordheim, K. Hjelle, K. L., Bjune, A. E. & Moen, A. Long-term rich fen development, vegetation history, and agricultural land-use in boreal outfields in Nordmøre, Norway. To be submitted to *Vegetation History and Archaeobotany*.

III Fjordheim, K. & Hjelle, K. L. Holocene rich fen evolution, wildlife grazing, and historical land use: From natural vegetation and Viking Age mowing to contemporary management in Central Norway. *Manuscript.*

The papers are referred to by their roman numerals in the text.

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Author contributions

Contributions to the papers in this PhD dissertation are classified based on the CRediT (Contributor Roles Taxonomy). Authors are listed alphabetically in the table. Initials used in the list:
KF – Kristine Fjordheim [1, 2], KLH – Kari Loe Hjelle [3], AM – Asbjørn Moen [4], AEB – Anne Elisabeth Bjune [5], HHB – Hilary H. Birks [5], HJBH – H. John B. Birks [5, 6]

Task	Paper I	Paper II	Paper III
Conseptualisation	AM, **KF**, KLH	AM, **KF**, KLH	AM, **KF**, KLH
Data curation	**KF**	**KF**, KLH	**KF**, KLH
Formal analyses	**KF**	**KF**	**KF**
Investigation	**KF**	**KF**	**KF**
Methodology	AM, HJBH, **KF**, KLH	**KF**, KLH	**KF**, KLH
Software	**KF**	**KF**	**KF**
Validation	**KF**	**KF**	**KF**
Visualisation	**KF**	**KF**	**KF**
Writing – original draft	**KF**	**KF**	**KF**
Writing – review & editing	AB, AM, HHB, **KF**, KLH	AB, AM, **KF**, KLH	**KF**, KLH
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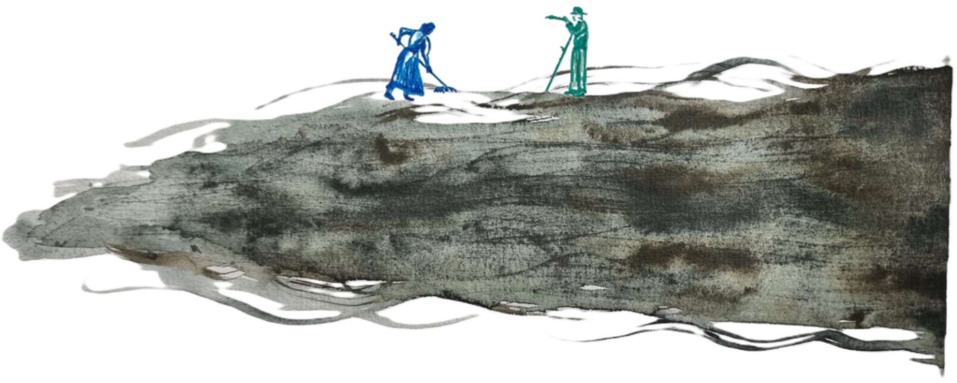
Flower imprints from the history of mires and humans: A palynological study of rich fen development and periods of human land use over the last 8000 years in boreal Norway

Blomsteravtrykk frå myrene og menneska si historie: Eit palynologisk studium av rikmyrsutvikling og periodar med menneskeleg arealbruk dei siste 8000 år i boreale Noreg

Contents



1. Introduction

vi ska møtast e sommå tæja,
når haustkvellsdåjja e skåra skin

The lines from the poem "E slåttatæja" ("In the scything field") by Hans Hyldbakk (2010) can be summarized as follows: we shall meet in the same hayfield, when autumn evening's dewdrops in the stubble shine. Hyldbakk frequently drew inspiration from his native Surnadal, and, as in this poem, the scything field and haymaking – where only the herb stubbles remain after the hay has been scythed – are the starting points for this study.

In a time of global reduction of areas with a diversity of vegetation types, understanding the dynamics of the vegetation and ecosystems related to traditional and sustainable land use has become increasingly important. Traditional land use has formed a variety of cultural vegetation types, where the semi-natural vegetation represents one category characterised by quantitative changes compared to its natural vegetation following sustainable extensive land use. Here, the vegetation maintains the species composition found in its natural counterpart, but the relative presence of species changes, and natural processes, like succession, will occur when land use ends. Semi-natural boreal hayfields support a high level of biodiversity under the limited disturbance of mowing, and retain their natural characteristics and processes (Moen, 1990, 2000). Today, the semi-natural hayfields in boreal areas face a critical situation; they are diminishing and are at risk of becoming rare or disappearing entirely, following the cessation of traditional management and the transition to modern agriculture from around 1950 (Emanuelsson, 2009). In Norway, semi-natural hayfields are assessed as 'critically endangered' vegetation types according to the Red List for ecosystem and habitat types, due to the reduction in area following the end of traditional mowing (Hovstad et al., 2018).

In the boreal vegetation region semi-natural hayfields on rich fens, which are minerotrophic mires, have historically been an important resource for winter fodder prior to the modern agriculture in Europe, with a transition around 1950. Through traditional agricultural activities, this landscape has been influenced and altered in a sustainable way. Today traditional fen hayfields are mainly either left for succession to take place, drained, and altered into landscapes such as modern agricultural meadows or forests, or even removed and replaced with various infrastructure, leaving the landscapes less diverse in terms of species and ecological functions. The reduction in functional biosphere integrity, the ability of the biosphere to maintain its key ecological processes and life-support systems effectively (Richardson et al., 2023), sets focus on not just preserving a large variety of vegetation types, but also understanding the role and functions of vegetations like the scythed mires. Further, mires accumulate large amounts of carbon and methane and represent a vital storage and sink of greenhouse gasses in the present situation of human induced climate warming (Fortuniak, 2021; Sirin, 2022), making their preservation as mires vital for future sustainable development (Richardson et al., 2023).

It is increasingly important to collect present-day vegetation data from areas where traditional land use still occurs, before succession alters the vegetation and the characteristics of the semi-natural vegetation disappear. Further, this knowledge is essential to be able to reconstruct landscape history. This thesis seeks to bridge gaps in our knowledge about mire initiation and development, vegetation dynamics, and vegetation history, particularly focusing on the land use history of mire hayfields in outfields and their development in boreal areas. The history of traditional outfield scything has largely been unknown prior to c. 1650 (Reinton, 1957; Lunden, 2002). By reconstructing the vegetation histories, the research aims to provide insights into long-term ecological changes, human-environment interactions, and the evolving management practices in mire ecosystems.

This study will investigate data from the present-day plant cover and its pollen deposition in mown vegetation to understand the plant-pollen relationship of scythed mires. This data will be compared with pollen in older peat samples to reconstruct land use from previous periods and combine palaeoecological and statistical methods. The results will be contextualized with natural conditions, archaeological discoveries, and historical records to deepen our understanding of the historic and contemporary natural and cultural landscapes. Given this specific discipline and subject area, it is pertinent to extend the analysis beyond the field of botany of individual species and community composition in these outfields. Consequently, the emphasis is not exclusively on the dynamics within the plant community, but also encompasses the cultural factors of need for resources and land use, influencing species composition over time, with changes in whether the plants are left undisturbed, harvested, or grazed.

Two traditionally scythed rich boreal fen areas are investigated in this study, located in Tågdalen Nature Reserve in Surnadal, Nordmøre, and the Sølendet Nature Reserve in Røros, Trøndelag. These fens with a rich plant composition have historically been utilized for hay collection (Øien, 2023), and the vegetation has been shaped by long periods of mowing by the scythe. After the end of scything around 1950, a slow succession started on these fens. Beginning in the mid-1970s the areas in the two nature reserves have been maintained as semi-natural landscapes as management mowing commenced in the nature reserves to preserve the semi-natural vegetation (Moen, 1990, 2000; Moen et al., 2015). Currently, these managed fens exhibit remnants of traditional scything practices, including hay barns, stack poles left from haystacks, and tools such as grindstones.

This research offers new insights into the rich fen development and human activities in the rich fens, including outfield scything as part of agricultural organization and local settlement history, as well as the impact of grazing by wild and domesticated animals.

1.1 Cultural landscapes

A diversity of past human activities has shaped a variety of plant vegetation compositions and structures on a global scale. Cultural vegetation types form assemblages that range from semi-natural to fully cultural landscapes (Behre, 1988; Ellenberg, 1988; Emanuelsson, 2009; Krzywinski et al., 2009). In this study cultural vegetation represents the vegetation component of cultural landscapes. The remains of traditional farming landscapes, originating before c. 1950, are known internationally as socioecological production landscapes or more commonly, cultural landscapes, as the mown fens in Figure 1. From the 1890s, the term was largely used by geographers; however, since the 1960s,

Figure 1. The flowering plants of *Eriophorum latifolium* (broad-leaved cottongrass, breiull) are widespread among the herbs in the rich fen landscape in Sølendet.

'cultural landscapes' have been included in several fields, including botany, archaeology, history, and agriculture (Jones, 1988; Daugstad & Jones, 1998).

Cultural landscapes represent the combined effect of nature and influence of humans, based on the local ecosystem and with their specific land use as part of human history (Behre, 1988; Birks et al., 1988; Berglund, 1991). However, the concept of cultural landscape has different meanings in different settings (Daugstad & Jones, 1998; Jones, 2003), but is often limited to agricultural activity, covering both cultivation and animal husbandry (Framstad et al., 2006). It has been argued that the term is of limited use since all landscapes in areas and regions including Norway have been influenced by humans, and that no opposite exists (Widgren, 1997). However, the broad understanding of the concept has still not been considered problematic in research or landscape management (Norderhaug, 1999). In the following discussion, this term will be broadened to include historical cultural landscapes. These are landscapes that have been shaped culturally, often but not necessarily through economic practices, prior to 1950.

Cultural landscapes may be presently used by ongoing activities as part of contemporary agriculture or other practices or represent historical landscapes where such activities are no longer prevalent in current socioeconomic contexts. Instead, they can be preserved as part of management strategies and museum landscapes (Moen & Olsen, 1997; Moen et al., 2012, Eiter et al., 2019), or they may be abandoned, becoming remnants of the cultural landscape as plant succession occurs (Olsson et al., 2000). Changes in land use have for a long time been a critical consideration in the preservation of such landscapes (Moen, 1990, 2000; Nilsson, 2016). The continuation of these activities is essential for maintaining cultural landscapes for future references, research, and teaching (Øien, 2023), as well as preserving the diversity of species in the landscapes (Hovstad et al., 2018).

Every landscape we encounter represents the past that has been decisive in forming it (Antrop, 2005) and the present as the place where we experience it (Mayall, 1935; Melnick, 2016). Many often perceive cultural landscapes not primarily for their physical elements but through the feelings and experiences encapsulated in the concept of 'a sense of place' (Agnew, 1987; Agnew & Duncan, 1989), and are important for people's sense of belonging and identity. In addition to representing the history and activities of present or former economies, cultural landscapes also serve as areas for outdoor activities and recreation (Jones, 2008). The varied role of, approach to, and view of cultural landscapes are depicted through, e.g. travel literature (Schøning, 1910; Swensen & Daugstad, 2012; Ringer, 2013), visual arts and literature (Langnes, 2012; Hauge, 2020) as well as in the mentioned poem of Hyldbakk (2010) (Appendix C). In such presentations, some cultural landscapes are regarded as more or less valuable to us from different point of views (Jones, 2008). Traditional cultural landscapes such as the species-rich and flowering meadows and pastures that have been economically important, have generally been viewed positively, while barren heaths and poor bogs have to a lesser extent yielded returns and have represented a poorer landscape both in terms of production and esteem. Further, cultural landscapes where the physical traces are clear has gained more focus than landscapes where the cultural knowledge and tradition of the resources is less clearly seen from the landscape itself (Jones, 2008). From all these perspectives, cultural landscapes are regarded as valuable, not only for their natural attributes and cultural values, but also for the perceptions we hold of them (Meining, 1979; Antrop, 2005). When traditional land use comes to an end, both the physical landscapes and experiences and memories associated with them will be lost.

The present study examines one subcategory of cultural landscapes: semi-natural landscapes, and particularly the vegetation found within rich fen hayfields. Within this cultural landscape, the 'cultural vegetation' component, including the 'semi-natural vegetation' component, specifically refers to the plant life that has been influenced or managed by human activity, reflecting the cultural, socio-economic, and aesthetic values of societies over time. The semi-natural vegetation as found in the outfield rich fens in Tågdalen and Sølendet, is characterized by quantitative differences compared to the natural mire vegetation (Moen, 1990, p. 270). Semi-natural hayfield vegetation includes areas with grasses (Poaceae) and sedges (Cyperaceae), where the vegetation and soil have not been altered by the introduction of new species or fertilizers, as noted by Hovstad et al. (2018). In the outfields, traditional land-use practices and low-intensity activities have shaped the landscapes and their vegetation into semi-natural forms, forming an essential part of the landscape in Northern and Central Europe (Behre, 1988). Mowing was primarily carried out with scythes, among other tools, as exemplified in Figure 2. The relatively extensive agricultural management practices from traditional hayfield harvest, with varying intensity, shape and maintain this semi-natural vegetation. Here, the relative abundance among species varies from the natural vegetation, and specialized low-competitive and stress tolerant fen species, along with those less reduced by human activities, like mowing, thrive under the activity and with reduced interspecific competition from fast-growing or large species during the historical land use (Moen, 1990, 2000). In the semi-natural vegetation, a comparable vegetation assemblage as in a natural vegetation exists, largely with limited introduction or removal of species, and rather with the increase in some species and reduction of others. Mowing, as well as grazing, leads to changes in resources within the plant communities, disturbances, and changes in competition (Crawley, 1997; Grime, 2001). Semi-natural landscapes are among the most species-rich plant community types in Northern Europe (Kull & Zobel, 1991; Ellenberg, 1996; Moen et al., 1999, Myklestad & Sætersdal, 2004). Semi-natural vegetation host species with high conservation value (Bedford & Godwin, 2003), and they provide a habitat for rare and endangered species (Svalheim & Asdal, 2011; Sletvold et al., 2013), like *Nigritella nigra* and *Pseudorchis albida* (Moen, 1990; Moen & Øien, 2002). 22 percent of the threatened and near-threatened species in Norway belong to the agricultural cultural landscape (Solstad & Elven, 2021), and are dependent on the various vegetation types within this landscape in the present and future.

Fens and wooded grasslands have represented the major mown outfields in the boreal areas of Norway (Reinton, 1957; Moen, 1990; Moen et al., 2012). Scythed fens are areas with moisture-demanding vegetation that forms or has been forming peat and is characterized by a long-lasting tradition of scything. The harvesting on the fens has shaped large areas into open landscapes. Outfield mires influenced from human activity as scything and grazing constitute a semi-natural vegetation that will change back to natural mire vegetation when scything ends. Present day management mowing in nature reserves preserves a landscape where the vegetation testifies to the old tradition of outfield hay collecting.

Figure 2. Drawing from Spind in Vest-Agder, Norway. While the harvest was mainly carried out with scythes, the last straws could be harvested with a sickle. During the 1800s, the focus on the amount of hay, the desire to utilize all resources, and a focus on making use of all the blessings God bestowed were important. Drawing by Lindequist (1856).

1.2 The infield and outfield system from the Iron Age farming

In Norway, the natural conditions and human adaptations have led to a long history of division in the farm's landscape, between intensively used infields and, to varying degrees, more extensively used outfields.

The terms outfield and infield are used in an agrarian setting (Myhre, 2002) and contrast with the use of resources in hunter-gatherer societies (Bergstøl, 2005). The division between the infield and outfield has been dated to the Iron Age, at its earliest from 500 BC, and its content and history have been discussed (e.g., Myhre, 2002, pp. 138–139, 143–145; Øye, 2002, pp. 294–296). The early outfields have been reconstructed from traces of fences around the arable infields, marking the boundary to the outfield, where the outfields further away from the farms have been common land for periods (Øye, 2002, p. 230).

From the Late Bronze Age and increasingly in the Roman Iron Age, Norwegian farms, particularly in Southern Norway extending along coastal districts towards Finnmark, became reliant on resources from a large area (Myhre, 2002) This expansion of agricultural land and the establishment of infields and outfields divisions has been dated to the Pre-Roman Iron Age in Nordmøre and Trøndelag (Binns, 1993). In summer, farm animals grazed in the outfields, while in winter, they were sheltered in barns and stables. The winter fodder supply from outfields constrained the number of livestock a farm could sustain, which in turn was crucial for manure availability and infield productivity (Tretvik & Krogstad, 1999). Prior to the intensification of farming using chemical fertilizers, the outfields were vital for ensuring sufficient production of winter fodder. The outfields were thus referred to as 'the mother of the arable fields' (Alsvik, 1989, p. 35). These resources not only supported domestic animals but as the animals provided manure for infields, they contributed to the sustenance of farm inhabitants (Kjelland, 1982, 1996). Even in regions where hunting or fishing supplemented farming, outfield hay remained essential for the farm economy. The tradition of extensive outfield activities, including hay scything, continued as a part of the farm economy from its inception until the end of the traditional farming era, ceasing around 1950 for most farming areas due to significant shifts in agricultural practices and societal changes (Kjelland, 1982; Almås, 2002).

The infields on a farm from the Iron Age to Historic Time were limited in area and the farms were dependent on what the infields and the outfields could yield, where the outfield represented crucial supplementary grazing areas and winter fodder. Along the coast, the heathlands were essential for winter grazing and fodder collection (Vandvik et al., 2005; Kaland, 2014; Mehl et al., 2015; Hjelle et al., 2018), while pollarded woodlands (Austad, 1988), hayfields (Hjelle, 1999), and hay mires (Moen, 1990, 2000) were important in fjord areas and in valleys and towards the mountains. In northern boreal and mountain areas, both leaf fodder and hay have been collected from summer farms, and these areas were used for grazing in summertime by farm animals (Hjelle et al., 2012; Solem et al., 2012). These areas also supported large herds of wild, and later domesticated, reindeer, as evidenced by the evolution of modern reindeer herding practices (Braseth, 2014; Pilø et al., 2018). Furthermore, the outfields were important sources of timber, as well as sites for gathering and hunting (Fjellheim, 1999).

1.3 Traditional scything on rich fens in Surnadal and Røros

This study focuses on the history of outfield hayfields, particularly the agricultural traditions related to them as known during the first half of the 1900s. 'Scything', the traditional method of mowing in these hayfields, involved the use of a scythe from the Early Roman Period (1–400 AD) (Myhre, 2002) until around 1950 when the harvesting of hayfields ended (Almås, 2002). The term 'mowing' in this context refers to general hay collecting techniques and is used for the motorised harvesting process, a practice that has been in use since the 1970s in the experimental management of outfield rich fens in nature reserves (Moen, 1990).

Winter fodder was partly obtained from the home fields in traditional farming, and from outfields near and far from the farm, in addition to mountain meadows the practice of mountain summer farming became common. The scything tradition on sloping rich fens in the outfields is well known from the 1800s and the first half of the 1900s (Volden, 1977; Kjelland, 1982; Tretvik & Krogstad, 1999), but little has been known about the onset and development of this tradition in the study region prior to this investigation.

In the boreal region, the indoor feeding period for livestock would often extend from October to May due to the climate with cold winters, necessitating large quantities of hay (Øye, 2002). To utilise the significant resources in the outfields, considerable labour was required, which was available on the farms to increase output by collecting hay from small and large areas, near and far from the farm, and from areas with smaller or larger yields of hay. Scything and grazing in the outfields were vital parts of past farming practices, and until 100 years ago, most of the fodder on farms, as in Surnadal and Røros, came from the outfields (Moen, 1989; Tretvik & Krogstad, 1999; Øien & Moen, 2006). The outfield mires and wooded grasslands were regularly mowed with a scythe in periods of both good and lesser yields from the infield, and an equivalent area was mowed each year (Tretvik & Krogstad, 1999).

The scything at the outfields close to the farms, as for Tågdalen and Sølendet, occurred before and after the haymaking on the infields, continuing until mid-September (Moen, 1990, p. 73). As scything was carried out in late summer for large areas, flowering, seed production and dispersal of seeds were ensured prior to hay cutting. The herbage was dried on the ground and then stored in haystacks, see Figure 3, or in outfield hay barns before being transported by horse and sledge to the farms, usually in the winter (Volden, 1977; Kjelland, 1982; Tretvik & Krogstad, 1999).

Traditionally, each area of the fen was scythed every two years. Farmers knew from experience that this frequency ensured the optimal long-term yield relative to the labour input and that this practice was the most cost-effective method of harvesting (Øien & Moen, 2006; Moen et al., 2012, 2015). A reduction in yearly output to 50–60% is observed when mowing annually is compared to mowing every two years (Moen, 1998; Lyngstad, 2010). All types of minerotrophic mires were part of the mown area, but sloping and flat fens with rich (basiophilous) vegetation and high plant production were the most important among the fens.

Despite lower grass yields per unit area in outfields compared to infields, the total hay output from outfields was significant, forming an essential part of farm hay in Trøndelag (Reinton, 1957). Outfield fens and meadows, often under large common ownerships (Øye, 2002), contributed to rich harvests, especially in the upper boreal regions of inner Nordmøre and Trøndelag (Grimeland, 1925; Tretvik & Krogstad 1999; Norges officielle statistikk, 1910, 1911). Mire scything typically yielded 130–140 g/m^2 on rich fens and woodlands, with variations from 200 g/m^2 to as low as 20 g/m^2 (Moen, 1989; Tretvik & Krogstad, 1999; Øien & Moen, 2006, Lyngstad et al., 2017). In Sølendet, scything of nearly 2 km^2 area, where half of this area was scythed in one year, yielded over 100 tons of hay during peak periods in the late 1800s (Moen, 1998). In 1907, when the scything still was in an intensive phase, outfield hay production in Brekken surpassed that of home-farm meadows (Statistisk Sentralbyra 1911). During the 1930s, in the last part of traditional scything on the mires, around 174 loads of hay were collected each year from Sølendet, comparable to c. 61 tons (Moen, 1989). The reduction in outfield scything had already begun by then. In 1723, farms in the inner rural communities in the former county of Sør Trøndelag typically reported 20 loads of hay from the outfields, around 7 tons, the highest value in Norway at that time (Reinton, 1957; Moen, 1989). In 1907, Sør-Trøndelag had the largest area of scythed outfields in Norway, just over 2% of the total area in the county. Farms in this area had up to 1–2 hectares of scythed outfield per person, harvesting 8–10 tons of hay each year (Norges officielle statistikk, 1910, 1911). At this time, outfield scything was reduced compared to its peak in the mid-1800s when most rich mires in the region were used for hay collection.

The inner parts of Nordmøre had a very high amount of outfield hay collection. Farms in Surnadal commonly harvested 150 loads of hay each year. In one winter load there were 240 kg of hay, and three winter loads of hay were needed to feed one cow during the winter season (Grimeland, 1925). In the area Nordmarka, where Tågdalen is situated, in an area of 13 km^2, there were 33 hay barns, some double barns. Based on this number and average hay per barn, a maximum of 130 tons of hay could be harvested each year, and between 4 to 10 tons/km^2 as a minimum when half of the areas were scythed annually (Moen, 1989).

The way the hay was collected, and the efficiency of haymaking varied through time. During the Pre-Roman Iron Age (500 BC–AD 1) the sickle would have mainly been used to collect hay. In addition, the short scythe and the hay-rake were common prior to the Early Roman Iron Age (1–200 AD) (Myhre, 2002, p. 148), and this period witnessed their improvement (Øye, 2002, pp. 197–199).

During the Merovingian Period, AD 570–800, advancements in iron production led to improved iron tools, making the scythe more widespread. From AD 700, the long scythe is documented in Norway (Myhre, 2002; Solberg, 2003). Modern investigations suggest that the transition to the iron long-scythe meant that one could cover an area of 1200 m^2 per day, double that of a short-scythe and four times more than Bronze Age flint sickles (Steensberg & Calvert, 1943). Eight days of work could be needed to secure the winter fodder for one cow, and on large farms this work alone could demand 280 days' work (Hagen, 1953). The number of animals on a farm would decide the quantity of manure available for the infields for fertilization and the total productivity of the farm (Tretvik & Krogstad, 1999). If the soil did not receive sufficient fertilizer or other nutrients, it was necessary to leave parts of the land fallow. A reduction in cultivated areas was to be avoided and was regulated in the 1000s–1200s through provisions in the regional laws of Frostatingsloven (Hagland & Sandnes, 1994; Øye, 2002, p. 229) and the national law 'Magnus Lagabøters landslov' from 1274 (Rindal & Spørck, 2018). Hay collecting tools were further improved and new tools introduced during the Viking Age. The pitchfork and hayfork are first known from the Viking Age in the region, though this is somewhat uncertain, as the parts of wood would not be well-preserved (Øye, 2002, p. 347). The Early and High Middle Ages saw technological advancements in agriculture, with new iron production methods and a trade network enhancing iron accessibility and the intensification of outfield activities (Tveiten, 2005; Emanuelsson, 2009). This progression was integral to the intensification of

Figure 3. The hay is ready for storage in one of the many haystacks in Sølendet. From left to right are Petra Lien, Ivar Kurås, and Kasper Haugen Lien. Kasper is ready to hand over a piece of turf to be placed on top of the haystack to protect it from the rain. Photo: Unknown. RMUB.16154, courtesy of the Rørosmuseet Collection (Røros Museum).

Figure 4. Traditional outfield haymaking with the long scythe and the rake in the summer farming area of Søyådalen, Surnadal. Photo by Hans Hyldbakk (1975).

the outfield activities. The long scythe and the rake played the main roles in scything for centuries to come, as seen in Figure 4, from Søyådalen in Surnadal.

The tradition came to an end, both locally and regionally, around the mid-1900s following a period of reduced scything activity due to changes within agriculture and society in general, including modernization, increased efficiency, and new economic conditions (Hyldbakk, 1975; Volden, 1977; Kjelland, 1982). The focus on the farms shifted to the infields, with substantially larger output from these areas, leaving the outfields and fen margins to grow over as people no longer needed to collect meager matgrass (*Nardus stricta*) in old barns, as reported in a local history book (Ryen & Aaspaas, 1974). Even as Tågdalen and Sølendet represented richer vegetation than this would imply, with limited cover of *Nardus stricta* and rich vegetation of among others *Eriophorum* species, the outfield's role in providing resources to the farm diminished as purchasing artificial fertilizers became more cost-effective and infield cultivation was made more efficient. The studied localities were part of the nature reserves with managed mown areas established in the 1970s. These localities are situated in homogenous fen areas, and the studied permanent plots in the nature reserves have been scythed regularly, including every two and every four years, since 1973 in Tågdalen (Tretvik & Krogstad, 1999) and since 1974 in Sølendet (Øien & Moen, 2006). The hay crop of the studied communities has been estimated on average at about 110 g/m^2 and 140 g/m^2 in plots scythed every two and every four years, respectively (Moen et al., 2012). The highest output from rich fen is as high as 200 g/m^2 with scything every two years (Tretvik & Krogstad, 1990). Traditionally, on the rich fens studied, haymaking involved scything every two years, and with this practice, which entailed scything half of the area each year, the harvest output each year was maximized in relation to the labor invested (Moen, 1989). Traditionally, the scythe was used, but since the 1970s the managed mowing has been carried out with a motorized mowing machine.

1.4 Grazing history on rich fens – from wild to domesticated animals

The two investigated fen areas have a long history as outfields to nearby farms and are today mainly seen as a part of the agricultural history. Grazing has also been an important factor influencing such vegetation types and has taken place in Tågdalen and Sølendet both before and during the periods of outfield scything. Such high-quality grass- and sedge-dominated fens have first been grazed by wild animals, like reindeer (*Rangifer tarandus*), moose (*Alces alces*) and red deer (*Cervus elaphus*).

Hunter-gather communities were for a long time dependent of the resources in the boreal areas and the mountains, and their history is linked to that of these animals. The many trapping pits in combination with traces of dwellings and place names points towards a long history of large herds of wild reindeer and hunter settlements in the Røros area (Fjellheim, 1999). The relics from such activity are rare in the Surnadal area and are so far not found near Tågdalen. This suggests regional differences in historical practices. This regional hunter-gatherer society present in northern boreal areas in Mid Scandinavia developed into one Sámi hunter-gatherer society alongside a hunting-agrarian society, consolidated from the Bronze Age and during the Pre-Roman Iron Age (Binns et al., 1999; Zachrisson, 2004; Amundsen, 2011; Hansen & Olsen, 2022, pp. 56–60), and was well established in the region in the Roman Iron Age (Fjellheim, 1999) or sometime later (Bergstøl, 2008). Both societies continued to be dependent on the hunting of these large mammals (Zachrisson, 2004; Fjellheim, 1999, 2012). An extensive grazing pressure left only limited traces in the vegetation at Surnadal and Røros during the Iron Age.

The onset of reindeer domestication involved keeping a few domesticated reindeer in a predominantly hunting-based economy in the Røros area. The initiation of this process has been debated among researchers, with different opinions based on various areas (Aronsson 1991; Ljungdahl, 2007; Bjørnstad et al., 2012). An economy with small herds of domesticated reindeer is reconstructed in the Røros area from AD 500–600 (Narmo, 2000; Ljungdahl, 2007) and was widespread long before the intensive semi-nomadic pastoralism became common in the region from around the mid-1500s and during the 1600s (Zachrisson, 1984; Mulk, 1987, 1994; Aronsson, 1991). The presence of these animals led to sustained grazing activity in these areas, and a potential for lightly grazed fen vegetation in Sølendet, as domesticated reindeer passed these areas on their migration routes (Fjellheim, 2012). In the Røros area, domesticated reindeer have played a role along with wild animals in shaping open vegetation areas, as grazed areas and reindeer pens on grasslands and mires, possible as early as from the Middle Ages (Fjellheim, 1999).

The social and economic development differed in the low-lying valley and fjord district in Surnadal from that of the Røros district, as the former was culturally oriented westward. A hunting-based economy was replaced by first a mixed economy and then an agrarian economy in these lowlands from the Middle Neolithic, c. 3300 BC, to the Late Neolithic, 2300–1800 BC (Myhre, 2002; Nyland, 2006; Riksantikvaren, 2024). The outfields at and around Surnadal were less influenced by extensive grazing by reindeer but periodical grazing from wild animals is likely.

In addition to the domesticated reindeer, and wild animals that would graze the outfields, farm animals were sporadically allowed access during certain times of the year in such scythed outfields, typically early in spring and after scything (Sandnes, 1989; Kjelland, 1991). Generally, the farm animals were kept away from the scythed outfields in the latter part of historical scything to secure a larger harvest, during the first half of the 1900s (Myhre, 2002). Husbandry grazing would probably have had some impact on the fen during periods of both traditional and management mowing.

The extent of local influence on vegetation from reindeer grazing prior to 1800 is unknown and is also considered limited afterwards. The impact from reindeer wandering over large areas is extensive and can be difficult to detect in the vegetation (Kamerling et al., 2017). However, it is well-established that reindeer were present around and in the Sølendet area and they would occasionally pass by (Kjelland, 1991). There was cooperation between the Sámi and the farmers in the area around Brekken, especially related to reindeer herding and slaughtering (Fjellheim, 1999). From 1905, the Sámi community transitioned from intensive milk production to extensive meat production in Gåebrien sijte/Riast-Hyllingen reindeer grazing district, in and around Sølendet. One reason for making this transition was linked to the challenge with economic demands to pay compensation for grazing in the farmers' outlying areas, sometimes rightfully, other times not (Fjellheim, 1999). The presence of reindeer in this area supports some grazing in the areas where the farmers conducted scything. Sølendet is part of this grazing district, and the reindeer were and still are dependent on and use these grazing areas. The areas around lake Aursunden have high-quality pastures during the summer season. During the period of management mowing, there has been limited restrictions on grazing on the fens, and herds of reindeer have crossed the reserve on their migration between seasonal pastures (Moen, 1990; NIBIO, n.d. a).

2. The aims and objectives of the thesis

The overarching aim of this thesis is to reconstruct the local fen vegetation history in two fen areas and to establish how this history is intertwined with the various factors driving fen vegetation dynamics and development. The main focus is on the human land use of the vegetation, but this investigation will encompass both natural and anthropogenic factors shaping the vegetation history, exploring influences on fen formation from its inception through its development, and the evolution of vegetation over time. Additionally, this study will contextualize these findings within the broader scope of local and regional development. While these areas are known to have been utilised for hay collection through scything from at least the mid-1600s to the mid-1900s, the origins, duration, and intensity of the practice in the local farm communities have been unknown. In addition, the relationship between cultural and natural factors in influencing the agricultural vegetation on boreal rich fens over time will be investigated.

The overarching aim encompasses the subsequent specific objectives:

- Investigate modern plant-pollen relationships in rich-fen vegetation to identify pollen indicator taxa and develop association indices for pollen taxa from rich-fen vegetation subjected to mowing every two years, every four years, and unmown rich fens, to make a data set for vegetation reconstructions (Paper I)
- Create a modern analogue data set for fens mown every two years, every four years, and unmown fens to identify changing land use based on the pollen data from peat cores (Papers I, II and III)
- Reconstruct the fen history and natural vegetation history of two rich sloping fens, based on indicator taxa, modern analogues, and pollen assemblages, based on a peat core from the rich fen Nedre Tågsletta in Tågdalen (Paper II) and a peat core from the rich fen Bustmyra in Sølendet (Paper III)
- Reconstruct the cultural history of the vegetation development, including the onset and history of the fen scything, based on indicator taxa, modern analogues, and pollen assemblages, based on a peat core from the rich fen Nedre Tågsletta in Tågdalen (Paper II) and a peat core from the rich fen Bustmyra in Sølendet (Paper III)
- Discuss the relationship between natural conditions and human activities, including resource utilisation, as factors influencing vegetation formation in the fens in Tågdalen and Sølendet from a local to regional scale (Papers II and III)

The hypothesis posits that the rich fens' natural and cultural vegetation history, previously utilised for hay collection, can be accurately reconstructed. It anticipates that pollen analysis and statistical interpretations from peat cores will reveal the initiation and duration of land use in these areas. Furthermore, it is hypothesized that both cultural and natural factors driving vegetation changes will be identifiable, allowing for an investigation into their relative contributions to vegetation formation over time. This understanding will stem from interpreting pollen data, supplemented by archaeological, historical, and natural archival data from other studies.

3. Study areas: The sloping rich fens of Tågdalen and Sølendet and their vegetation

Tågdalen Nature Reserve and Sølendet Nature Reserve both encompass areas of middle boreal and northern boreal vegetation within their territories (Moen, 1999) (Figure 5). Tågdalen is situated in Surnadal municipality, between 440 and 475 m a.s.l., in the inner valley area with fjord areas to its west. Sølendet in Røros municipality, Trøndelag, to the east is situated further inland, between 715 and 785 m a.s.l. Tågdalen is situated in the markedly oceanic climate, in the oceanic vegetation section, while Sølendet has a continental climate and falls within the transition between the indifferent and slightly oceanic vegetation sections (Moen, 1999). Both areas have a long season of snow cover lasting until mid-May and the growing season lasts from the end of May until the beginning of September (Meteorologisk institutt, 2024a, b).

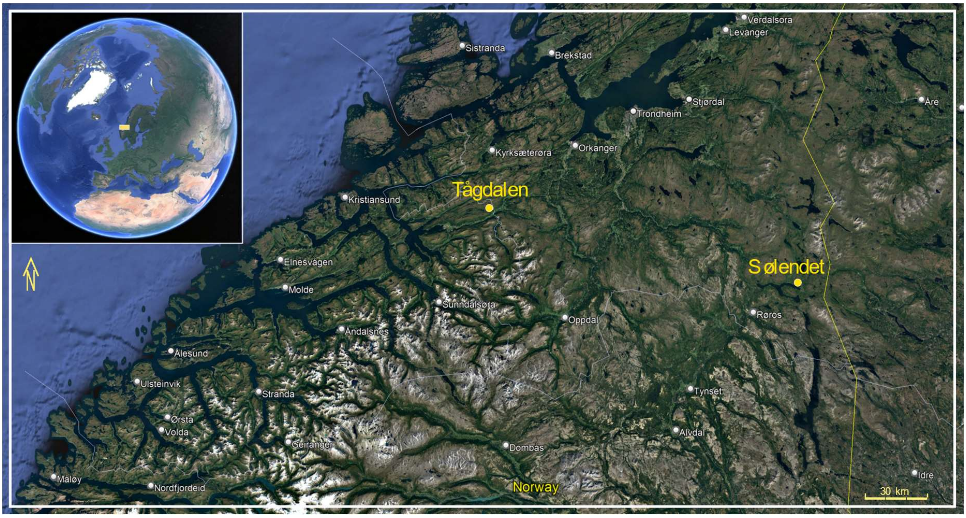


Figure 5. Location of Tågdalen and Sølendet Nature Reserves. Map source: Google Earth Pro. Projection: Google 3D globe view.

The two outfields share common characteristics as they are situated on calcareous Cambro-Silurian bedrock (Sigmond et al., 1984). Consequently, the till formed over this bedrock is base-rich (Follestad, 1995; NGU, n.d.), leading to a base-rich water content. The limited permeability of the till leads to a high water-content in the soil and waterlogging and thus paludification. These rich fen areas have been influenced by base-rich water from their inception, resulting in a continuous history of rich fen (Moen 1990; Rydin & Jeglum, 2006). The nature reserves are covered with extensive mire areas (Moen, 1990, 2000), including rich fens, also known as minerotrophic mires. These are peat-forming mires where the vegetation is dominated by brown mosses in the ground layer, in these areas mainly consisting of *Campylium stellatum,* and where the water is base-rich (pH > 6).

The sloping rich fens are categorized by slopes above 3°, and in Tågdalen they can be as steep as 12° but more often up to 7°, while in Sølendet the majority are up to 6° and some up to 8° (Moen, 1990, 2000). Sloping fens have some minerogenic content due to constantly overflowing water and therefore there is minerogenic material throughout the entire peat column. The sloping fens range from 20 to 100 cm deep, while smaller ombrogenous mires are up to 1.4 m deep in Sølendet and often exceed 2 m in Tågdalen. In Sølendet, more than 50 springs with base-rich water are found.

The rich fen areas, along with areas of grasslands and woodlands, represent semi-natural landscapes shaped by a long history of scything (Moen, 1990). A third of the Tågdalen Nature Reserve is characterized by vegetation of good hay-making land, and a quarter is adequate hay-making land (Moen, 2000). The fen vegetation is rich with a high variety of species. These areas are the outfields of four properties at Dalsegga, on the northern slope of Surnadal valley (Tretvik & Krogstad, 1999). Sølendet Nature Reserve is part of the outfields of 9 farm properties at and around Brekken, with the historical farms mainly 2–4 km away: there were formerly 4 hay sheds and 8 hay barns in Sølendet (Moen, 1990).

The traditional scything at these rich fens was the intensive scything, carried out every two years. The tradition declined in both areas during the 1930s and ended in the 1950s (Volden, 1977; Kjelland, 1982, 1996; Tretvik & Krogstad, 1999), following the general trend of outfield scything in Norway. The management mowing started in 1973 in Tågdalen and in 1974 in Sølendet nature reserves (Øien & Moen, 2006; Moen et al., 2015). These reserves have vegetation plots mown intensive every two, extensive every four year and unmown (Moen, 1990, 2000). Outside the plots, some areas are mown more seldom. Wild animals graze very extensively in the areas. Bustmyra, in the Sølendet Nature Reserve, is located within the spring, summer, autumn, and partly in the autumn-winter grazing area for the reindeer of Gåebrie sijte/Riast-Hyllingen, and the route of the migration paths between seasonal grazing areas passes here. These grazing areas are categorized as less central and/or less intensively used areas (NIBIO, n.d. a). Investigations have been conducted in both mown and unmown areas across numerous permanent plots within the nature reserves. Long-time studies have been and still are being carried out investigating mown and unmown fen vegetation and single species and vegetation assemblage responses to land use and climate during the period of management in the nature reserves (Moen,1990, 2000; Aune et al., 1996; Moen et al., 1999, 2012, 2015, 2020; Øien & Moen, 2001, 2002, 2006; Sletvold et al., 2010; Lyngstad et al., 2017; Ross et al., 2019). An area of long-time studies is illustrated in Figure 6.

Rich to extremely rich fen vegetation is common in both Tågdalen and Sølendet, covering all the investigated permanent plots (Moen, 1990, 2000). The mire terminology used for these areas follows the Fennoscandia mire ecology tradition (sensu Sjörs, 1948; Rydin et al., 1999), and the mires investigated here belong to the alliances *Caricion davalianae* Klinka 1934 in Tågdalen, and in Sølendet *Caricion atrofuscae* Nordh. 1936 (Moen, 1990; Moen et al., 2012). The vascular plant species on the semi-natural fen vegetation is generally the same as found in the natural vegetation of rich to extremely rich fens. Common vascular plant species in both nature reserves include *Carex dioica*, *Carex flava*, *Carex hostiana*, *Carex lasiocarpa*, *Carex panicea*, *Carex rostrata*, *Eriophorum angustifolium*, *Eriophorum latifolium*, *Equisetum palustre*, *Euphrasia wettsteinii*, *Molinia caerulea, Parnassia palustris*, *Pinguicula vulgaris*, *Potentilla erecta*, *Selaginella selaginoides*, *Succisa pratensis*, *Thalictrum alpinum* and *Trichophorum cespitosum* ssp. *cespitosum*. In Tågdalen some western/lowland species are present, as *Schoenus ferrugineus* (Moen, 2000), and in Sølendet the alpine/inland species *Pedicularis oederi* and *Carex simpliciuscula* are present (Moen, 1990). Several

Orchidaeae species, as *Dactylorhiza* spp. like the widespread *Dactylorhiza lapponica* and *Dactylorhiza maculata* and the rare *Pseudorchis albida* are found in the rich fens. The bottom layer is dominated by *Campylium stellatum*, a brown moss typical for rich fens.

The dominant rich-fen vegetation in Tågdalen and Sølendet forms an assemblage with mire margins, grassland, heath vegetation, and *Betula pubescens* woodlands. Around the fens, *Alnus incana*, scattered *Pinus sylvestris* trees, various shrubs and dwarf-shrubs are common.

Historically, these fen areas have been an important factor for the farm communities for the hay resources they provided (Volden, 1977; Kjelland, 1982, 1996). The fens were also influenced and potentially shaped by periodic grazing by wild animals, farm animals and domesticated reindeer (Moen, 1990, 2000; Moen et al., 2012). This rich history of fen use, from traditional scything practices to grazing by a range of animals, underscores the complex interplay between human activity and natural fen dynamics. It frames the context for the current investigation into the early history and development of these practices and the role of various factors in shaping the fen vegetation composition.

Figure 6. Fen area in Sølendet nature reserve with permanent monitored vegetation plots. The sign says: "Research. Much of the research is linked to such fixed experimental routes. The most low-growing route is cut every year, the tall-growing is never cut". Photo: Bjarte Gees Bokn Solheim.

4. Theory

4.1 Natural and cultural factors

I use two categories of influencing factors on the fen vegetation. The ‘natural’ category includes, but is not limited to, elements such as vegetation and biodiversity, geology, hydrology, topography, and climate. Conversely, the ‘cultural’ category includes, among others, traditional practices, historical and social traditions, social organization, economic systems and policies, legal frameworks, and technological advancements, which are also commonly referred to as anthropogenic factors. Semi-natural landscapes, as previously described, are cultural landscapes defined as those in which the natural vegetation has been somewhat altered due to anthropogenic factors, yet the fundamental characteristics of the natural environment are retained (Hovstad et al., 2018). They are neither entirely natural nor predominantly modified by cultural influences. In these landscapes, processes such as ecological succession and natural regeneration are ongoing, and these dynamics become more pronounced when cultural impacts diminish or cease. In contemporary landscapes, ranging from the Arctic tundra and remote rainforests to polder landscapes and urban streets, elements of both nature and culture are present to varying extents. This includes everything from the minute traces of human-induced gas and chemical emissions and novel entities in air and water to a complete transformation of the landscape in many urban areas (e.g., Richardson et al., 2023).

4.2 Pollen analysis and the potential for fen vegetation reconstructions

Pollen analysis can be approached from two distinct perspectives: as a theoretical framework that underpins our understanding of past vegetation and climate, and as a methodological tool used to extract and analyse data from sediment cores. Its theory employs the principle of stratigraphy to study accumulated layers of plant materials, primarily sub-fossil pollen and spores, with the oldest deposits at the bottom and the most recent at the top. Pollen analysis encompasses not only pollen but also spores and non-pollen palynomorphs (NPPs). The observed relation between present-day terrestrial vegetation and the pollen assemblage it produces and deposits at the same location forms the basis for reconstructing past vegetation at the fens from the pollen and spore signatures the plants once produced (Kneller, 2009), and can be used to reconstruct land use as well as natural vegetation (Solem, 1986; Hafsten, 1987; Overland & Hjelle, 2009; Fjordheim, 2012; Sjögren, et al., 2015; Halvorsen & Hjelle, 2017; Hjelle et al., 2018; Lagerås & Fredh, 2020). Pollen analysis is a key tool for investigating historical vegetation conditions and change (Fægri & Iversen, 1989; Birks et al., 2016; Birks, 2019). The quantitative aspects of vegetation, including the abundance of individual plants and the overall species composition, cannot be directly deduced from the fossil pollen assemblage due to variations among species in pollen production, dispersal, and deposition, as well as preservation (Sugita, 1994). As a result, fossil pollen data act as indirect proxies for the reconstruction of past flora and vegetation (Prøsch-Danielsen & Sørensen, 2010; Hjelle et al., 2018). Knowledge of the local pollen assemblages from various land uses are thus essential in this study. Uniformitarianism underpins this study, as it is assumed that the relationships between vegetation and the factors influencing its formation were consistent with those observed today, both as natural conditions as well as land use practices. This assumption extends to the production, transport, and deposition of pollen and spores under varying land use. The more accurately the understanding of the correlation between plant composition and its corresponding pollen deposition in the investigated vegetation is, the more precise the reconstructions of past vegetation will be. The historically scythed fens provide an archive of past vegetation within their peat layers. Utilizing this type of reconstruction enables us to discern the underlying drivers of vegetation composition and change.

Pollen and spores are produced in generally high quantities. However, differences can be observed, such as between the anemophilous (Greek: 'wind-loving') plants producing high quantities of light pollen grains adapted to wind pollination, and entomophilous (Greek: 'insect-loving') plants, which generally produce a lower number of pollen grain that are heavier and rely on sticky pollen to be transported by insect pollinators. Characteristics of the plant, of the pollen grain and the vectors plants rely on for pollen transport, such as wind, insects, water, birds, and other animals, have implications on how far the pollen grains are dispersed. In this fen vegetation, common species of Cyperaceae, Poaceae and *Thalictrum alpinum* are anemophilous and are assumed to be widely dispersed around the plants on the fen and then retrieved in the peat in the form of moss polster samples. Conversely, *Succisa pratensis*, is an entomophilous taxon that produces pollen in lower quantities, which is less likely to be dispersed widely or deposited in rich fen peat. Such variations in pollen production, dispersal qualities and preservation lead to variation in spread of pollen, quantities deposited, what is potentially retrieved and thus variations in the representation of pollen taxa in both surface moss polster samples and samples deeper in the peat (Kneller, 2009). As the relationship between plant cover, plant biomass, and flowering is closely connected for many of the species present on such a fen, also under various land use, as shown by Moen (1990, 1995), Aune et al. (1996) and Lyngstad et al. (2017), the approximate relationship between plant cover and pollen retrieved in moss polster samples can be used in a study of vegetation change. Nevertheless, all these factors must be taken into consideration when interpreting the results from pollen analysis.

Moss polster pollen assemblages have been documented to be well-suited for comparison with pollen assemblages from mire peat sequences, since pollen deposited on the surface is generally well preserved in the moss (Hicks, 1977; Hjelle, 1998) and reflects from a pair to several years of pollen deposition (Caseldine, 1981; Bunting et al., 2013). In areas dominated by low-growing herbaceous vegetation, as for the fen areas in this study, the relevant pollen source area (sensu Sugita, 1994) is generally only a few meters (Bunting, 2003; Bunting & Hjelle, 2010; Waller et al., 2017). Consequently, peat from rich fens is well suited for reconstructing local fen vegetation.

Pollen analysis integrates knowledge from many disciplines to reconstruct vegetation and can be utilised in various fields to further reconstruct natural and semi-natural vegetation history, land use, and climate change, among others. In this study botany and ecology plays a central role, along with geology, climatology, history, and archeology. In Norway and neighbouring areas, pollen analysis have been used in numerous cultural landscape reconstructions, as the introduction of and development in agrarian societies (Odgaard & Rasmussen, 2000; Prøsch-Danielsen & Sørensen, 2010; Soltvedt & Henningsmoen, 2014; Halvorsen & Hjelle, 2017; Hjelle et al., 2018), the history of summer farming (Solem et al., 2012; Sjögren et al., 2015), and Sámi settlements and reindeer hunting (Hicks, 1993; Hörnberg et al., 2005; Josefsson et al., 2010).

4.3 Source research and research focus

Palynological reconstructions focusing on vegetation history and cultural landscapes will be strengthened by integrating archaeological and historical knowledge. The finds and sources will provide various information and might need interpretation to provide relevant and reasonable information. Source criticism, or rather source research, as described by Kjeldstadli (1999, p. 169), forms a fundamental activity in reconstructing cultural landscapes, although it is not always clearly pointed out in such studies. The documented history of scything provides information about the tradition dating back to the 1800s. For earlier periods, knowledge about outfield scything relies on remains of tools and settlements, cadastre, laws, and documents, along with the interpretation of these.

In both archaeology and history, questions regarding the ownership of history have emerged (Bergstøl, 2009), where a significant portion of historical research in the past 150 years has exhibited an ethnic bias, with an emphasis on a common Norwegian perspective, particularly focusing on agricultural aspects (Hansen & Olsen, 2022, pp. 14–18). Furthermore, while agricultural history is more extensively documented, written Sámi sources from within their communities before the 1800s are rare. Consequently, relatively limited traces remain of the Sámi hunting-gathering and herding economy, as well as the nomadic pastoralist economy (Seitsonen & Viljanmaa, 2021). This disparity in available sources and findings from various societies could result in further bias in future research.

Source research have led to the use of among others the overview of the properties of the Archdiocese of Nidaros in Aslak Bolt's cadastre from 1432–33 (Jørgensen, 1997) and other documents of property and taxations, along with work of Sandnes (1971) on the abandonment and restoration of farm following the Black Death in central Norway. Many other studies have dealt with the topic of the settlement history in the Middle Ages based on local and regional source material (Hamre, 1983; Indset et al., 1954; Jørgensen, 1997). This work has yielded rich knowledge about the agricultural history in the region. Outside the agrarian history, the view on the South Sámi settlement history, on the other hand, has been debated. South Sámi oral tradition states that the Sámi people have always inhabited the region around Røros, 'from time immemorial' (Declaration, 2005). The general perception in academic circles in the 1800s and early 1900s shared this view (Falsen, 1821; Christie, 1842). Even so, the immigration theory by Nielsen (1891), stating that the Sámi people had a short history in these southern areas became influential in the second half of 1800s onwards (Bergsvik 2001). The theory was based on argument from silence as he could not find traces of South Sámi activity prior to the Middle Ages (Nielsen, 1891).

Sandnes (1971) interpreted from an extensive array of source materials on farm history that prior to the Black Death there was an extensive farm settlement in the border districts such as in Brekken, and that the farmers would have used the outfield intensively, as for hay collecting. He concluded that not until after the Black Death was there resources enough for a South Sámi population as well in these areas (Sandnes, 1971, 1996). As Nielsen (1891), Sandnes (1971, pp. 300–301, 1996) based his theory on the argument from silence, as he found no traces of South Sámi society and thus proposed alternative explanations prior to 1350. Further, as he could not find documentation on agricultural activity in the Røros areas during the late Middle Ages, Sandnes (1971, pp. 195–205) suggested that generally both the infields and outfields at a deserted farm in the inner areas and towards the tree limit would have been left until the resettlement in the mid-1600s.

The perspective presented by Sandnes (1971, 1996) and other researchers in agreement (Sars, 1873–1891; Wolf, 1982; Haarstad, 1992) on South Sámi history has since been disproven and lost its foundational basis. Archaeologists as well as historians have challenged the view of the immigration theory (Bergsland, 1970; Solli, 1996; Eriksen, 1996). There has been an increased focus on finds and sources documenting continuous Sámi presence from the prehistorical hunting societies, both in the Gåebrien Sijte, in the Røros area, and in the region (Fjellheim, 1999, 2012; Løøv, 1983, 1998; Zachrisson, 1988, 1997). However, Sámi history has had, and continues to have, a smaller role in the representation of history, as discussed by Henriksen (2001), Mathisen (2019) and Fjellheim (2020) and as seen in both local history books and regional historical presentations, as in Kvikne, et al., (1974) and Ryen and Aaspaas (1974) and in the historical volume of Bull et al. (2005).

The misguided conclusion of a shorter South Sámi history has led to challenging interpretations, as when reconstructing the vegetation history on historical summer farms in Trøndelag, as in Røros, where such areas for periods have been reindeer grazing ground, and the pollen signal can be similar between these different land uses (Aronsson 1991; Fjellheim 1999; Ljungdahl, 2007). In the Røros area, the interaction between farming and Sámi societies has led to shared traditions. Traces of several milking pits for storage are found on the fen areas surrounding Sølendet and in the Røros area (Fjellheim, 2012; Riksantikvaren, 2024). These milk storage sites have traditionally been used by both the Sámi and the local farmers, and these contexts can be associated with either of these activities. The historically scythed rich fens have been investigated with the recent history of agricultural outfields as a starting point where a variety of factors must be considered, as grazing, scything and the activities by hunters, herders, and farmers.

For Surnadal and Røros, a rich history relating to various aspects of human activity and societies exists (e.g, Kvikne, 1942; Reinton, 1957; Binns et al., 1999; Tretvik & Krogstad, 1999; Prøsch-Danielsen & Sørensen, 2010). However, several periods, places, and aspects of these activities and settlements have not been thoroughly covered by previous comprehensive historiography. This situation necessitates a careful consideration of various sources when reconstructing the cultural factors related to the history of Tågdalen and Sølendet.

5. Research design and methods

5.1 Research design

In this study, data from peat cores and surface samples, combined with mapped fen vegetation, form the foundation for reconstructing the history of vegetation and land use in boreal rich fen areas, as depicted in Figure 7. The investigation will analyze contemporary plant-pollen relationships and current land use data from the study sites, creating a database to aid in reconstructing land use history. This approach is illustrated in the lowermost part of Figure 7. Pollen and spores collected from the fens will be identified and quantified through the peat layers, as shown in the middle part of Figure 7. Based on these parts of the investigation, this comprehensive study aims to reconstruct the historical development of the vegetation, including land use patterns, as presented in the upper part of Figure 7. The study further leverages previously established plant-pollen relationships, and the natural and cultural history in the investigated region. The methods can identify periods when prehistoric and historic vegetation closely resembled modern vegetation types, thereby enhancing the reconstruction process, and contributing to our understanding of vegetation history.

The vegetation composition in boreal rich fens across north-western and central Norway exhibits considerable similarities, making these fens appropriate for use as modern analogues for both unmown and mown fen vegetation, in various vegetation sections ranging from oceanic to continental. Based on the comparison, in conjunction with knowledge from other studies about this relationship, the pollen assemblages from two peat cores from rich fen areas were analysed. This analysis aimed to reconstruct the vegetation history and interpret the factors influencing the fen vegetation and its changes. The cores were retrieved from the sloping rich fen Nedre Tågsletta in the oceanic Tågdalen, Figure 8, and from the less sloping rich fen Bustmyra at slightly continental Sølendet, Figure 9. Note the difference in scale between Figures 8 and 9.

Paper I focuses on vegetation from areas subject to three different land use regimes as part of nature reserve management: two different mowing regimes and some areas left unmown. This dataset will form the basis for improving the interpretation of subfossil pollen in peat core samples for vegetation reconstructions. The hypotheses are that there is a close connection between the taxa registered in the fen vegetation and the local pollen deposition, that there is a high degree of similarity in local plant-pollen relationships within rich fens, and that differences between the various mowing frequencies and the unmown vegetation can be detected from the contemporary pollen assemblages.

Paper II investigates the vegetation history from a rich fen, Nedre Tågsletta, in Tågdalen Nature Reserve and paper III investigates the vegetation history from the rich fen Bustmyra in Sølendet Nature Reserve. The pollen assemblage from the peat core samples through one peat sequence from each fen will be investigated. From these data the history of the rich fen with fen development, vegetation history, known historical scything history and the factors shaping the development will be reconstructed.

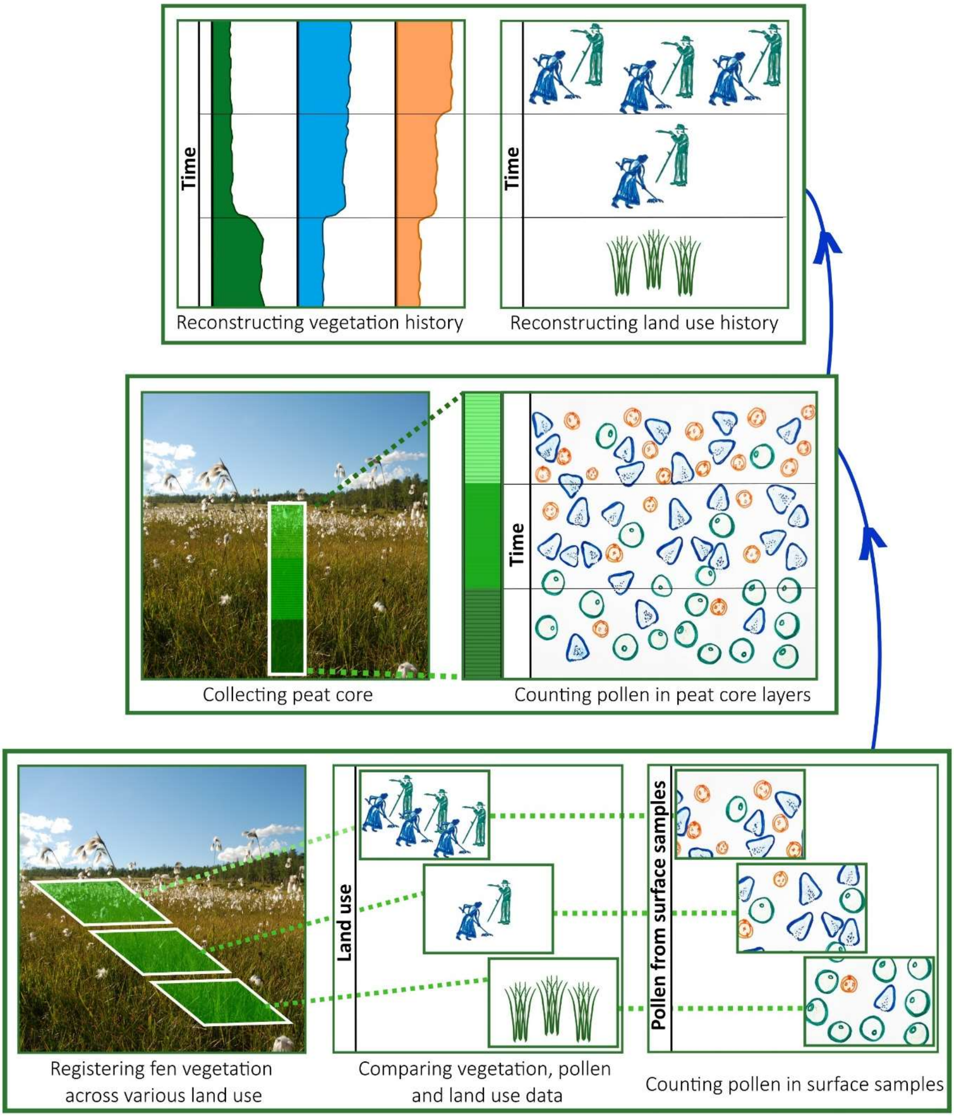


Figure 7. The research design in a simplified diagram. Pollen reconstruction is represented by common fen species Poaceae pollen (large, round, and green; left graph), *Eriophorum*-type pollen (pear-shaped and blue; middle graph), and *Thalictrum*-type pollen (small, round, and orange; right graph). Intensive land use with scything is represented by several workers, extensive scything by one scyther and one raker, and no land use by Poaceae plants. Pollen analysis and vegetation mapping in surface samples are represented in the lower row, with peat core pollen analysis in the middle row. The top row illustrates the reconstructed vegetation and land use history, building on the analyses from the two former rows.

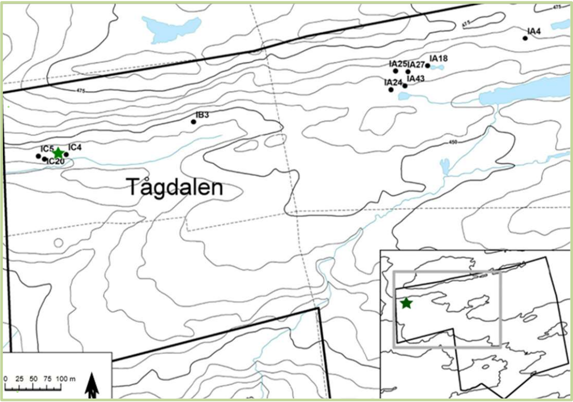
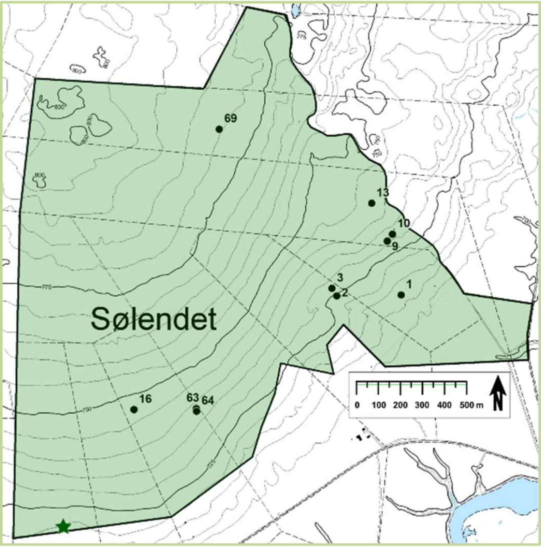


Figure 8. Tågdalen Nature Reserve in Surnadal municipality (black line). The coring point at Nedre Tågsletta fen is marked by a star at 63º 03' 25'' N, 9º 04' 05'' E (EU89). 10 permanent vegetation plots where surface samples for modern pollen data and vegetation data are collected are numbered by their permanent numbering according to the long-term studies in the nature reserve, described in Øien (2023). The present property boundaries are marked by dotted lines. Map based on Moen (2000) and Paper II.

Figure 9. Sølendet Nature Reserve, Røros municipality, Trøndelag. The nature reserve is marked in green. The star marks the location of the peat core from Bustmyra, 718 m a.s.l., 62º 40' 31'' N, 11º 49' 10'' E (EU89). 10 localities where surface samples for modern pollen data and vegetation data are collected are numbered by their identification under the long-term studies in the nature reserve (Øien, 2023). Map based on Paper III.



5.2 Field work

In late July 2008 vegetation was mapped and moss polster samples collected for surface pollen assemblage investigation. This was done across 49 permanent monitored vegetation plots, located at 20 localities, with 10 in Tågdalen, where some are located at Nedre Tågsletta in Figure 10, and 10 in Sølendet. These plots represent three different management regimes that have been maintained since the 1970s: 1) fen mown every two years, 2) fen mown every four years, and 3) unmown fens since the 1950s.

In the investigated plots, as illustrated in Figure 11, the species cover was visually registered in sample plots of 1 × 1 m placed in the center of permanent plots, using the following cover classes [percent range of cover — cover class mean]: 1 [1–2 plants — 0.25%], 2 [0–1% — 0.5%], 3 [1–2.5% — 1.75%], 4 [2.5–5% — 3.75%], 5 [5–10% — 7.5%], 6 [10–20% — 15%], 7 [20–30% — 25%], 8 [30–40% — 35%] and so on up to class 14. The nomenclature follows Lid and Lid (2005) in Paper I and Elven et

Figure 10. Field work at Nedre Tågsletta with plant cover registration for permanent plots belonging to the 1C area plots around the sampling point for the peat core. The sloping fen is viewed towards southeast. Photo: Bjarte Gees Bokn Solheim.

al. (2022) in Papers II and III for vascular plants and Frisvoll et al. (1995) for mosses. Plant taxa presented in the text is listed in Appendix A and B with their Latin, Norwegian and English names. For each taxon, the mean plant cover from each management regime was calculated using the average of cover class means from all plots of similar management regime. The taxa registered in these plots represents those taxa included in the category 'local terrestrial pollen' (Papers II and III). The plot size 1 × 1 m was chosen after initial studies of different sizes of sample plots (ranging from 0.25 m^2 to 4 m^2) showed that this size was representative of the plant composition of the stand (Mueller-Dombois

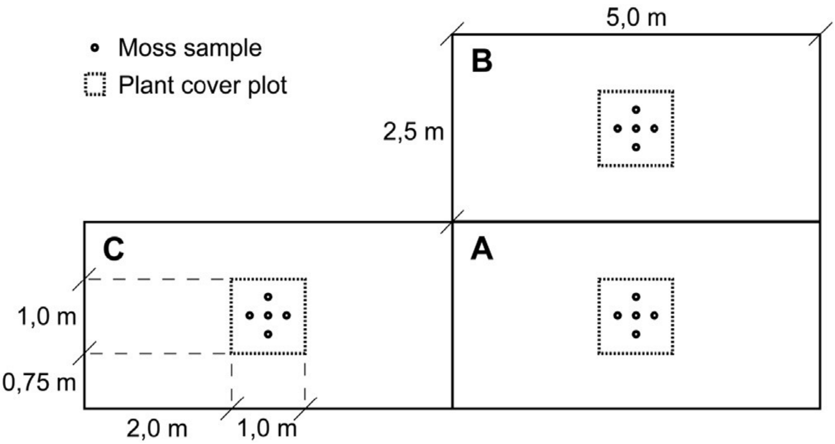


Figure 11. Schematic presentation of a permanent monitored plot from the field areas, with the placement of investigated sub-plots of 1 m^2 for the present study and collection points for moss polster samples. Key: A = mown every two years, C = mown every four years, and B = unmown. From Paper I.

& Ellenberg, 1974). This registration of the vegetation can only provide an overview of typical rich fen species, as the plots under investigation constitute a limited area of the rich fens.

From each sample plot, one moss polster sample was collected, with the moss functioning as traps for pollen deposition (Hicks, 1977; Hjelle, 1998). A single moss sample from a plot consisted of five merged sub-samples: one from the center of the plot and four others from each direction, located halfway to the border of the 1 x 1 m plot. Surface samples from this type of vegetation are regarded to largely reflect local pollen assemblages (Bunting, 2003). To collect moss polster samples representative of the investigated vegetation community and to even out the effects of single-year fluctuations observed in fertility (Lyngstad et al., 2017) and pollen production (Hicks, 2001; Hättestrand et al., 2008; Nielsen et al., 2010), moss polster samples were collected as whole moss turfs, extending from the upper part down to the soil surface. This approach increases the likelihood of including several years of pollen deposition, typically ranging from two to several years (Räsänen et al., 2004; Pardoe et al., 2010; Bunting et al., 2013), making the modern moss polster samples comparable to the peat core samples.

Figure 12. The peat core collection equipment, with a black plastic tube containing the peat core sample, located in rich-fen vegetation in Sølendet.

One peat core was retrieved from Tågdalen and one from Sølendet. A plastic tube, 110-mm diameter wide, was hammered down into the peat and the core was jacked up (Hafsten, 1986) (Figure 12). The peat core from Nedre Tåglsetta, Tågdalen, was collected from an area of firm peat mat surface in the center of the sloping rich fen and made up a sequence of the 48.5 cm deep peat. Underneath the peat a layer of unsorted, angular minerogenic material, representing the upper part of the underlying moraine was collected. The peat core from Bustmyra in Sølendet originates from a moss carpet and made up a 76 cm deep peat sequence. Beneath the peat, a layer of unsorted, angular minerogenic material was found, representing the upper part of the underlying moraine, and was included in the collected peat and sediment core. Due to springs and small streams in the area, some parts of the accumulated peat on the fens in Sølendet were prone to erosion. Therefore, a location for the core retrieval was chosen in a less sloping part of the fen, at a distance from springs and streams to mitigate these concerns.

5.3 Laboratory work

Pollen assemblages were analysed from the 49 moss polster samples collected from the sample plots and for the peat core samples from the two cores. The moss polster samples were prepared according to standard methods for pollen analysis, including adding known quantity of exotic spores (Fægri & Iversen, 1989) and pollen and spore identification was aided by modern reference materials from the collection at the University of Bergen and identification keys (Moe, 1974; Fægri & Iversen, 1989; Moore et al., 1991; Beug, 2004).

The outer part of the pollen and spore grain, the exine, is largely made up of sporopollenin, a very stable and often well-preserved structure after deposition in soils, sediments, and peats as the sloping fen. Even if less moist condition can be found in the uppermost moss and peat in sloping fens for periods during the year (Moen, 1990) the pollen and spores will be preserved (Waller et al., 2017). The species- or taxa-specific patterns and morphologies facilitate the identification of key species (e.g., Twell, 2000), such as *Thalictrum* pollen, which in these fens originates from *T. alpinum*. As plant species have various responses to natural conditions and land use, identifying pollen and spores to the lowest possible taxonomic level was essential, such as *Carex*-type and *Eriophorum*-type pollen in this vegetation type. However, the similarity in pollen morphology between species and with fragile pollen grains this identification level can be challenging to achieve for identification of pollen within the Cyperaceae family (Fægri & Iversen, 1989). Along with pollen and spores, other microscopic fragments of organisms are included in the analysis. Such useful finds can be microscopic charcoal and non-pollen palynomorphs (NPPs), representing a variety of microscopic, resistant organic remains and debris produced by a wide variety of plants, animals, fungi, and protists (van Geel et al., 1983; Carrión & Navarro, 2002). Their occurrence can assist in identifying the composition of vegetation and changes therein. For example, perforation plates originating from leaves of *Alnus*, *Betul*a, and *Corylus* species can be used to indicate the local presence of shrubs and trees and were included in the investigation.

For the peat core samples from Nedre Tågsletta and Bustmyra Loss-on-ignition (LOI) was registered as percentage weight loss in samples dried at 105 °C for 12 hours then ignited at 550 °C for 6 hours (Bengtsson & Enell, 1986). The largely decomposed peat core content and underlying moraine material was described according to the classification of Troels-Smith (1955). Selected levels in the core were AMS radiocarbon (^{14}C) dated at several laboratories, from hand-picked vascular plant material to avoid incorporating of calcareous material or younger roots (Olsson, 1986).

5.4 Data analysis and data integration

5.4.1 Modern pollen sample and vegetation cover analyses

As the production of pollen and spores are generally high, leaving high numbers of microfossils that have not germinated but rather accumulated in peat and lake deposits, these microfossils are suitable for percentage calculations. Concentration values are useful for identifying absolute changes but represent a challenge when calculated for peat core samples with varying peat accumulation over time. The use of pollen influx values accounts for varying sedimentation rates but would require good data on chronology through the peat core and is not calculated.

For the analysis of modern moss polster samples, the sum of local terrestrial pollen, as plant taxa present in the investigated plots, was chosen as the calculation basis to remove issues related to absolute variations in extra-local and regional pollen in percentage calculations, which could be problematic for species like *Pinus sylvestris* and *Corylus avellana* (Paper I). Further percentage values were also preferable as pollen trapping ability and concentration values might vary due to annual variations in moss growth rates among and within moss taxa, as well as due to mowing, as reported by Moen (1995). The pollen data were analysed using TILIA for percentage calculation (Grimm, 1990). Plant species were grouped according to the pollen taxa that represent them to ensure comparable taxonomic groups. Analyses were conducted for both individual plant species and for the corresponding palynological taxonomic groups for some species. Gradients in the modern pollen sample data set were investigated using Principal Components Analysis (PCA) analysed in CANOCO for Windows 4.5 (ter Braak & Šmilauer, 2002). This analysis was applied to 49 vegetation plots based on the pollen taxa they contained using species centring with square-root transformed data. To obtain inter-species correlations, the species scores were divided by their standard deviation. Pollen percentages, also square-root transformed, from the plots, encompassing all taxa and the three management regimes, were included as passive samples and environmental variables, respectively, in the ordination diagram (Paper I).

To identify general plant occurrence and cover in vegetation plots, average values were calculated for the different management regimes. The vegetation composition plots, and the moss polster samples, with their respective pollen assemblages grouped into pollen taxa, were analysed through ordination to search for taxa grouped according to land use and plant taxa content.

A paired comparison from mown and unmown vegetation was conducted to compare the vegetation composition in pairs of mown–unmown plots within each locality. An exact Wilcoxon signed rank test, run in R version 2.11.1 (R Core Team, 2010), was employed to identify taxa from the nonparametric data set and to detect statistically significant differences in mean percentage plant cover between land-use regimes, where $p < 0.05$. Three sets of tests were conducted using the combined data from Tågdalen and Sølendet: 1) comparing plots from biennially mown and unmanaged plots, 2) comparing plots mown biennially and quadrennially, 3) comparing plots mown quadrennially and unmown plots. All tests included taxa with plant cover registrations in ≥ 6 plots.

The Spearman-rank-correlation coefficient, ρ (rho) was employed to assess the statistical dependence of pollen percentages and plant cover measured in all plots with the three management regimes (Webb et al., 1978). The test for the nonparametric coefficient ρ was run in R version 2.11.1 (R Core Team, 2010), to identify the absolute percentage difference of paired plots, with the statistical significance level of 0.05.

Analyses of differences in species plant cover between management regimes were conducted using the Indices of Difference (ID). This approach determines whether and how often each taxon increases, shows no change, or decreases in vegetation cover when comparing unmown plots with their mown counterparts. Additionally, indices of pollen association and representation were calculated (Davis, 1984; Hjelle, 1997; Bunting, 2003). The presence/absence data of vegetation and pollen from all investigated plotsmake the basis for the identification of indices of association. These calculations were performed to identify coincidence (A), over-representation (O) and under-representation (U) for the taxa. Based on these findings, taxa were categorised into the following associations: strongly associated types, associated types, weakly associated types, over-represented types, under-represented types, and unassociated types.

Indicator pollen taxa related to the various land uses were identified from the paired comparison from mown and unmown vegetation, their statistical dependence of pollen percentages and plant cover within land use, and whether plant cover change with land use took place.

5.4.2 Peat core analyses

For the two peat cores from Nedre Tågsletta (Paper II) and Sølendet (Paper III), the results of the pollen analysis were calculated and visualised in pollen diagrams made using TILIA (Grimm, 1990) and TGView 2.6.1 (Grimm, 2004). Due to variations in peat accumulation over time, as evidenced by the age-depth relationship for the peat core from Tågdalen, pollen percentages provide a generally accurate approximation of the vegetation composition in and around the sampled site. Concentration values were derived by comparing with added exotic spores of a known number to samples of a known volume.

To identify the main changes in the vegetation history, the pollen assemblages in the core were divided into zones and sub zones. This division was based on the occurrence of local and extra-local pollen taxa, based on square-root transformed data and Edwards and Cavalli-Sforza's chord distance as the dissimilarity coefficient in CONISS (Grimm, 2004). Local pollen and local spores derive from plants on the sampled fen site, while extra-local pollen and spores come from plants growing in nearby meadow, shrub, and woodland vegetation, based on the definition by Janssen (1966). This approach follows the registration results outlined in Paper I.

The ^{14}C-dated levels were employed to construct an age-depth model for each peat core, based on five dated levels for the Nedre Tågsletta core and nine dated levels for the Bustmyra core. The models were made with clam (Blaauw, 2010) version 4.2.2 and were based on the IntCal20 calibration curve (Reimer et al., 2020) run in R (R Core Team, 2023) for both peat cores. The construction of the curves was based on the weighted means of the dated levels, calculated based on the 95% confidence range. The age models were established using linear interpolation between the dated levels. For the Nedre Tågsletta age-depth model two samples were excluded as they were deemed too young and potentially contaminated with roots (Paper II). One date was considered an outlier in the Bustmyra data set and was excluded from the age-depth model (Paper III). The ages are displayed as years BC/AD and calibrated years before present (BP), where 'present' is AD 1950. Dates are rounded to the nearest 5 years. Rounding to the nearest 5 years reduces the risk of increased deviation due to potential rounding in the wrong direction relative to the actual age, but it must be emphasised that the uncertainty in the age-depth model and the date of each level in the peat core is significantly greater than the rounding value.

Pollen indicator species identified in Paper I were employed to interpret the peat core data from Nedre Tågsletta (Paper II) and Bustmyra (Paper III). Additionally, the Modern Analog Technique (MAT) was applied using the dataset of modern vegetation and modern pollen from 49 plots in Tågdalen and Sølendet (Papers II and III). The data set from Tågdalen and Sølendet (Paper I) did not exhibit sufficiently wide variation to identify modern analogues on its own. The data set for the MAT requires a variety in taxa composition to be able to identify similarity with peat core samples. By combining the local data set with the dataset from Hjelle (1997, 1999), which includes mown and grazed meadows, grazed pastures, heathlands, and grazed forests, the MAT was able to identify modern analogues for some samples in the peat core. Analogue matching algorithms were used with chord distance, due to its good signal-to-noise properties (Overpeck et al., 1985), and the analysis was run in the R package 'analogue' (Simpson & Oksanen, 2013).

With multiple modern analogues for single peat core samples in Paper III, ordination was conducted to discern differences and similarities among samples in the Bustmyra pollen data set. Detrended Correspondence Analysis (DCA) was the chosen ordination technique, selected for the data set's variability (Hill & Gauch, 1980), run in R (R Core Team, 2023).

Quantitative and qualitative assessment of the pollen diagrams were performed based on the pollen, spores and NPPs within the known chronology. Pollen indicator species, in conjunction with the identified modern analogue land use types from the MAT data results, were used to reconstruct the fen vegetation history, in combination with botanical data from other studies, and archaeological and historical sources.

6. Results and summary of the papers

6.1 Paper I

Modern pollen–vegetation relationships in traditionally mown and unmanaged boreal rich-fen communities in central Norway

The main findings from the investigation of plant cover and pollen deposition in surface moss polster samples in 49 plots in rich-fen vegetation from Tågdalen and Sølendet were:

- Most of the plant and pollen taxa on the fens were found in plots from both study areas and in plots with all three land-use categories. Quantitative differences in vegetation cover and pollen percentages identified the difference between mowing and fallow regimes on the rich fens.
- Of the 89 plant species (77 vascular plant and 12 moss species) registered in the vegetation of the investigated plots, 57 plant species were grouped into 26 corresponding taxa of pollen and spores, sufficiently represented in both vegetation and as pollen or spores, to allow direct comparisons of these two data sets (Table 1).
- The relative difference in plant cover was largest between biennially mown and unmown plots. 12 species exhibited a significant positive correlation with variance in plant cover between mown and unmown areas, most notably for *Molinia caerulea*, most common in unmown plots, and *Carex dioica* and *Thalictrum alpinum*, most common in mown plots. The other species most common in mown plots were *Pinguicula vulgaris*, *Carex flava*, *Carex hostiana*, *Carex limosa* (only Tågdalen), *Eriophorum angustifolium*, *Eriophorum latifolium* and *Pedicularis palustris*. *Betula nana* var. *nana* and *Succisa pratensis* displayed a preference to unmown plots. These 12 species correspond to eight pollen taxa.
- A significant positive plant-pollen correlation was identified for 10 pollen taxa. These taxa were grouped according to indices of association. Rosaceae, *Potentilla*-type, *Thalictrum*, *Selaginella selaginoides*, *Eriophorum*/*Eriophorum* spp., Poaceae/*Molinia caerulea* and Cyperaceae were classified as strongly associated pollen types. *Pedicularis*-type was classified as strongly associated pollen type, and *Succisa pratensis* and *Menyanthes trifoliata* were classified as weakly associated pollen types.
- Based on plant correlation with land use and their plant-pollen correlation several species can be used in reconstructing land use conditions and changes. *Thalictrum alpinum* is categorised as a very good pollen indicator of mowing, and Cyperaceae, *Eriophorum*-type and *Pedicularis*-type are good pollen indicators of mowing. Poaceae/*M. caerulea* and *Succisa pratensis* are good pollen indicators negatively correlated with mowing. This investigation shows that other taxa have potential in land use reconstruction from pollen. For the potential pollen/spore indicators: *Selaginella selaginoides* shows an increase with mowing, while *Potentilla*-type and Rosaceae show a reduction with mowing.
- The impact of mowing on species composition was similar for the oceanic and indifferent vegetation section, indicating similarity in boreal rich-fen vegetation along this climatic gradient.

- As mown and unmown areas were distinguishable in the vegetation data and could be differentiated in modern pollen data, these results will enhance the interpretation of past land-use practices through pollen analysis of rich-fen vegetation.

Table 1. The 26 pollen and spore taxa, along with their corresponding 57 plant species present in the studied vegetation plots. Only taxa registered in both investigated vegetation plots and as pollen in moss polster samples are included. The nomenclature for pollen taxa follows Fægri and Iversen (1989), while plant taxa nomenclature is in accordance with Elven et al. (2022) and Frisvoll et al. (1995). Species with changed nomenclature from Paper I (Lid & Lid, 2005) to Papers II and III have the previous plant name included in brackets. 'T' indicates taxa only registered in investigated plots from Tågdalen, and 'S' denotes those only registered in plots from Sølendet. Table based on data from Paper I.

Pollen/spore taxa	**Plant species in the vegetation plots**
Anemone	*Anemone nemorosa*$^{\mathrm{T}}$
Asteraceae Cichorioideae	*Crepis paludosa*$^{\mathrm{S}}$, *Scorzoneroides autumnalis*$^{\mathrm{S}}$ *(previously Leontodon autumnalis*$^{\mathrm{S}}$)
Betula	*Betula nana, Betula nana* x *pubescens, Betula pubescens*
Bistorta vivipara-type	*Bistorta vivipara*
Calluna vulgaris	*Calluna vulgaris*$^{\mathrm{S}}$
Cyperaceae	*Carex* spp., *Carex simpliciuscula*$^{\mathrm{S}}$ (previously *Kobresia simpliciuscula)*, Eleocharis quinqueflora, Eriophorum* spp., *Schoenus ferrugineus*$^{\mathrm{T}}$, *Trichophorum* spp.
Drosera rotundifolia-type$^{\mathrm{T}}$	*Drosera longifolia*$^{\mathrm{T}}$, *Drosera rotundifolia*
Dulichium-type/*Carex*-type	*Carex capillaris, Carex chordorrhiza*$^{\mathrm{T}}$, *Carex dioica, Carex echinata, Carex flava, Carex flava* x *hostiana*$^{\mathrm{S}}$, *Carex hostiana, Carex lasiocarpa, Carex limosa*$^{\mathrm{T}}$, *Carex nigra, Carex panicea, Carex pauciflora*$^{\mathrm{T}}$, *Carex rostrata, Carex vaginata*$^{\mathrm{S}}$
Ericaceae	*Andromeda polifolia, Calluna vulgaris*$^{\mathrm{S}}$, *Erica tetralix*$^{\mathrm{T}}$, *Vaccinium uliginosum* ssp. *uliginosum*
Eriophorum-type	*Eriophorum angustifolium, Eriophorum latifolium, Eriophorum vaginatum*$^{\mathrm{S}}$, *Trichophorum alpinum, Trichophorum cespitosum* ssp. *cespitosum*
Galium-type$^{\mathrm{T}}$	*Galium boreale*
Juniperus communis	*Juniperus communis*
Menyanthes trifoliata$^{\mathrm{T}}$	*Menyanthes trifoliata*$^{\mathrm{T}}$
Pedicularis-type	*Pedicularis oederi*$^{\mathrm{S}}$, *Pedicularis palustris*
Pinguicula-type$^{\mathrm{S}}$	*Pinguicula vulgaris*$^{\mathrm{S}}$
Poaceae	*Deschampsia cespitosa*$^{\mathrm{S}}$, *Festuca ovina*$^{\mathrm{S}}$, *Festuca vivipara*$^{\mathrm{T}}$, *Molinia caerulea, Nardus stricta*
Potentilla-type	*Potentilla erecta*
Rhinanthus-type$^{\mathrm{S}}$	*Bartsia alpina*$^{\mathrm{S}}$, *Euphrasia wettsteinii*
Rosaceae	*Potentilla erecta*
Salix$^{\mathrm{S}}$	*Salix glauca*$^{\mathrm{S}}$
Saxifraga oppositifolia-type	*Saxifraga aizoides*$^{\mathrm{S}}$
Selaginella selaginoides	*Selaginella selaginoides*
Solidago-type	*Solidago virgaurea*$^{\mathrm{S}}$
Sphagnum	*Sphagnum warnstorfii, Sphagnum* Section *Subsecunda*
Succisa pratensis	*Succisa pratensis*
Thalictrum	*Thalictrum alpinum*

* Included in Cyperaceae as it was previously classified as *Kobresia simpliciuscula*

6.2 Paper II

Long-term rich fen development, vegetation, and agricultural land-use history in boreal outfields in Nordmøre, Norway

The main findings from the reconstruction of plant composition in the peat core from Bustmyra rich fen in Sølendet were:

- The sloping rich fen Nedre Tågsletta probably developed from smaller patches expanding in a discontinuous process, from around 2350 BC (4300 cal. BP) in the central part of the fen to the present-day cover around AD 985.
- The use of traditional scything indicator species data from this area allowed the determination of the initial traditional scything as well as information on its intensity.
- Indication of scything with a fen vegetation comparable to modern cultural vegetation was detected from the Roman Age, c. AD 40, probably as an extensive scything practice carried out every fourth year or less, possible in combination with extensive grazing (Figure 13).
- Among the indicator taxa used to identify the initiation of the scything were *Thalictrum*, *Eriophorum*-type and *Cyperaceae*-type pollen and *Selaginella selaginoides* spores (Figure 13).
- The scything practice changes in the early High Middle Ages, from c. AD 1135, detected with the use of modern pollen analogues (Figure 14). The data reflected a well-developed farming community with traditionally biennially scything, comparable to known historic scything. This scything practice further increased the plant cover of taxa like *Thalictrum*, probably *T. alpinum* and *Eriophorum* spp., among others probably *E. latifolium*, representing mainly a quantitatively change in fen plant cover.
- The outfield scything continues through the Middle Ages and during the historic time. A possible scything intensification was detected from c. AD 1850, at the time of the highest intensification in Norwegian outfield resources, followed by a reduction in scything from c. AD 1920.
- The abandonment of scything was seen in plant composition from approximately 1950, in accordance with historical data and resulting from a general change in national agriculture traditions (Figure 13).
- The outfield scything continued during more than 1900 years, showing that such outfields were important resources under different cultural, social, economic, and climatic conditions. The main changes in fen vegetation during the period of scything were related to variations in agricultural practices, so cultural factors represented the most important factors for changes during this period.
- The comparison of pollen in the pollen assemblage and the local pollen indicator taxa both identified to a finer taxonomic resolution proved to be useful in the reconstruction, as demonstrated for *Eriophorum*- and *Carex*-type pollen (Figure 13).
- The study demonstrates the benefit of using modern analogue technique from known land use in combination with local indicator taxa to quantitatively reconstruct cultural landscapes and anthropogenic activity from fossil pollen and spore data. The technique also makes it possible to infer presence of taxa with poorly preserved pollen taxa like Orchidaceae from pollen peat assemblages and into past scythed vegetation reconstruction.
- The palaeobotanical study has bridged gaps in the outfield history of Tågdalen.

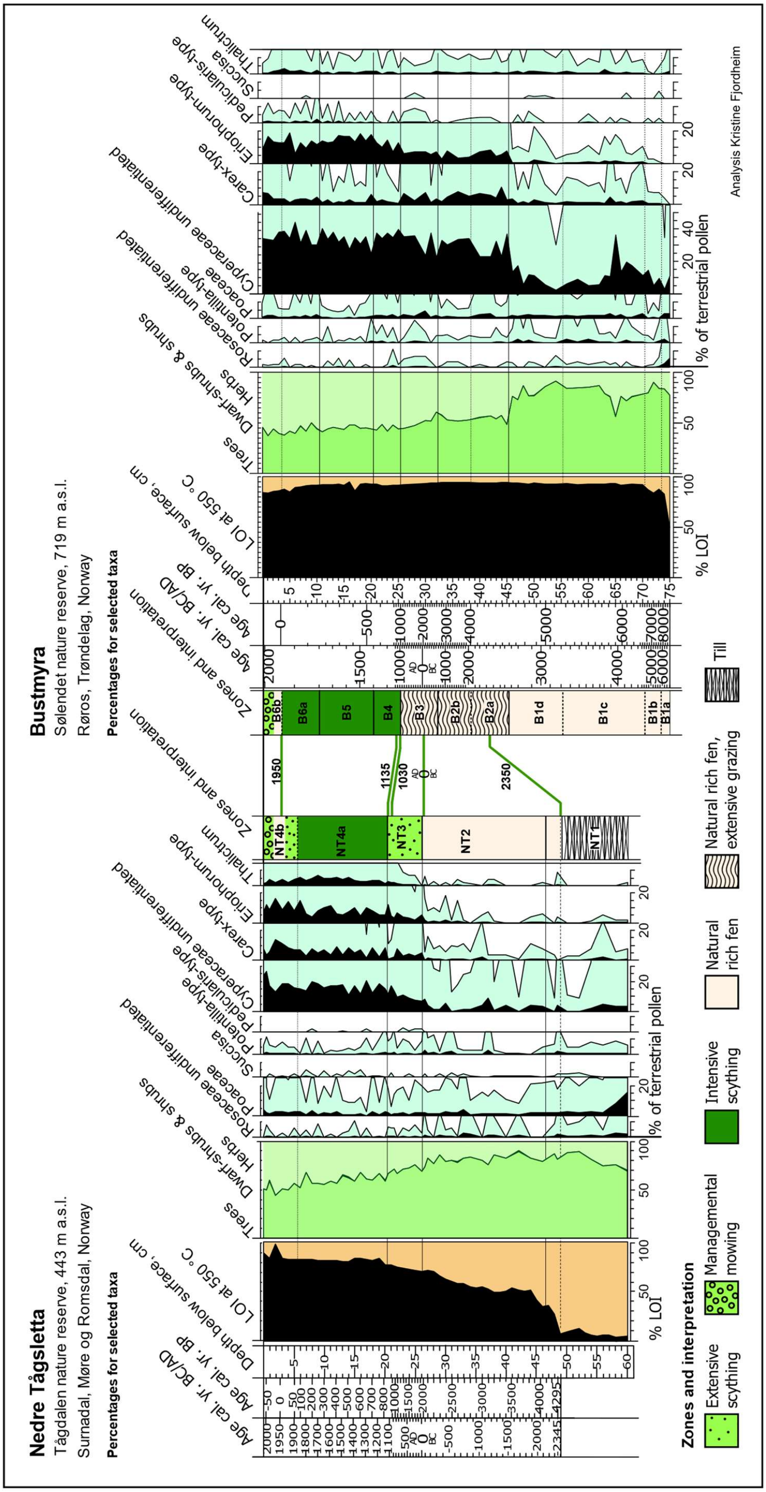


Figure 13. Pollen diagram for selected herb taxa from Nedre Tågsletta, left, and Sølendet, right. LOI and zones are presented with the interpretation of the vegetation and periods with land use. Pollen taxa are sorted by their centroid value for each peat core. Data from Paper II and III.

6.3 Paper III

Holocene rich fen evolution, wildlife grazing, and historical land use: From natural vegetation and Viking Age mowing to contemporary management in Central Norway

The main findings from the reconstruction of plant composition in the peat core from Nedre Tågsletta rich fen in Tågdalen were:

- The fen formation at Bustmyra started c. 6585 BC (8535 cal. BP) initially as a rich fen with a continuous rich-fen vegetation persisting to the present day. The peat formation at this site began following a fire and is interpreted to have expanded in fen area towards c. 2000 BC, with some further expansion towards 605 BC.
- The main change in the vegetation to a fen comparable to present-day rich-fen vegetation occurred c. 2605 BC. Extensive grazing from wild animals, such as reindeer (*Rangifer tarandus*) and moose (*Alces alces*) is inferred from around this timed, based on MAT and pollen assemblage data (Figure 13) and MAT (Figure 14).
- From c. 605 BC the reduction in tree cover around the fen could be indicative of human activity, possibly due to limited forest clearance.
- The initiation of scything s dated to c. AD 1030, coinciding with the end of the Viking Age, as evidenced by, among other indicators, an increase in *Eriophorum* taxa and reduction in *Carex* taxa (Figure 13). Scything is interpreted as part of the outfield resources utilised by nearby farms at Brekken. An ordination of the data shows similarity between pollen assemblages from c. AD 1030 to the period of modern management mowing, indicating a general similarity in the history of mowing (Figure 15).
- The known abandonment following the Black Death is not precisely dated locally but is estimated to have occurred sometime between 1350 and the change in land use in Sølendet c. AD 1415. A potential cessation of mowing during this period would not be identifiable in the data due to the slow succession on the rich fens.
- At c. AD 1415 a change in scything is identified from the vegetation reconstruction, interpreted to represent an intensification in scything related to summer hay collecting from farms distant from Sølendet. Grazing during this period is plausible but challenging to ascertain from the data.
- A limited change in the vegetation is detected c. 1700, marked by a decrease in scything tolerant *Eriophorum* species. The scything activity comparable to that from 1415 continues.
- From c. 1815 continued scything is identified, showing similarities to historical scything practices in the early 1900s, typically carried out every two years.
- The inferred vegetation changes around 1950, including an increase in Poaceae and a decrease in *Thalictrum alpinum* cover, indicates a slow succession following the end of historical scything (Figure 13). The management mowing that began in the mid-1970s does not appear to alter the succession process on the fen areas based on the current data, only for limited areas.
- The use of MAT made it possible to identify the periods of rich-fen vegetation and potential grazing by wild reindeer and other wild animals (Figure 14). However, the interpretation of MAT did not detect all reconstructed periods of scything, possibly due to slight differences in fen conditions between the modern analogue data set from firm peat mat and the pollen peat core from a moss carpet.

- Despite some variations between the firm peat mat vegetation from which most of the modern plant-pollen data is collected and the moss carpet at Bustmyra, the indicator pollen data and finer taxonomic resolution in the pollen data sets proved useful in reconstructing land use, as exemplified by the *Eriophorum*- and *Carex*-type pollen curves (Figure 13).
- This study demonstrates that changes in land use activities primarily respond to social and economic conditions, rather than variations in natural factors. Furthermore, palaeobotany has contributed significantly to the reconstruction of fen development, vegetation history, and cultural history at and around Sølendet.

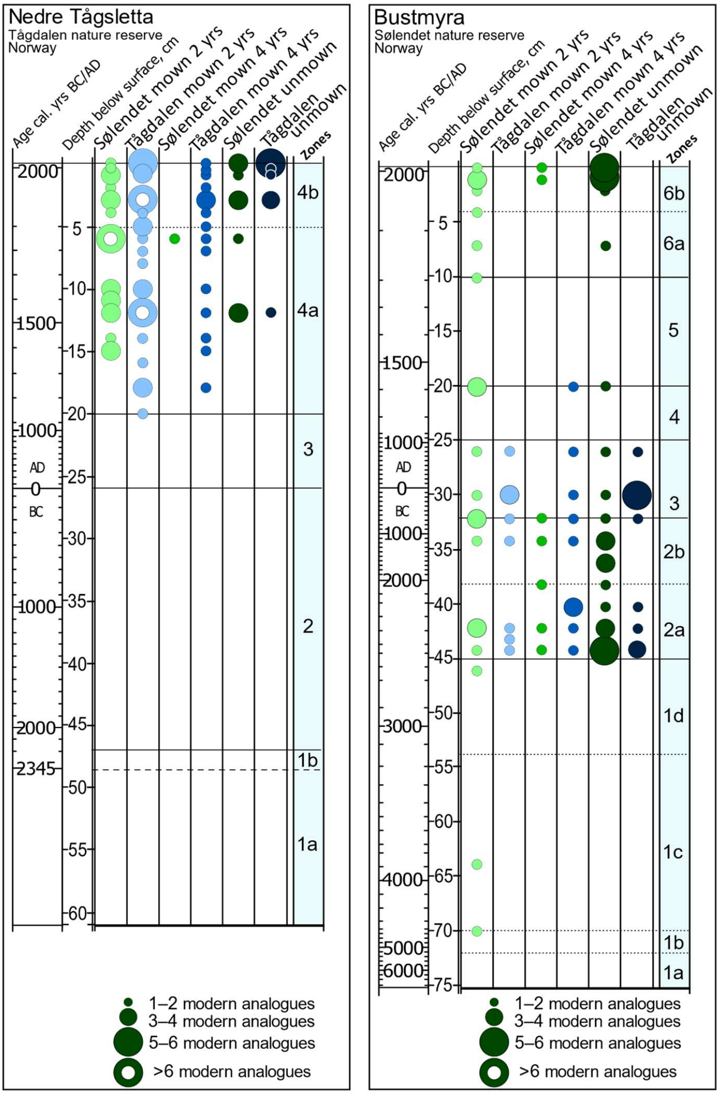


Figure 14. Nedre Tågsletta and Bustmyra modern analogue matching results identifying the modern analogues. For each pollen sample from the core, identified analogues from the modern pollen samples from plots mown every two years, mown every four years, and unmown plots are displayed. Modern pollen sample localities are described in Moen (1990), Moen et al. (2012), and Paper I. Data from Paper II and III.

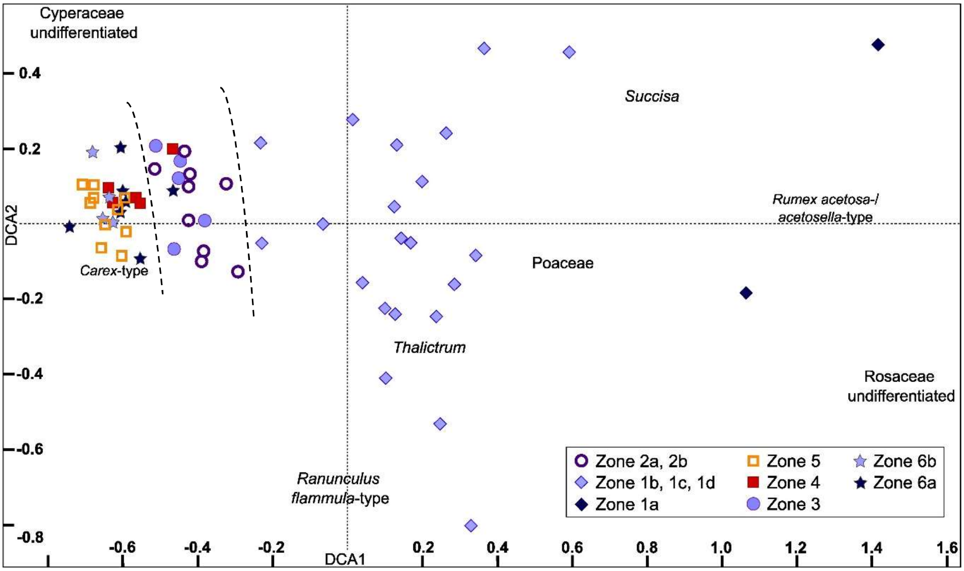


Figure 15. DCA ordination plot of peat core samples and selected taxa from the Bustmyra peat core. Samples with the lowest values on DCA axis 1 are the youngest samples and represent traditional scythed vegetation, vegetation after scything and during management mowing, zones 4, 5 and 6. Those situated to the right of those mentioned and on the negative side of DCA axis 1 represent rich-fen vegetation with similarities with present-day vegetation but interpreted to represent unmown vegetation, with the exception of two samples belonging to zones 4 and 6a, which are from scythed areas. Samples on the positive DCA axis 1 signify early rich-fen vegetation. Data from Figure 8 in Paper III.

7. Discussion – Vegetation Reconstruction: Gaining new botanical and historical insights and methodological perspectives

This study has demonstrated that in rich fen areas, both natural and cultural vegetation, can be reconstructed over extended time periods using pollen analysis and relevant statistical methods. Moreover, the activities deduced from the reconstruction are primarily linked to outfield scything. Extensive grazing, involving both wild and domesticated animals, is inferred to have taken place in the inland Sølendet area. This pattern reflects the grazing of wild animals and might to some degree be related to the practices of early hunter-gatherers and later to those of subsequent herding communities. However, the activity related to agriculture is more evident, whereas the potential human communities behind grazing activities are more challenging to identify. The findings of this vegetation reconstruction will be discussed within the wider framework of the cultural landscapes, emphasizing how the rich-fen vegetation was both influenced by and contributory to these environments. Following this, considerations regarding the methods used and future possibilities for fen land use and cultural vegetation reconstructions are discussed.

7.1 The role of pollen indicator taxa, association indices and high taxonomic resolution in cultural vegetation reconstruction

Ten pollen taxa have been identified as pollen indicator taxa, with several showing strong associations with the vegetation from which they originate (Paper I); see Table 2. In reconstructions of different rich fens, *Thalictrum alpinum* has proven to be very useful for land use reconstruction on firm peat mats (Papers I and II) (Figure 13). Generally, *T. alpinum*, Figure 16, is observed to increase in biomass, cover, and flowering with scything on rich fens, and this is particularly evident on firm peat mats (Aune et al., 1996; Moen, Lyngstad & Øien, 2012). However, in softer and less species-rich moss carpets*, T. alpinum* proved to be less suitable as an indicator of land use changes (Paper III). The vegetation history reconstructed from Bustmyra demonstrates this relationship, with the investigated peat core retrieved from a moss carpet where the increase in cover and flowering is less evident. This observation aligns with its reduced cover on moss carpets, as documented by Moen (1990).

Several taxa displayed change in vegetation cover and pollen percentage between plots scythed every two years and unmown vegetation, while the areas mown every four years to a lesser degree were statistically different with regard to the plant-pollen relationship compared to plots scythed every two years or unmown plots (Paper I). In the following discussion the variation between plots mown every two years and unmown plots are in focus. The good pollen indicators in the reconstructions in Tågdalen and Sølendet, played various roles in the interpretation of land use (Table 2). Indifferentiated Cyperaceae represents a wide range of species with differing responses to mowing (Moen, 1990, 2000). Overall, the taxon increases with mowing (Paper I) and indicates scything in the Tågdalen reconstruction (Paper II). In the Sølendet reconstruction, this pollen taxon is interpreted to represent rich-fen vegetation (Paper III). Here, the two identified subgroups of Cyperaceae, *Eriophorum*-type and *Carex*-type pollen reflect scything, showing opposite responses, as seen from Figure 13. *Eriophorum*-type pollen notably increased with mowing and was crucial in land use reconstructions.

Figure 16. *Thalictrum alpinum* (alpine meadow-rue, fjellfrøstjerne): From the left a drawing by Anton Hartinger from ’Atlas der Alpenflora’ (1882), a photo of the plants in a rich fen in Tågdalen and images of the pollen grains viewed through a microscope, with the grains measuring approximately 15 µm.

Eriophorum-type pollen provided essential data for identifying periods of scything, even when modern analogues were not present, as observed in Tågdalen c. AD 40 to 1135 and in Sølendet from c. AD 1030 until the cessation of scything around 1950 (Papers II and III). *Eriophorum*-type pollen represents *Eriophorum angustifolium* (Figure 1), *Eriophorum latifolium*, *Eriophorum vaginatum* (only in Sølendet), *Trichophorum alpinum*, and *Trichophorum cespitosum* ssp. *cespitosum*. While the *Eriophorum* species generally increase in cover with scything, the *Trichophorum* species show a tendency to decrease in cover. The pollen analysis revealed an increase in *Eriophorum*-type pollen with scything, interpreted to primarily represent the change in cover and flowering of *Eriophorum* species, especially *Eriophorum latifolium*, in these boreal rich fens (Papers I, II, and III). The pollen deposited primarily reflects variations in *Eriophorum* species within these rich fens, since changes in these species tend to overshadow the pollen signals from other species belonging to the same taxon (Papers I, II and III). For *Eriophorum*-type and *Carex*-type pollen an interpretation of extensive scything, defined as scything every four years can also be made based on the modern plant-pollen study (Paper I). Such an interpretation was made based on these two taxa for the period of less intensive scything in Tågdalen from c. AD 40 to 1135 and based on the occurrence of *Eriophorum*-type pollen in Sølendet from 1030 to 1415.

Carex-type pollen is not identified as one of the pollen indicator taxa in this study, and not used individually to interpret scything or absence of scything in the palaeobotanical reconstructions based on changes of its percentage in peat core samples. However, when considered as part of the overall interpreted pollen assemblage and in conjunction with the probable single plant taxa that *Carex* might represent in the contemporary vegetation, this data can contribute to the reconstruction. The usefulness of *Carex*-type pollen, when combined with the rest of the pollen assemblage, is demonstrated by the observed reduction of *Carex*-type pollen in scythed vegetation starting c. AD 1030 at Bustmyra. This reduction coincides with a decrease in Poaceae pollen among other pollen taxa (Paper III).

Poaceae pollen is primarily interpreted as representing *Molinia caerulea*, along with some *Nardus stricta* at both areas, *Festuca vivipara* identified in Tågdalen and *Deschampsia cespitosa* and *Festuca ovina* found in Sølendet (Paper I). This pollen taxon shows a notable reduction in response to mowing, as reported from vegetation studies (Moen, 1990, 1995; Aune et al., 1996), and can when it is commonly present indicate various land use intensity (Paper I). In the present study Poaceae proved an important taxon for land use reconstructions (Papers II and III). Other taxa that decrease in pollen recovery with mowing include *Succisa*, interpreted as representing *S. palustris*, and *Pedicularis*-type pollen, which display low occurrences in the pollen peat cores. *S. palustris*, a good pollen indicator taxon, diminishes with mowing. However, being an entomophilous taxon, it disperses pollen only to a limited extent and is less likely to be present in peat core samples. This is evident in the data from Tågdalen and Sølendet, where *Succisa* pollen is present but at too low a level to significantly aid in interpretations of scything. Instead, it represents one of several taxa indicating rich fen conditions. For future studies *Succisa* could be useful in land use reconstructions. At Bustmyra, *Pedicularis*-type pollen is more prevalent. *Pedicularis*-type pollen found in this study represent two species found in the vegetation (Table 1): *P. palustris*, which increases with mowing, and *P. oederi*, which decreases with intensive mowing. At Nedre Tågsletta the pollen recovery of *Pedicularis*-type pollen is limited, whereas at Bustmyra *Pedicularis* primarily represents rich-fen vegetation, and was interpreted as a part of the pollen assemblage to detect scything (Paper III). *Potentilla*-type pollen, mainly representing *Potentilla erecta* (Figure 17), and Rosaceae, also mainly indicative of *P. erecta* on the fen but encompassing varied woodland species like *P. palustris* and *Sorbus aucuparia*, are identified as potential pollen indicator taxa (Table 2). These taxa, which generally exhibit high cover on the fens and show some variation both between and within fens of varying land use, did not display statistical differences in occurrences between land use in the present study, even though a decrease in pollen recovery in mown areas was observed (Paper I). Consistent with findings from this study, other

Figure 17. Flowering *Potentilla erecta* (tormentil, tepperot) observed in a rich fen, accompanied by a high-resolution scanning electron microscope image of a *Potentilla erecta* pollen grain, c. 20 µm. Pollen image by Jan Berge, with the courtesy of the University Museum of Bergen.

research has also demonstrated that *P. erecta* diminishes with mowing, both in terms of cover and flowering (Moen, 1995; Aune et al., 1996). Based on these findings, both *Potentilla*-type pollen and Rosaceae pollen have been demonstrated to be useful for identifying periods of scything, as presented in Figure 13 (Papers II and III).

Selaginella selaginoides is identified as a potential pollen indicator as the taxon lacks a clear difference in plant cover occurrences between the three land-use categories but displays correlation between plant cover and pollen percentages. *S. selaginoides* is interpreted to reflect variations in other ecological factors, such as rich-poor mire gradients as seen in Moen (1995) and Aune et al. (1996). In addition to representing rich-fen vegetation at Nedre Tågsletta and Bustmyra, its presence is in this study interpreted to reflect openness on the fen. *Menyanthes trifoliata*, serves as a good pollen indicator reflecting its plant cover, However, its presence does not reflect variations in the land use of scything and the identified weak association in this study is interpreted as being mainly related to variations in moisture between sampled sites, as indicated by Moen (1990).

Table 2. The roles of studied plant taxa in the interpretation of land use reconstruction, based on the plant-pollen data set from modern vegetation (Paper I) compared with the pollen data from peat core sequences from Tågdalen (Paper II) and Sølendet (Paper III). Pollen and spore indicator taxa identified for management mowing regimes in boreal rich fens are based on the results from the Wilcoxon signed rank test (relationship between vegetation and management regimes) and the Spearman rank-correlation coefficient (relationship between plant and pollen percentages) (Paper I). For *Eriophorum*, the analysis is made from *Eriophorum*-type pollen and *Eriophorum* species in the vegetation only, as detailed in Paper I. The effect of traditional biennially mowing on the vegetation cover (plants expressed as pollen taxa) in fens is displayed as: + for positive effect of traditional mowing, • for no effect, and – for negative effect. The indices of association were classified into SAT (strongly associated types), AT (associated types), WAT (weakly associated types), ORT (over-represented type), URT (under-represented type) and UT (unassociated type). Results from earlier studies in the study areas (Moen, 1990, 1995; Moen et al., 1999) are displayed in brackets. T = interpretations from Nedre Tågsletta (Tågdalen), S = interpretations from Bustmyra (Sølendet).

Plant-pollen relationship	**Pollen/spore taxa**	**Mowing effect**	**Association**	**Role as indicator in land use interpretation in Tågdalen and Sølendet**
Very good pollen indicator	*Thalictrum*	**+**	**SAT**	Very good (T)/Partly good(S)
Good pollen indicators	Cyperaceae	**+**	**SAT**	Good (T)/Rich fen indicator (S)
	Eriophorum-type	**+**	**SAT**	Very good
	Poaceae	**–**	**SAT**	Good
	Succisa	**–**	**WAT**	Limited presence
	Pedicularis-type	**+**[a]	**AT**	Limited presence (T)/Rich fen indicator (S)
Potential pollen/spore indicators	*Potentilla*-type	**(–)**	**SAT**	Very good
	Rosaceae	**(–)**	**SAT**	Good
	Selaginella selaginoides	**(+)**	**SAT**	Rich fen indicator
Pollen type reflecting unidentified factors in present study	*Menyanthes trifoliata*	(+/•)	**WAT**	Indicator of other factors

[a] *Pedicularis*-type pollen increases with mowing, but single species are reduced in cover in mown vegetation.

Given the known rich-fen vegetation and its species' varying responses to land use changes it is crucial to identify taxa with differing responses to scything, known to exhibit varying plant cover in areas with different land uses. To achieve high taxonomic resolution, *Eriophorum*-type pollen was distinguished from *Carex*-type pollen (*Dulichium*-type pollen according to Fægri & Iversen, 1989). This distinction increased the number of scything pollen indicator taxa (Paper I), enhanced the resolution of inferred plant species in the vegetation, as a high cover and flowering of especially *Eriophorum latifolium* during scything. *E. latifolium* also aided in identifying the initiation of scything at both Nedre Tågsletta and Bustmyra (Papers II and III). For single species within Cyperaceae as a whole, and for species of *Carex*-type pollen, a varying response to scything was identified. In contrast, Eriophorum-type pollen as a group showed an increase in plant cover and pollen deposition (Paper I). The easily crumpled and corroded pollen grains of Cyperaceae are often difficult to fully differentiate into lower taxonomic groups, but also Cyperaceae indifferentiated, significantly aids in interpreting vegetation and land use reconstruction.

Used in combination, an assemblage of several pollen taxa, each with a documented response to changes in plant presence related to land use, is essential in palaeoreconstructions, as corroborated by other studies (Gaillard et al., 1994; Hjelle, 1999; Mehl & Hjelle, 2015). The distinction between areas mown biennially and quadrennially is not clearly identified through pollen indicator taxa alone (Paper I); however, this relationship can be discerned through visual interpretation of these taxa, particularly when analysed as part of the overall pollen assemblage (Papers II and III). This approach was especially useful in identifying the onset of scything and changes in its intensity, following the resettlements of the farms at Brekken and the transition from summer hayfields to local hayfields of nearby farms (Papers II and III). This study has demonstrated the ability of pollen and spore analysis in reconstructing past vegetation and land use on fen outfields. Further, it has been shown that known plant pollen relationship from local and similar vegetation types is central in vegetation reconstruction in semi-natural vegetation where differences between land use is mainly quantitative and generally limited.

7.2 The use of local modern analogue technique in natural and cultural vegetation reconstructions

The pollen assemblage, utilizing the modern analogue technique with local data, can identify specific land use in vegetation, as demonstrated by the reconstruction from Nedre Tågsletta (Paper II). As the analogue matching is carried out for mainly herbs this reflects a change on the fen and nearby vegetation and not the extra-locally. The intensive scything regime in Tågdalen, dating from c. AD 1135, was identified using the method. Here, analogues from rich-fen vegetation mown biennially constituted the majority of modern analogues until c. 1940 (Figure 14), aligning with historical sources that indicate a reduction in scything intensity (Ryen & Aaspaas, 1974; Moen, 1998; Tretvik & Krogstad, 1999). After 1940, samples in the peat core show the presence of unmown modern analogues, interpreted as a reduction in scything followed by subsequent succession. The similarity in land use and its intensity appears significant when reconstructions are made using this technique. The extensive land use interpreted from the same area from c. AD 40 was not identified using the modern analogue technique, which is thought to result from differences in land use compared to modern land use regimes. This discrepancy may relate to a less intensive scything regime, with each land area being scythed less frequently than around every 3–4 years.

In firm peat mats, *Thalictrum alpinum* is an indicator of scything (Paper I); however, this is not as clear in a moss carpet like Bustmyra (Moen, 1990). At Bustmyra, scything as a land use was not identified based on the modern analogue technique, but the technique did reveal similarities between periods with no scything on rich-fen vegetation and modern unmown analogues. The different results from the modern analogue technique for the Nedre Tågsletta and Bustmyra peat core samples are interpreted to result from their differences in fen type. The similarity in vegetation and pollen data between the modern moss polster samples and Nedre Tågsletta coring site, with firm peat mats, made it possible to find modern analogues for scything for the Nedre Tågsletta peat core samples. The ability of the MAT to identify analogues in a fen vegetation similar to the one where the moss polster samples are collected and less so in a slightly different fen vegetation highlights the sensitivity of modern analogues in drawing parallels between reconstructed and contemporary vegetation.

The peat core from Sølendet was collected away from areas with springs and streams, as illustrated in Figure 18, and areas where erosion or deposition of minerogenic or peat material could have disturbed the peat accumulation. Test coring was conducted in areas of firm peat mat in Sølendet where obtaining a continuous peat sequence was considered challenging (data not included). Subsequently, the sample was retrieved from a moss carpet, differing from the core at Nedre Tågsletta and most of the investigated permanent plots. A peat sequence from a firm peat mat and an area without these challenges might have provided more detailed data for reconstructing land use. This underscores the usefulness of modern analogues from near the coring point, as evidenced at Nedre Tågsletta where nine sub-plots within three permanent plots out of the total 10 (Figure 8) were examined for their plant-pollen relationship near the coring site (Paper II).

The use of the MAT in rich-fen vegetation presents a challenge due to the similarities across various land uses on these rich fens. The main distinctions between land uses are quantitative where the vegetation composition is generally similar between land use, but the plant cover of several species change with variation in land use (Paper I), necessitating a data set with a robust plant-pollen relationship for individual taxa over time, under diverse natural and cultural conditions. Key indicator taxa of various land use in fen vegetation, such as *Eriophorum*-type pollen (Paper I), were not identified to this taxonomic level in the modern analogue data set (Papers II and III), which might have complicated the analysis. As *Eriophorum*-type pollen and *Carex*-type pollen were merged into the taxonomic group Cyperaceae in the MAT analysis, the potential variation in pollen percentage of *Eriophorum* as a response to changes in land use could not be identified.

In addition to the local data set of plant-pollen from the modern vegetation of Tågdalen and Sølendet, a larger data set encompassing a wider range of vegetation types and land uses was required (Papers II and III). This need arose from the substantial similarity within the local rich-fen vegetation, even with different land uses. Incorporating a broader variation in rich-fen vegetation types, from moist to dry and from extremely rich to poor as identified in Moen (1990), and possibly including land uses such as grazing from the local fens, could have provided additional information to enhance the interpretation of the peat sequences from Nedre Tågsletta and Bustmyra.

Figure 18. Sølendet Nature Reserve with a view towards the south. Continuous springs and smaller and periodically present groundwater springs with base-rich water (pH > 7) are present in the highest areas of the reserve, and streams transport the water over the fens.

In utilizing modern analogues, understanding the current vegetation and all its influences is crucial. Sølendet is located within the Gåebrien Sijte reindeer grazing area, and grazing by reindeer has been reported during the period of management mowing from the 1970s. There have been limited restrictions on grazing, and large herds of reindeer have historically crossed the reserve (Moen, 1990; Fjellheim, 2012; NIBIO, n.d. a). The exact impact of reindeer grazing in the modern vegetation has not been possible to reconstruct. Therefore, the modern analogues may reflect both mown and unmown vegetation with some grazing effects, although the intensity of the grazing is challenging to assess. They are presumably extensive and occur only during specific periods of the year. The reconstruction identifying scything is probably not influenced by this effect to the same degree, as the effect of scything is probable higher than the effect of low-scale grazing.

To assist in interpreting land use, ordination with high taxonomic resolution was employed. *Eriophorum*-type and *Carex*-type pollen were identified as extensively as possible, which helped pinpoint the onset and duration of scything in Sølendet (Figure 13). The similarities between peat core samples from c. AD 1030 onwards, specifically in zones 4, 5, and 6, combined with the use of indicator pollen taxa, facilitated interpretations of scything duration and variations in scything intensity (Paper III). Notably, the resemblance between these peat core samples from the latter part of the Viking Age onwards and those from around 1970, a period of management mowing, was crucial for the analysis. Peat core samples from periods of scything were identified based on this ordination and with similarities between scythed peat core samples in this moss carpet vegetation, when the modern analogue samples were from a different vegetation type and the resolution of taxa groups in the MAT data set were lower.

The MAT facilitated the identification of the period from c. AD 1135 in Tågdalen during which the cultural vegetation resembled that observed during the historically known scything tradition. MAT also helped to reconstruct the practice of scything every two years during this time. In the reconstruction of both cultural and natural vegetation, there may be scenarios where no modern analogues exist. This could occur in cases where the past vegetation was significantly or slightly different from modern vegetation types, such as the scything practice c. AD 40 in Tågdalen. To accurately identify vegetation conditions and changes, the integration of additional methods is vital.

The use of modern analogues has enabled interpretation of vegetation composition beyond the taxa identified from pollen analysis. This applies to the scythed rich-fen vegetation from around 1135 in Tågdalen, and from around 1820 in Sølendet. During these periods the reconstructed vegetation was found to be similar to the modern mown vegetation where the vegetation was mapped (Paper I). These sites were interpreted as supporting various Orchidaceae species, both in terms of species diversity and coverage, similar to conditions observed during management mowing. During this period, the vegetation composition was comparable to the historically scythed fen vegetation of the early 1900s. Common Orchidaceae species in the fen likely included *Dactylorhiza lapponica*, *D. maculata* and *Gymnadenia conopsea*, the latter seen in Figure 19. During earlier periods, the vegetation on rich fens is interpreted to have included various Orchidaceae species, based on knowledge of modern rich-fen vegetation. However, the specific species and their abundance might have been different prior to the period when scything was intensely practiced.

Figure 19. Flowering *Gymnadenia conopsea* (chalk fragrant-orchid, brudespore) in Tågdalen, visited by a *Plebeius idas* butterfly (Idas blue, Idasblåvinge).

7.3 Natural rich-fen vegetation and fen development

The onset of fen formation at the investigated area at Bustmyra c. 6585 BC (8535 BP) is interpreted as an immediate result of local fires, coupled with the general development of fens in the area (Paper III). A fire would have reduced the shrubbery and woodland, leading to swamping of the area. The sloping fens' formation, starting later at the central point at Nedre Tågsletta c. 2350 BC (4300 BP), is viewed as part of the broader development of fen areas in a landscape characterized by older fen and bog areas, with different parts of the fen beginning to form at varying times (Papers II and III).

The reduction in minerogenic material up core as the peat adds layers in the fen at Bustmyra suggests an expansion of vegetation cover around the sampling site and a decline in areas with erodible soils, as observed in Paus et al. (1987) (Figure 13). A larger continuous fen around the location of the sampled core is reconstructed from c. 6140 BC onwards. The process of peat formation and the period of reduced influx of minerogenic material, measured by the LOI measurements (Figure 13), took longer time at Nedre Tågsletta. Here, the slope angle might explain the extended duration from c. 2350 BC to c. 150 BC before the reduced minerogenic content in the peat core suggested a larger and more continuous fen area with limited minerogenic runoff and deposition on the slope (Paper II). The two area are situated in different vegetation sections, but both areas experience increased moisture in their sloping terrain during the growing season. This is due to both snowmelt runoff in spring and early summer and rain during the growing season, leading to moist fen conditions (Papers II and III). Furthermore, both areas are situated atop less permeable calcareous moraine material, which contributes to the paludification process. As the minerogenic content decreases a larger cover of fen vegetation at Bustmyra is further supported by the decrease in perforation plates in the peat core samples.

This process of increasing fen area aligns with the Momyr model (Solem, 1986, 1991), describing how sloping fens develop from several patches and cover larger areas as damming takes place. The Bustmyra fen is located in an area with a gentler slope angle, which may explain why the fen formation at the sampled site at Bustmyra represent an earlier stage in the development of a sloping fen area and predates that at Nedre Tågsletta. The investigated site at Nedre Tågsletta is in the central part of the sloping fen and may represent a more recent initiation of fen development than the margins of Nedre Tågsletta fen, both downslope and upslope from the peat core. Both fen areas are thought to have expanded from flat or less sloping fen areas that started peat formation earlier in these landscapes. The continued expansion of fen areas, as can be attributed to climatic conditions, particularly periods of increased moisture and/or cooler climates. The reconstructed increase in fen areas around Bustmyra from c. 4380 to c. 3160 BC can be partly a result of cooler and moister climate in the area and region (Kullman, 1995; Haugland, 2010; Paus, 2010). A further increase in fen areas during the Pre-Roman Iron Age (500 BC–1 BC/AD) took place during a cooling period (Hammarlund et al., 2004; Paus, 2010; Prøsch-Danielsen & Sørensen, 2010). In Tågdalen the fen formation from c. 2350 BC at the central area of Nedre Tågsletta took place during a cooler period (Paus et al., 1987) and cooling and increased precipitation regionally towards around 1000 BC (Bjune et al., 2005; Lilleøren et al., 2012). Additionally, sloping fen expansion can be a consequence of locally heightened moisture in the peat and soils of the sloping terrain during the growing season, where the enlargement of fen areas itself contributes to further paludification, as discussed in Papers II and III.

In the early history of the boreal fens in Tågdalen and Sølendet, the inferred fen vegetation predominantly comprised a large cover of various *Carex* species, along with *Eriophorum* species, likely including *E. latifolium*, *E. angustifolium*, and *E. vaginatum*. Other species, such as *Trichophorum cespitosum* ssp. *cespitosum* and *Molinia caerulea*, were also present throughout the period (Figure 13). Additional species identified through the reconstructions likely include *Potentilla erecta*, *Thalictrum alpinum*, and *Succisa pratensis*. The primary plant families and species are consistent across the two studied areas of rich fen. Notably, *Campylium stellatum* was the most frequently sampled moss in both localities and is probable present during the rich fen history in both areas. The reconstructed vegetation represents a boreal rich fen ecosystem, characteristic of an area in the oceanic to indifferent climate sections (Papers II and III).

Both areas are interpreted to have been covered by rich-fen vegetation from their initiation onwards. This interpretation is based on the inferred presence of *Thalictrum alpinum*, *Crepis paludosa*, *Selaginella selaginoides*, and periods with *Succisa pratensis*, in addition to relatively low plant cover of *Sphagnum*, in accordance with the definition by Fremstad (1997). The presence of rich-fen vegetation in both areas is probable, given their location on calcareous-rich bedrock and moraine material (Sigmond et al., 1984; Follestad, 1995; NGU, n.d.), where sloping terrain facilitates the flow of calcareous water across the area. This history is typically for rich fen formation, where the high calcareous content in water has been available for the vegetation throughout the fen history (Rydin & Jeglum, 2006).

7.4 The history of rich fen cultural vegetation and the cultural landscapes of Tågdalen and Sølendet

The reconstructed semi-natural vegetation history from this study will be explored within the broader framework by focusing on local and regional settlements, historical land use practices, societal changes, and cultural developments that have influenced the types of vegetation present in the area. Archaeological and historical ages and periods are presented in Table 3, with the main events in the fen and land use history, and especially outfield activity, discussed in the following.

The botanical results in the present study and their interpretations are combined with botanical data from other studies for a more comprehensive understanding. Additionally, archaeological and historical sources have been studied to evaluate the probable historical development in the area.

7.4.1 Traces of local settlements prior to the initiation of outfield scything

In this study, extensive grazing in Sølendet is dated from circa 2605 BC and lasted until the initiation of scything around AD 1030. The grazing likely relates to the wild herds that were hunted by the hunter-gatherers known to inhabit the area (Binns et al., 1999). Apart from activities possibly related to grazing animals, no other evidence of human activities has been identified from this period in the current study; therefore, it is not possible to confirm the presence of local settlements. The lack of settlement traces aligns with few finds of hunting settlements in previous studies (Fjellheim, 1999, 2004).

The first possible indications of human impact in the Surnadal area are evidenced by charcoal fragments dating from 2350 BC onwards, interpreted mainly as reflecting small-scale local agrarian settlements, as previously documented in the region (Nyland, 2006). This impact might also include, to some extent, periodic natural fires (Paper II). High percentages of arboreal pollen and natural vegetation composition on the fen indicate limited human activities in Tågdalen prior to the Roman Iron Age.

Table 3. Reconstructed fen vegetation and land use history at Nedre Tågsletta, Tågdalen, close to the farms at Dalsegga in Surnadal, and Bustmyra, Sølendet, close to the farms at Brekken in Røros, based on data from Papers II and III. Local and regional information from Riksarkivet (1652, 1661), Indset et al. (1954), Sandnes (1971), Kjelland (1982), Binns (1993), Ringstad (1993), Jørgensen (1997), Fjellheim (1999), Tretvik and Krogstad (1999), Almås (2002), Lunden (2002), Myhre (2002), Øye (2002), Tveiten (2005), Nyland, (2006), Aspheim (2010), Amundsen (2011), Hansen and Olsen (2022). The chronology follows Bergsvik (2002) from the Mesolithic to the Bronze Age and Solberg (2003) for the Iron Age until the Viking Age.

Historical and archaeological ages and periods	Age (BC/AD)	Nedre Tågsletta in Tågdalen	Bustmyra in Sølendet	Local and regional history
The welfare state and Norwegian petroleum era **Recent time**	AD 1945 – present	Post-war reduction in outfield scything. All scything ceased in the 1950s, initiating plant succession. Tågdalen and Sølendet nature reserves were established, and management mowing started in 1973 and 1974 respectively. Succession ongoing in parts of the reserves.		Modern agriculture led to decreased activities, focusing on grazing in outfields. Outfield scything declined from the 1930s and ceased by around 1950.
Independence and World Wars **Recent time**	AD 1905 –1945	Scything on rich fens persisted. Outfield scything activity slightly decreased in the 1930s. Scything activity increased and sustained during the Second World War.		Outfield scything decreased from the 1930s, with grass production in infields increasing. During the Second World War, outfield scything played a key role in enhancing self-sufficiency and local production.
The modern Norway **Historic time** (HT)	AD 1814 –1905	Intensive outfield scything, akin to early 1900s practices, continued; mainly scything every two years per area, with half scythed annually.		A transformation in the 1800s led to significant changes in agriculture. Outfield scything for hay production continued, marking the period with the largest extent of outfield utilization.
The early modern period **Historic time** (HT)	AD 1536 –1814	Intensive outfield scything.	The intensive scything persisted from 1415 to until 1820 with slight differences from later historical practices. Periodic, extensive grazing likely occurred.	Increasing population. Extent of farmland areas comparable to High Middle Ages in the second half of the 1600s. Brekken resettled around 1650 and land use included the outfields.
Late Middle Ages (LMA)	AD 1350 –1536	Intensive outfield scything continued. Agricultural activity at local farms sustained.	Intensive scything continued. Local farms were deserted, possibly around 1415. From 1415, scything was carried out by distant farms.	The Black Death of 1349–1350, followed by subsequent plagues until the 1660s, resulted in a sharp decline in population and farm numbers. Many settlements in Surnadal persisted, but most farms in Røros, such as at Brekken, were abandoned sometime after the Black Death.
High Middle Ages (HMA)	AD 1130 –1350	Change to scything comparable to known historical scything c. 1135, probable intensive scything every two years at each hay fen area.	Scything persisted. Likely periodic, extensive grazing by wild animals and herding communities.	Population growth, intensification of farming, and advancements in agricultural technology. Some agrarian stagnation occurred in the first half of the 1300s.
Early Middle Ages (EMA)	AD 1066 –1130	Outfield scything.	Scything persisted. Likely periodic, extensive grazing by wild animals and herding communities.	Society saw increased regional and local power, necessitating greater surplus production for land rent and taxation.
Viking Age (VA) Late Iron Age (LIA)	AD 800 –1066	Outfield scything.	Scything began in 1030; intensive, akin to scything every two years. While specific instances of grazing during the scything period are not identifiable, it is likely.	An established and stratified society present in Surnadal and Røros, with permanent settlements at Brekken.
Merovingian period (MVP) Late Iron Age (LIA)	AD 570 –800	Outfield scything.	Rich-fen vegetation.	An established and stratified society present in Surnadal and Røros.
Migration period (MP) Early Iron Age (EIA)	AD 400 –570	Outfield scything.	Rich-fen vegetation.	Stratified chiefdom society with a growing population in Surnadal and agricultural settlements at Brekken.

Historical and archaeological ages and periods	Age (BC/AD)	Nedre Tågsletta in Tågdalen	Bustmyra in Sølendet	Local and regional history
Roman Iron Age (RIA) Early Iron Age (EIA)	AD 1–400	Outfield scything in Tågdalen initiated around AD 40. Scything frequency less frequent than every two years, differing from historically known practices.	Rich-fen vegetation.	Stratified society and increasing population in Surnadal. In Brekken, possibly both permanent and short duration settlements of agriculture and one of hunters. Agriculture with an infield/outfield system. Advancements in farming tools, including the use of the iron short-scythe.
Pre-Roman Iron Age (PRIA) Early Iron Age (EIA)	500 BC –AD 1	Rich-fen vegetation.	Rich-fen vegetation with coverage to current extent.	Society evolved, population grew, and technological advancements occurred. Agriculture employed both infield and outfield systems. Settlements in the Surnadal and Røros area persisted.
Late Bronze Age (LBA)	1200–500 BC	Rich-fen vegetation with coverage comparable to present-day conditions.	Decrease in trees from around 600 BC onwards likely indicates wood extraction by nearby settlements.	Agricultural settlements were established in Surnadal and around Aursunden, coexisting with the local southern Sámi hunting population in the Røros area.
Early Bronze Age (EBA)	1800–1200 BC	Rich-fen vegetation.	Rich-fen vegetation.	Local settlements in Surnadal and around Aursunden, near Brekken.
Late Neolithic (LN)	2300–1800 BC	Rich fen formation in central Nedre Tågsletta sloping area c. 2350 BC. Fen area increases thereafter.	Rich-fen vegetation.	Agricultural settlements in Surnadal. Both an agriculture and hunting present in the mountain areas from this time onwards.
Middle Neolithic B (MNB)	2600–2300 BC	Rich-fen vegetation.	Expanded fen areas in Sølendet and reduced forest cover. Extensive grazing by wild animals starting around 2690 BC.	Early agriculture, characterized by grain cultivation and husbandry, was regionally present in combination with hunting, especially in valley and fjord areas. A prehistoric hunting population persisted in the inner and mountain regions.
Middle Neolithic A (MNA)	3300–2600 BC	Rich-fen vegetation.	Rich-fen vegetation	Prehistoric hunter-gatherer population, to some extent merged with small-scale agricultural practices.
Early Neolithic (EN)	4000–3300 BC	Rich-fen vegetation.	Continued rich-fen vegetation and increased fen cover in the area.	Prehistoric hunter-gatherer population.
Mesolithic	9200–4000 BC	Earliest mire formation in Tågdalen identified around 8990 BC, southeast of Tågsletta.	Rich fen formation started c. 6585 BC.	Stone Age hunter-gatherer population.

7.4.2 Outfield scything in Tågdalen from the Roman Iron Age

The initial cultural impact on the fen vegetation in Tågdalen, evidenced by extensive scything activities from around AD 40 based on the age-depth model of the present study, coincides with the early Roman Iron Age (RIA) (Paper II); see Figure 13. This study is the first to identify the initiation of scything in outfield fen vegetation in the Iron Age. The long-standing presence of farms in the Surnadal area (Aspheim, 2010; Hyttebakk et al., 2021) suggests that outfield scything could have commenced earlier, possibly closer to the farms. It is important to note that the dating of the activity is interpolated and may slightly deviate from the actual commencement of scything. Nonetheless, the onset of the Roman Iron Age marks a significant period of expansion of agricultural land in the region based on archaeological data (Binns, 1993; Ringstad, 1993; Riksantikvaren, 2024), potentially representing the general start of outfield scything in the area.

While the main taxa on the fen in Tågdalen remained largely consistent before and after the onset of scything, the vegetation composition underwent significant changes in relative plant cover for taxa like inferred *Thalictrum alpinum*, and parallel to changes seen from present-day mown vegetation (Moen et al., 2012). A notable increase was also observed in *Eriophorum* species, primarily interpreted as *E. latifolium*, in addition to other *Eriophorum* species and *Trichophorum cespitosum* ssp. *cespitosum*, and *Carex* and Cyperaceae species, followed by a further rise in *Thalictrum alpinum* (Figure 13). The scything practice from the Roman Iron Age is interpreted to have been extensive, with no comparable modern analogues of mown fen vegetation.

The initiation of scything at Nedre Tågsletta highlights a local focus on husbandry and the need for increased local agricultural production, achieved through the expansion of land for hay collection. Similar developments and expansions in cultural landscapes during the period are observed in other areas in Norway (Myhre, 2002; Mehl & Hjelle, 2016). A division of farms into infields and outfields was established in Nordmøre at the time (Binns, 1993), representing an increase in resources available to the farms. The introduction and widespread use of the iron short-scythe and wooden rake during the Roman Iron Age (Solberg, 2003; Myhre, 2002, pp. 148) facilitated the expansion of agricultural land as the outfields of Tågdalen. Surnadal had long been influenced by settlements further south, as seen from cultural traces from the Late Neolithic and Early Bronze Age (Nyland, 2006). The coastal and valley areas in this region were culturally oriented westward, with societal development influenced by contact and trade along the coast and southwards (Myhre, 2002, pp. 168–169), explaining the development in Tågdalen as a part of the regional history along the coast.

As the outfields of Tågdalen are situated at some distance from the nearest farms and even further away from the most densely populated area in the valley floor, where agricultural conditions and soil were optimal (Binns, 1993; NIBIO, n.d. b), this suggests an increased resource pressure from an increasing population and the society's need for increased surplus from this period onwards in the local stratified chieftain society (Ringstad, 1993; Myhre, 2002, pp. 119, 137–139). Pollen data have primarily identified scything as a part of the farm economy on the fen, and even if Sámi activity is not identified in this study, wild herds were probably present in the area. While low-intensity, periodic grazing by wild animals is plausible, the pollen data from Tågdalen is interpreted to reflect small-scale scything.

In Sølendet, located at a higher altitude, there are no traces of farming in this outfield area in the Early Iron Age. The agrarian settlements during the Roman Iron Age are believed to have been small, utilising resources closer to the settlements (Aspaas & Aspaas, 1974; Binns et al., 1999). Such settlements would rather have impacted the landscape at and around Sølendet through the extraction of forest in the nearby area and region, as indicated by the further reduction in arboreal pollen, particularly from *Pinus sylvestris*. The vegetation at Bustmyra has remained similar since the Bronze Age onwards, and extensive and periodic grazing was likely influential on the fen areas throughout the Iron Age. The presence of large wild animals is interpreted to have been an important resource to both a hunter-agrarian society and a hunter-gatherer Sámi society, which has been claimed to have been consolidated into two distinct communities in the Roman Iron Age (Zachrisson, 2004; Amundsen, 2011; Hansen & Olsen, 2022, pp. 58–60).

7.4.3 Late Viking Age to the Early Middle Ages

At c. AD 1030 the first evidence of scything is identified in Sølendet (Paper III). Meanwhile, outfield scything continues in Tågdalen (Paper II). Sølendet is situated at a distance from the farms that existed at that time along Aursunden, and other outfield areas might have been utilised for scything earlier.

The land use of scything at both investigated areas is interpreted from the general similarities in the pollen assemblage, partly from modern analogues in Tågdalen (Figure 14), ordination from Sølendet (Figure 15) and the pollen data from indicator taxa (Figure 13). Among other indicators, scything is identified by an increase in *Eriophorum*-type pollen, likely originating from primarily *E. latifolium*, in addition to *E. angustifolium* and *E. vaginatum*. The Nedre Tågsletta and Bustmyra peat core samples have no modern analogues during the Viking Age and the Early Middle Ages. Due to differences in vegetation between this period's scything and modern mowing, scything from the late Viking Age to the Early Middle Ages is believed to differ from modern mowing in Sølendet and Tågdalen. However, it likely shares general similarities with traditional outfield scything, as shown in Figure 20. In Sølendet, a slight reduction in *Corylus* inferred to be *C. avellana*, followed by a reduction in *Picea abies*, which is considered to represent a signal of logging (Fjordheim et al., manuscript in preparation).

Figure 20. Haystacks, where the hay was dried and stored, in Sølendet from the last part of the outfield scything. To the left is Søren H. Nordset and to the right is Henning Nordbrekken. Photo: Unknown. Courtesy of the Rørosmuseet Collection (Røros Museum).

The start of Sølendet outfield scything at the end of the Viking Age took place at a time when the farms at Brekken were a focal point in the settlement in the Røros district (Sandnes, 1971, p. 23). During the Viking Age, a period marked by population growth and agricultural expansion, the inner landnam or settlement expansion was less extensive towards the forest limits (Binns et al., 1999; Solberg, 2003). However, it could still explain the increase in agricultural activity in the district associated with the Sølendet scything. With extensive farming based on husbandry, in addition to gathering and hunting (Jørgensen, 1997; Sandnes, 1971; Prøsch-Danielsen & Sørensen, 2010), there was a large demand for hay. The continued practice of scything is explained by the fact that the farm community remained an important agricultural area, one of five farm communities in Røros during the High Middle Ages, and a regional thoroughfare passed by here (Jørgensen, 1997; Sandnes, 1971, p. 349), a route seen in the map from c. 1650 (Figure 21).

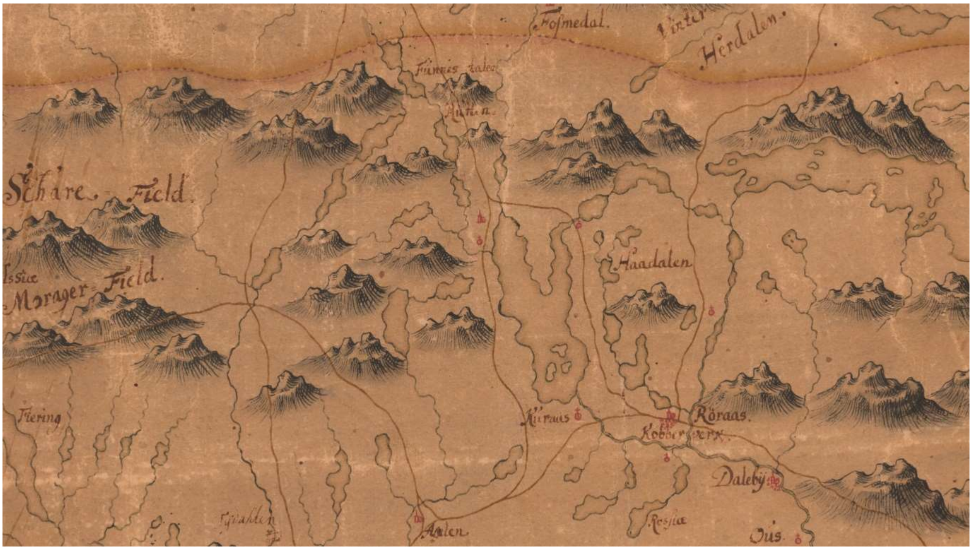


Figure 21. Excerpt of a map of Trondhjems Stift, uncertain dating around 1650. The top of the map is towards east with the Swedish border, and lake Aursunden is in the center of the map. The settlement Brekken with the church is situated along the river Glåma in the eastern part of Aursunden, and Kurrås (Kuraas) is on the western side of Aursunden. Source: Kartverket/The Norwegian Mapping Authority (1650).

From this study, the scything activity identified in Tågdalen and Sølendet is interpreted to represent a general agricultural trend. This trend involves the utilisation of outfield resources, more efficient use of technology, improvements in tools, and new land clearing during the Viking Age and Early Middle Ages (Øye, 2002, pp. 347–349). In the region, the summers became warmer from the Viking Age (Thun, 2006; Linderholm & Gunnarson, 2005), which could partly explain the agricultural expansion in higher-lying areas such as Brekken. Nonetheless, the farm communities in Røros were then as now situated well above the climatic limit for grain production (Lunden, 2002; Bjørkelo et al., 2022), and an increase in population and technology is likely the main explanation for the identified development.

During periods of reconstructed scything within this study, it was not possible to identify extensive grazing (Paper III). Alongside the agrarian settlements, the Sámi hunter-gather society was present in the area around Brekken and Røros in the Viking Age and the High Middle Ages (Bergsland, 1943). The presence of large herds of reindeer, inferred from extensive trapping systems around Sølendet as well as in the region (Mikkelsen, 1994; Weber, 2007; Jordhøy, 2008; Riksantikvaren, 2024), suggests periodically grazing on the scythed outfields (Sandnes, 1989; Kjelland, 1991), even though grazing to some degrees was hindered during periods of historical scything (Moen, 1990). Based on historical and archaeological data (Fjellheim, 2004, 2012; Riksantikvaren, 2024), grazing on the fens probably took place at low intensity even if it is not identified in this study.

The early outfield scything in Sølendet took place during the transition to a changing society in which a new religion became widespread and established, and technological development took place. The Viking Age farming practices evolved into their historically known forms, as the power of the church and state consolidated. The start of the scything history is interpolated to 1030, a well-known year in Norwegian history, marked by the Battle of Stiklestad, where the death of king Olav den Hellige (Saint Olav) represented further consolidation of power. The changes led to an increased demand for taxation and, consequently, an increased demand for surplus from the farms (Øye, 2002, p. 360, 409–411). These societal changes explain the increase in agricultural activity, of which the reconstructed history of scything in this study is a part.

7.4.4 Land use intensification from c. 1135–1415

A mowing practice comparable to the historical scything of the early 1900s is detected in the early High Middle Ages, from around 1135, at Nedre Tågsletta, based on the age model from the present investigation (Paper II). The changes in pollen assemblage, especially the increase of inferred *Thalictrum alpinum*, *Eriophorum latifolium*, and other *Eriophorum* species, and some decrease in Poaceae, which is inferred to be mainly *Molinia caerulea*, reflect increased scything of the semi-natural vegetation (Figure 13). Scything every two years is probable as the peat core samples have modern analogues from scythed vegetation of this intensity. The change is primarily quantitative in the pollen assemblage (Paper II), in accordance with previous studies from semi-natural rich-fen vegetation (Moen, 2000).

The increase in scything intensity reconstructed from Tågdalen coincides with a period of prosperity during the latter part of the Early Middel Ages (Sturlason, 1959, p. 632; Øye, 2002). From the High Middle Ages, the population in Norway was increasing, leading to the cultivation of new lands around existing settlements, and outfields, formerly mainly commons, became private property, particularly in the first half of the 1300s, and this shift reflected broader changes in land use and ownership patterns during the Late Middle Ages (Øye, 2002). A further indication of increasing pressure on resources is the development of the system of land rent tenant farmers had to pay, a system known from the 1100s and possibly earlier (Øye, 2002, pp. 228–229, 267). The consolidation of royal power, along with the development of church organization, led to a larger portion of production from the farms being diverted in the form of taxes and duties to the kingdom and church during the Middle Ages (Øye, 2002, pp. 409–411). The increase in hay collecting in Tågdalen is interpreted to result from the mentioned changes in society, and increased areas used of scything were probable common locally as part of a developed agricultural community.

The outfield activity and interpreted general farm activity continued for both investigated areas with outfield scything though the Middle Ages (Papers II and III). With a decrease in population following the Black Death and subsequent plagues (Lunden, 2002), the remaining population and the farmers would have had more infields available, potentially leading to lesser exploitation of outfields in some districts. Based on the reconstructed vegetation, my interpretation is that the farming settlements at Dalsegga or nearby areas in Surnadal continued to be inhabited and maintained farming activities after the Black Death and onwards, whereas the outfields in Sølendet were continuedly used by the nearby farms at Brekken until 1415.

7.4.5 Land use variation and stability 1415–1650

There was no identified change in the fen vegetation around the transition to the Late Middle Ages in either of the two areas, suggesting the continued practice of scything and maintenance of the semi-natural vegetation (Figure 13). Consequently, the farms near Tågdalen and in Brekken are interpreted as having remained operational in the period following the Black Death. Archbishop Aslak Bolt's cadastre from 1432–33 (Jørgensen, 1997) indicates that farms at Dalsegga were inhabited during this period, signifying their inclusion in the local settlements (Grimeland, 1925). Many farms in Trøndelag, abandoned at the end of the Middle Ages, were still settled during the 1400s and early 1500s (Sandnes, 1971, 1973). Similarly, in Brekken, a marked change in outfield scything c. 1415, as indicated by the age model of this study, may relate to farm abandonment and changes in land rights. The same cadastre does not mention settlements at Brekken or in the Røros district, suggesting that they were abandoned at the latest by 1433 (Jørgensen, 1997), and possibly earlier.

From around 1415, continued local scything in Sølendet is interpreted as representing summer hay collection from distant farms, along with possible pastures. Farmers travelling a distance to collect hay following the abandonment of farms is a tradition known from later periods in the Aursunden area (Indset et al., 1954; Reinton, 1957; Sandnes, 1989). The similarity with modern mown vegetation, an increase in fen covers of inferred *Eriophorum latifolium* and *Thalictrum alpinum*, and a decrease in *Molinia caerulea*, *Potentilla erecta*, and several *Carex* species, indicates a minor increased intensity of the scything practice (Figure 13). The similarities with pollen deposition from modern mown vegetation and weak indications of grazing, such as the inferred presence of *Rumex acetosa* and *Solidago virgaurea* and a slight decrease in *Juniperus communis*, probably ssp. *communis*, suggest periodic grazing in addition to scything, as demonstrated from other studies (Hjelle, 1999; Evju et al., 2006; George et al., 2021). Scything followed by subsequent grazing by farm animals for shorter periods and at low density is known for this type of semi-natural vegetation (Sandnes, 1989).

A continuation of Sámi settlements during the late medieval period has been reconstructed in the region (Fjellheim 1999, 2012; Narmo, 2000), and it has been suggested that the South Sámi people might have utilized the areas abandoned by farmers following the Black Death for grazing (Sandnes, 1971, 1973). Based on these reconstructions, it appears that other farms, rather than the South Sámi settlements, took over the utilisation of the local resources in Sølendet. Nevertheless, the utilisation of outfields by distant farms allowed for periodic grazing by wild animals, such as reindeer, supporting the economic activity for the South Sámi settlements.

Even with the challenges faced by the agrarian society towards the end of the High Middle Ages, settlements were maintained in good farming areas like in the Surnadal valley. A transition to larger farms with a focus on husbandry led to continued agriculture in most valley areas (Lunden, 2002; Øye, 2002), as evidenced in Tågdalen. A greater focus on livestock farming, albeit on fewer farms, could explain the sustained and comparable frequency of mowing in the areas of Surnadal.

7.4.6 The early modern period towards 1820

Brekken was still abandoned in 1647 (Fladby & Schou, 1974) and first appears in the subsequent cadastre in 1651 (Riksarkivet, 1652; Indset et al., 1954) with settlements being recorded from that time onwards. A map from around 1650 depicts the church at Brekken, further supporting resettlement at the mid-1600s (Figure 21), where Brekken once again became one of the focal points in the Røros district in the latter part of the century (Aspaas & Aspaas, 1974). The outfield Sølendet is not mentioned until 1688 (Kvikne, 1942). This settlement development is consistent with the general restitution of High Middle Age farms in the Røros district during the latter half of the 1500s and the 1600s (Indset et al., 1954; Solem et al., 2012; Tretvik et al., 2015). The vegetation changes around 1700 could reflect a delayed response to the shift in land use rights for local farm areas that occurred around 1650, or a change in or temporary cessation of scything practices in Sølendet. The interpreted shift from summer hayfields to local outfields with the continuation of scything might explain why the pollen data only displays this minor change in vegetation, as such activities would likely result in continued land use and comparable cultural influence. There is no indication from the data in Sølendet of the well-known deforestation following the establishment of the copper works in Røros in 1644 (Prøsch-Danielsen & Sørensen, 2010). This further emphasizes that pollen analysis can capture local vegetation signals from fen areas. Scything continued in Tågdalen, likely utilised by the nearby farms in Surnadal, which remained a central farming community from the Iron Age onwards.

7.4.7 Intensive fen scything from c. 1820

The peak utilization of outfield resources in Norway occurred during the 1800s, and the fen vegetation exhibits changes that reflect some increase in scything activity from around 1820 in both investigated areas (Papers II and III). In Tågdalen a quantitative change in interpreted plant cover took place, including an increase of *Eriophorum* species, high percentages of *Thalictrum alpinum,* a decrease in the Asteraceae Cichorioideae inferred to represent the species *Crepis paludosa* and *Scorzoneroides autumnalis* (Paper II), and low occurrences of *Solidago* species and *Potentilla erecta*. A reduction in Asteraceae Cichorioideae species has been related to an increase in scything activity from other studies (Moen, 2000). Alongside the presence of modern analogues, reduction in Asteraceae Cichorioideae (Figure 13) suggests an escalation in scything activity and harvest from both the infields and especially from the outfields. During this period, outfield activities, including trails and summer farms, are depicted in local maps as in Figure 22. In Sølendet, a simultaneous change in interpreted scythed fen vegetation shows a rich-fen vegetation comparable to that documented around 1900 and into the mid-1900s. There is

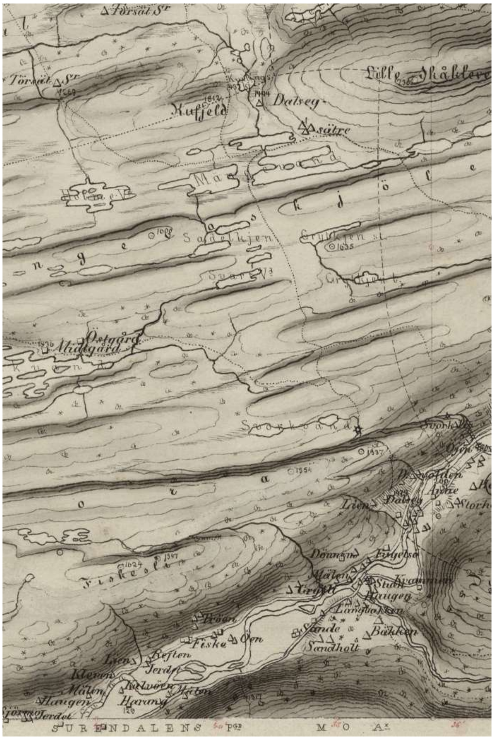


Figure 22. Excerpt from a map with the northeastern part of Surnadal in 1872. The Dalsegg farms are located on the northern side of the main river in the Surnadal valley, in the lower eastern part of the map. A trail from Dalsegg heads north, crossing Tågdalen (not labeled), and west of the lakes Store and Litl Grytkjern, leading to the summer farms at Dalseggsetra in the north. Source: The Norwegian Mapping Authority, 1872.

Figure 23. Haymaking season in Sølendet. From left: Nils Feragen, Arnt Solberg, Alfred Feragen, Ingeborg Feragen, Anders Feragen, an unknown individual, and Bjarne Feragen. Photo: Unknown. Courtesy of the Rørosmuseet Collection (Røros Museum).

an increase in *Thalictrum alpinum* and *Pedicularis* pollen, with the latter likely representing predominantly *Pedicularis palustris*, which is the most common among the *Pedicularis* species on these rich fens and increases in prevalence with mowing (Paper I).

Since both areas follow a similar trajectory from the early 1800s, leading to the eventual reduction and cessation of outfield scything, the factors driving the interpreted development are contextualized within the broader scope of national agricultural history. This intensification coincided with the changes describes as The Great Transformation, which impacted the economy and farming practices, leading to modernisation in farming communities and the reallocation of resources (Gjerdåker, 2002, pp. 293–296), subsequently resulting in increased efficiency in farming practices (Timberlid, 1988). Intensive outfield use continued in both study areas into the first half of the 1900s, with activities in Sølendet illustrated in Figure 23.

7.4.8 End of scything around 1950

A reduction in scything activity is observed from the Tågdalen pollen reconstruction after 1920 towards the end around 1950, reflecting the documented decline from the 1930s onwards (Moen, 1998; Tretvik & Krogstad, 1999). From the Sølendet pollen data, no clear reduction can be identified prior to the end of scything c. 1950, although historical sources suggest some decline a few years earlier (Moen, 1990). Vegetation reconstruction from both Tågdalen and Sølendet identifies the end of scything around 1950 in this study, following a general national trend in the long tradition of outfield haymaking (Statistisk Sentralbyrå, 1950; Moen, 1990, 2000). The reduction in scything during these decades was part of long-term changes in the national agriculture sector (Moen, 1990). Minor phases of increased activity during the Second World War and continued activity at some farms could not reverse the general trend in agriculture with more activity on the infields, as increasingly more farms ceased outfield scything

(Tretvik & Krogstad, 1999). Left in the landscape were hay barns and grindstones to reflect the activity that had ended, illustrated in Figure 24.

The changes that followed on the fens were quantitative, and no substantial change in the species present on the rich fen was registered in the present study, consistent with findings from earlier vegetation studies (Moen, 1990, 1995, 2000; Moen et al., 2012). The reduction in the utilization of the outfields led to significant changes in the landscape, characterised by a slow succession leading over time to overgrowth on parts of the fen, as observed in this study and others (Moen, 1990).

This study supports the earlier findings that succession is slow in such fen vegetation, and a slow change from mown to unmown vegetation characteristics took time after the mid-1900s and until the start of management mowing from the 1970s (Moen et al., 2012). Thus, a combination of both mown and unmown modern analogues is identified from the mid-1900s for both areas. Some changes following the succession can be observed, as for Sølendet with the increase in Poaceae, mainly *Molinia caerulea*, and *Juniperus communis*. A succession is less evident in Tågdalen, probably because the sampling point is situated in the center of a mown area, but an increase in Cyperaceae species reflects succession in the area. This change in the fen vegetation indicates that even though large fen areas are mown as part of the nature reserve management, some succession occurs in parts of the mires as the management activity is not as extensive and generally intensive across all fen areas as during historical scything.

The scything tradition is reconstructed continuously for over 1900 years in Surnadal and over 900 years in Røros, under various climatic, cultural, and demographic conditions. The development and condition within the agricultural sector and framework conditions with the resulting land use practices explain the main changes in the vegetation during the period of scything.

Figure 24. Following the cessation of scything, traces of the hay collection and the activity on the rich fen areas are found in the form of grindstones and barns, as at Dahlbua in Sølendet.

7.5 Pollen and NPPs in local fen vegetation reconstructions: some methodological considerations

The present investigation underscores the importance of identifying pollen to the lowest possible taxonomic level, particularly for *Eriophorum*-type and *Carex*-type pollen, which are crucial in detecting land use changes in boreal rich-fen vegetation. Due to the fragile nature of pollen grains in Cyperaceae, identifying the majority of these grains may not be possible. Nevertheless, with a large number of identified pollen grains per sample, the proportion of *Eriophorum*-type and *Carex*-type pollen can significantly contribute to the interpretation of vegetation types where Cyperaceae species exhibit varied responses to local cultural and natural factors.

Both 2007 and the moss polster sampling year 2008 were normal to good flowering years for most of the species studied, for example *Eriophorum latifolium* (Moen, 1990; Lyngstad et al., 2017), a primary species among the *Eriophorum*-type taxa in the vegetation. It is well-documented that there can be significant variations in flowering between individual years (Hicks, 1985), a phenomenon also observed in Sølendet (Moen, 1995). The good relationship between vegetation and pollen in the moss polster samples (Paper I), indicates that potential year-to-year variations in pollen production are evened out (Hicks, 2001; Bunting, 2003; Nielsen et al., 2010) and moss polster samples are considered comparable to average conditions in contemporary peat core samples, making the sampled period a reliable representation of the rich-fen vegetation sites.

Due to the variability in peat accumulation rates over time and the coarse resolution of dates throughout the core, the pollen concentration values are subject to both short-term and long-term variations in peat accumulation, making them difficult to interpret accurately over longer time periods. Therefore, pollen concentration values are used cautiously and may be more informative for interpreting relationships between species within peat core samples rather than between different peat core samples, as between Poaceae and *Eriophorum*-type pollen during periods with scything. For long spans where dates are only interpolated, pollen influx was not used as a measure of pollen content. Pollen percentages were used for most calculations. Alternative data from sediments with a more even deposition, like lake sediments, would not represent comparable and local vegetation in limited plots as needed in this study.

Sloping fens typically exhibit less moisture compared to other mire varieties, such as bogs located in flat areas and depressions, or mires with surfaces constantly covered in water (Moen, 1990). Despite this, sub-fossil pollen from these mires is preserved and incorporated into the accumulating peat over time (Papers II and III), as also observed in other studies (Wilmshurst & McGlone, 2005). Other plant remains, such as seeds and leaves, were largely decomposed in the peat and not found in sufficient quantities for statistical analysis. However, they were present in adequate amounts to provide material for ^{14}C dating in selected peat core samples throughout the cores.

The identification of NPPs, specifically the perforation plates of *Alnus*, *Betula*, and *Corylus* species, has aided in determining periods of limited fen extent. As other parts of leaves and seeds decomposed, only the most decay-resistant parts remained intact in the peat, as noted in Papers II and III. The early stages of fen development and areas of limited fen were reconstructed; trees and bushes, such as *Betula* species and *Salix glauca*, were interpreted to have been near the coring locality, as evidenced by registered perforation plates and pollen. The combination of pollen and macrofossil analysis is otherwise comprehensive for identifying local vegetation (Birks & Birks, 2000). Pollen analysis of fens, like those in this study, has been shown to effectively reflect local vegetation in areas with low plant height and limited pollen dispersal (Hjelle, 1999; Bunting & Hjelle, 2010; Waller et al., 2017). The combination of limited pollen dispersal on fen and the use of perforation plates enabled an identification of plant-pollen relationships within very limited areas, as seen from identified differences between investigated plots only one to few meters apart (Paper I). The surface sampling method, the open fen vegetation of limited heights of herbs where the pollen dispersal distance is relatively short

(Bunting & Hjelle, 2010), and the identification of herb taxa to low taxonomic resolution, as for *Eriophorum*-type and *Carex*-type pollen, and NPPs in sum made a modern pollen data set with mapped vegetation that has proven useful for the present study and will represent modern plant-pollen relationships for future reconstructions.

7.6 The role of natural conditions versus human activities for the development of cultural vegetation

The investigations from Tågdalen and Sølendet have demonstrated that the cultural conditions, to a much larger extent than natural factors like temperature, led to the observed changes in land use, including decisions on altering or continuing economic systems (Papers II and III). This significance of cultural factors is corroborated by other investigations (Huhtamaa & Ljungqvist, 2021). The main changes within the boreal fen vegetation in the investigated areas are interpreted to have occurred due to societal changes in population development, resource needs, available knowledge, and technology, as shown by Myhre (2002) and Øye (2002), and further factors such as demand for surplus and pressure from taxation, as well as societal desires for prestige, as discussed by Pedersen & Widgren (1998). The use of available resources in these study areas appears to compensate for single natural factors like climate change and individual years with poor harvests, as reported from other studies (Ogilvie, 1986; ter Schure et al., 2021). Years of poor harvests occurred in the early 1800s in the region (Nordli, 2004; Dybdahl, 2014) without leaving discernible traces in the scything activity in the investigated areas.

The role of society is evident, for instance, grain cultivation took place in mid-Norway during the Pre-Roman Iron Age, a period characterized by a cooler climate (Binns, 1993) and periods of increase in mowing activity and outfield scything, coincided with developments in tools and new land clearing (Solberg, 2003; Myhre, 2002). This can be linked to the initiation of scything in Tågdalen c. AD 40 (Paper II), associated with population increase and as part of the expansion and intensification within established farming communities during the Roman Iron Age (Binns, 1993; Hjelle et al., 2018). An increase in farm animals and the need for fertilizer and manure from the animals fed on outfield hay was essential for grain production on the infields. The intensification in scything practice from c. 1135 is further interpreted as following a period of population increase and larger agricultural activity regionally (Paper II), in line with Øye (2002).

The scything in Sølendet commenced during a period of warmer climate (Linderholm & Gunnarson, 2005), yet in an area that was probably above the climatic limit for grain production throughout the period of agrarian activity in the area (Lunden, 2002; Bjørkelo et al., 2022). Therefore, the climatic effect is not considered to have played a major role in the increase in farming area. Instead, it was more likely due to the increased need for resources, both to secure livelihoods on the farm and to generate the surplus needed to pay taxation (Paper III). Increased farming activity is also observed in other farm areas in Røros in this period (Prøsch-Danielsen & Sørensen, 2010).

The 1800s saw an increased intensity of outfield scything, as part of the general growth of the agricultural sector, following population increases and a greater need for resources. The intensification mirrors the developments in agriculture in the 1800s (Papers II and III), also described by Gjerdåker (2002). The observed cessation of scything later on was due to national agricultural changes influenced by technological development, mechanization, and political framework conditions (Papers II and III). The reduction and eventual end of outfield scything clearly demonstrates the impact of cultural factors external to the farm on land use continuation and change (Papers II and III). Thus, the findings from this study align with the condition that changes in cultural landscapes are often the result of cultural considerations and actions rather than isolated natural factors and environmental conditions, as demonstrated by other studies (e.g., Ogilvie, 1986; Huhtamaa & Ljungqvist, 2021).

Climatic changes during the period of outfield scything have led to minor variation in vegetation composition on the fens and of vegetation zones, in accordance with previous studies (Ross et al., 2019). Up to c. 2000 BC the vegetation at Bustmyra is interpreted as being within the southern boreal to lower middle boreal vegetational zone, shifting to the middle boreal zone thereafter. From around AD 1000, there was a slight shift to the upper part of the middle boreal and towards the northern boreal zone, comparable to the present-day situation (Paper III). Based on other studies in the region (Paus et al., 1987; Haugland, 2010), and assumed similar conditions in Tågdalen (Paper II), the vegetation zones for the two areas are interpreted to be similar. The interpretation of vegetation zones has largely been based on extra-local and regional vegetation (Paper III). Given the interpreted limited variations in fen vegetation over the investigated period, the fen as a resource would have contributed comparable fodder over time.

7.7 Historical contributions from the reconstructed local vegetation history

This study identifies the initiation of outfield scything in fen areas at Tågdalen in Surnadal and Brekken in Røros, providing information on the practice's extensive history (Papers II and III). The scything reconstruction at Nedre Tågsletta is the earliest documented example of outfield fen scything, dating back to c. AD 40. Scything is further evidenced to have persisted until around 1950, initially through extensive scything, followed by a shift to intensive scything akin to the biennial scything historically known in the region (Paper II). Further, this study has demonstrated that pollen analysis and the history of the local vegetation can aid in the interpretation of settlement history and land use practices over time.

In the Røros area, the onset of scything at Bustmura, Sølendet, is dated to c. 1030 (Paper III). Additionally, scything during the fallow period following the Late Middle Age abandonment is reconstructed. The identified period of scything by farms at a distance is suggested to have begun around 1415, lasting until the resettlements at the Brekken farms. Resettlement occurred by 1651 (Riksarkivet, 1652; Indset et al., 1954), and possibly as early as 1648, given these farms' absence from the 1647 tax register (Fladby & Schou, 1974). This finding contradicts earlier suggestions by Sandnes (1971) that the land at a farm distant from nearest farm with continued land use would lie fallow during the abandonment. Moreover, evidence of extensive grazing has been reconstructed from c. 2605 BC, continuing at least until scything began in 1030, and possibly taking place for periods during scything from 1030 onwards. However, if there were periods where scything and grazing occurred concurrently, identifying extensive grazing has been challenging. No clear evidence of Sámi hunting or later herding activities has been identified on the fen. Such activities cannot be ruled out but must have been limited, as animal grazing, if present, would have been limited to an area where hay was collected.

Centering this study on scythed rich-fen vegetation, the primary focus has been agricultural history. Both studied areas have constituted important resources for grazing animals, both near and far from settlements, and have also been integral to hunters and herders. The history of Tågdalen is largely interpreted as being predominantly connected to agricultural developments, from the time of the earliest evidence of outfield scything identified in this study. In Sølendet, these resources have been significant not only for farmers but also for hunters and herders as grazing areas. However, the identification of land use has primarily indicated farm-related activities. The selection of study areas inherently limits the scope of the historical narrative that can be reconstructed. Investigating the infields of farms in areas like Surnadal or Røros, or examining reindeer pastures and summer mountain farms, would reveal different aspects of the local history.

The results of the reconstructions in the present study have bridged gaps in the local history of Tågdalen and Sølendet nature reserves, as well as the agrarian district they are part of, thereby enhancing our understanding of the regional history of outfield land use.

8. Concluding remarks and further perspectives

The cultural vegetation and landscapes of hayfields on rich fens have been reconstructed over a 1900-year long period. By integrating a historical perspective with ecological analysis, the transformation to cultural landscapes and factors influencing the vegetation from the Roman Iron Age to the present day have been identified. Outfield scything was identified as far back as c. AD 40 from Tågdalen and c. AD 1030 from Sølendet. In both areas, scything continued with varying intensity. The intertwined relationship between the activity on the infields and the scything on the outfields enabled an increased output from the farm even if the extent of intensively used and fenced areas did not increase accordingly. This study has demonstrated that intensified use of outfields in Surnadal took place at a time when there was an increased need for resources and where technological improvements were in place in an established agricultural area. Population density and the pressure on resources were lower in inner and higher-lying areas, such as Røros, where the use of outfields was less intensive until the Late Iron Age and the Middle Ages, explaining the later start of the local outfield scything reconstructed in this study. The reconstructed agricultural history is comparable to results from other areas of Røros (e.g., Prøsch-Danielsen & Sørensen, 2010). The initiation of outfield scything on these fens reflects local conditions in agricultural societies and constitutes a part of the local as well as the regional history. From the 1800s, the reconstructed history of outfield scything in those areas converged, indicating that broader conditions in Norwegian society influenced the tradition of outfield hayfields. This period saw a high population and extensive use of large areas for agriculture. The tradition of outfield fen scything persisted until mechanization, technological advancements, and efficiency improvements in agriculture shifted the focus to yield from infield cultivation. These changes led to a significant reduction and eventual cessation of outfield scything around 1950, following the general change in Norwegian agriculture (Statistisk Sentralbyrå, 1950; Almås, 2002). Based on the present investigation, the agricultural activities and the extent of the area harvested by the farms during different periods were mainly a result of cultural variables. These included the local population number, available technology, and the characteristics of the harvested vegetation. Practices were adjusted to the natural conditions, which played a lesser role in determining the chosen activities.

The dating of periods of outfield fen scything identified in the study relies on outfields at some distance from the farms. It is possible that outfield scything, both near and further away from the farms, generally took place in the fjord and valley districts in western and central part of Norway from the Roman Iron Age. A goal for further studies can be to reveal whether outfields closer to Iron Age and Middle Age farms were used for hay collecting during an earlier time period, or if the large-scale outfield resource utilization mainly began in the Roman Iron Age.

The mires were rich fens from the outset of peat formation on the investigated slopes, with the initial date to c. 6585 BC at Bustmyra and c. 2350 BC at Nedre Tågsletta. The start of the peat formation at the investigated sites is interpreted to represent different stage of their rich fen formation, with the fens further increasing in extend over time, covering larger sloping areas. At Bustmyra, extensive grazing, suggested to have started around 2605 BC and continued at least until scything commenced, is interpreted to reflect grazing by wild animals, such as the wild reindeer that laid the foundation for the local hunter-gatherer society and later Sámi settlements.

The scything of the investigated rich fens formed a semi-natural vegetation, as found regionally where it has made up an important part of the cultural landscape during the modern period (Reinton, 1957). The quantitative changes in plant composition that characterised the semi-natural landscape were interpreted based on a larger reconstructed cover of taxa such as the genus *Eriphorum* and partly of *Thalictrum*, inferred to represent species like *Eriophorum angustifolium*, *Eriophorum latifolium* and *Thalictrum alpinum*. Periods of no scything or limited mowing were identified from larger plant cover of taxa like Poaceae and *Potentilla*, inferred to a large degree represent *Molinia caerulea* and *Potentilla erecta*. Pollen and spore analyses have been demonstrated to be well suited for reconstructing past vegetation and cultural activities related to outfield scything in semi-natural vegetation. The current findings underscore the significant influence of outfield scything in creating semi-natural vegetation. In addition to the reconstructed fen vegetation, a cultural landscape of more open wooded areas is reflected in the data.

Adopting the principle that ‘the present is the key to the past’ and leveraging knowledge of current land use and responses in vegetation composition, as well as examining the modern plant-pollen relationship, both past vegetation and land use patterns have been reconstructed. However, some variations in scything, as suggested by changes in vegetation over time at Nedre Tågsletta c. AD 40–1135 and Sølendet c. AD 1030–1415, have not been fully understood in terms of scything intensity. The variations in the intensity of historical scything and the identification of who carried out the scything of the fens in Røros following the Late Middle Age abandonment remain unresolved. Even though the past can be inferred from our understanding of the present and activities carried out in our recent past, the past remains ‘a foreign country’, as Lowenthal (1985) noted. This highlights the comprehension and reconstruction of the past as not complete but based on what is currently known and understood. Modern pollen-plant datasets from cultural vegetation types not yet studied and vegetation subject to various land use practices can significantly enhance our knowledge of cultural landscapes and their histories. During the investigated period, there was no data of the plant-pollen relationship from areas of quantified grazing pressure recorded from these areas, neither from agricultural husbandry nor reindeer grazing. Incorporating such data and the effect grazing ecology have on mire vegetation could substantially improve future studies and aid the reconstruction of various land use practices. Correlating pollen data with plant characteristics, particularly those related to flowering and land use, may provide valuable insights into variations in potential pollen production and deposition across different management practices.

Further, integrating ordination with the modern analogue technique is recommended for peat core pollen analyses in future analysis. This would strengthen the result from MAT and display similarities and variation between peat core samples within a peat core that might not have comparable modern analogues in vegetation data set, as seen from scythed moss carpet peat core samples from the end of the Viking Age onwards at Bustmyra.

Succession occurs when semi-natural vegetation is abandoned, as in parts of Tågdalen and Sølendet. Consequently, certain plant species, flourishing under traditional practices due to reduced competition, are at risk of significant decline, becoming threatened or even extinct across various vegetation types (Hovstad et al., 2018), resulting in decreased biodiversity due to the encroachment of taller herbs, shrubs, and trees. Additionally, both cultural and natural landscapes are increasingly being converted or removed for alternative land uses, leading to the removal and drainage of peat in boreal mires, thereby transforming them from carbon sinks to carbon sources (Fortuniak, 2021). Moreover, preserving biosphere integrity constitutes one of several critical thresholds anthropogenic impacts that are exceeding beyond sustainable development (Richardson et al., 2023). Maintaining biosphere integrity involves preventing the reduction of genetic diversity, the variation within and between species, and ensuring the preservation of functional diversity, which refers to the ecological functions of species within ecosystems, such as the boreal mires. It is imperative that these boundaries are not transgressed in the future, as they are today. Therefore, preserving mires and their vegetation composition, including rare and endangered species, is of vital importance.

The semi-natural landscapes, created and maintained by centuries of land use, represent an important component in preserving biodiversity amidst modern challenges. The dynamic interplay between human activity and ecological processes underscores the significance of understanding historical land use practices in informing contemporary conservation strategies. Further, cultural landscapes, as artefacts of agricultural history, contribute to our identity and sense of belonging (Agnew & Duncan, 1989; Skogheim et al., 2018), adding to the preservation value of these landscapes. Recognising the ecological and cultural value of traditionally managed landscapes can facilitate the development of more informed approaches to biodiversity conservation, ensuring that the rich mosaic of species fostered by historical scything practices continues to thrive.

To conclude, this study contributes to the knowledge of, and focuses on, boreal mire ecosystems highlighting the role the investigated areas have as conservers of biodiversity, cultural bearers, and historical archives. It aims to broaden the general understanding of the mires' history as well as to encourage an increased emphasis on and preservation of the crucial values. By doing so, this research underscores the importance of boreal mires, ensuring their role in securing biodiversity, storing carbon, and preserving cultural heritage for future generations.

Throughout the history of outfield scything, as generally in farming, the emphasis has been on the necessity for resources, with adaptations made to natural conditions and within cultural frameworks. The reliance on natural elements and the importance of one's endeavors to secure harvests and one's future are prevalent throughout history.

Å så æn mårgå ska såtåinn kastast,
da blir det spørsmål om vakkert ver.
Fær løinn skår lyt e sikkert lastast.
Meinn får du høytørk fær fager fer?

Hans Hyldbakk (2010)

And then one morning, the hay will be scattered,
then it will be a question of fair weather.
For poor scything, surely, I'll be blamed.
But do you get hay drying weather for your fair journey?

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Appendix

Appendix A – Plant species

List of plant species included in the text, listed alphabetically after their Latin name. Plant nomenclature for Latin and Norwegian for vascular plant names follows Elven et al. (2022), where older Latin nomenclature used in parts of the thesis is mentioned and market with * following Lid and Lid (2005), and other common Norwegian names are included for some species. For English vascular plant names are according to Poland and Clement (2020) except for species outside the British flora, where these are listed with their commonly used English plant names °. Nomenclature for mosses follows Frisvoll et al. (1995) for Latin and Norwegian names and Smith and Smith (2004) for English names.

Nomen Latinum	Norsk namn	English name
Alnus incana ssp. *incana*	skoggråor, gråor	grey alder
Alnus glutinosa	svartor	alder
Andromeda polifolia	kvitlyng	bog-rosemary
Anemone nemorosa	kvitsymre, kvitveis	wood anemone
Bartsia alpina	svarttopp	alpine bartsia
Betula nana var. *nana*	dvergbjørk	dwarf birch
Betula nana x *pubescens*		
Betula pubescens	bjørk	downy birch
Bistorta vivipara	harerug	alpine bistort
Calluna vulgaris	røsslyng	heather
Campylium stellatum	myrstjernemose	yellow starry feather-moss
Carex capillaris	hårstorr	hair sedge
Carex chordorrhiza	strengstorr	string sedge
Carex dioica	særbustorr	dioecious sedge
Carex echinata	stjernestorr	star sedge
Carex flava	gulstorr	large yellow-sedge
Carex flava x *hostiana*		
Carex hostiana	engstorr	tawny sedge
Carex lasiocarpa	trådstorr	slender sedge
Carex limosa	dystorr	bog-sedge
Carex nigra	småstorr	common sedge
Carex panicea	kornstorr	carnation sedge
Carex pauciflora	sveltstorr	few-flowered sedge
Carex rostrata	flaskestorr	bottle sedge
Carex simpliciuscula (previously *Kobresia simpliciuscula*[*])	myrtust	false sedge
Carex vaginata	slirestorr	sheathed sedge
Corylus avellana	hassel	hazel
Crepis paludosa	sumphaukeskjegg	marsh hawk's-beard
Dactylorhiza lapponica	lappmarihand	Lapland marsh-orchid °
Dactylorhiza maculata (ssp. *maculata*)	flekkmarihånd	heaths spotted-orchid
Deschampsia cespitosa (ssp. *cespitosa*)	sølvbunke	tufted hair-grass

Nomen Latinum	**Norsk namn**	**English name**
Eleocharis quinqueflora	småsivaks	few-flowered spike-rush
Equisetum palustre	myrsnelle	marsh horsetail
Erica tetralix	klokkelyng	cross-leaved heath
Eriophorum angustifolium	duskull	common cottongrass
Eriophorum latifolium	breiull	broad-leaved cottongrass
Eriophorum vaginatum	torvull	hare's-tail cottongrass
Euphrasia wettsteinii (var. *wettsteinii*)	fjellaugetrøst	arctic eyebright
Festuca ovina	sauesvingel	sheep's-festuce
Festuca vivipara	geitsvingel	viviparous sheep's-festuce
Galium boreale	kvitmaure	northern bedstraw
Gymnadenia conopsea	brudespore	chalk fragrant-orchid
Juniperus communis (ssp. *communis*)	bakkeeiner, einer	common juniper
Pseudorchis albida	kvitkurle	small-white orchid
Menyanthes trifoliata	bukkeblad	bogbean
Molinia caerulea	blåtopp	purple moor-grass
Nardus stricta	finnskjegg	mat-grass
Nigritella nigra	svartkurle	black vanilla orchid °
Parnassia palustris	jåblom	grass-of-parnassus
Pedicularis oederi	gullmyrklegg	Oeder's lousewort °
Pedicularis palustris	myrklegg	marsh lousewort
Pinguicula vulgaris	tettegras	common butterwort
Pinus sylvestris	furu	Scots pine
Picea abies	gran	Norway spruce
Potentilla erecta	tepperot	tormentil
Ranunculus flammula	grøftesoleie	lesser spearwort
Rumex acetosa	engsyre	common sorrel
Rumex acetosella ssp. *acetosella*	bakkesyre	sheep's sorrel
Salix glauca ssp. *glauca*	sølvvier	grayleaf willow
Saxifraga aizoides	gulsildre	yellow saxifrage
Schoenus ferrugineus	brunskjene	brown bog-rush
Scorzoneroides autumnalis (previously *Leontodon autumnalis*[*])	følblom	autumn hawkbit
Selaginella selaginoides	dvergjamne	lesser clubmoss
Solidago virgaurea	gullris	goldenrod
Sphagnum warnstorfii	rosetorvmose	Warnstorf's bog-moss
Sphagnum Section *Subsecunda*	kroktorvmosar	slender cow-horn bog-mosses
Succisa pratensis	blåknapp	devil's-bit scabious
Thalictrum alpinum	fjellfrøstjerne	alpine meadow-rue
Trichophorum alpinum	sveltull	cotton deergrass °
Trichophorum cespitosum ssp. *cespitosum*	småbjønnskjegg	deergrass
Vaccinium uliginosum ssp. *uliginosum*	storblokkebær, blokkebær	bog bilberry

Appendix B – Plant families

List of plant families mentioned in the text. Latin and Norwegian names after Elven et al. (2022), English names follows Poland and Clement (2020).

Nomen Latinum	Norsk namn	English name
Asteraceae	korgplantefamilien	aster family
Cyperaceae	storrfamilien	sedge family
Ericaceae	lyngfamilien	heath family
Orchidaceae	orkidéfamilien, marihandfamilien	orchid family
Poaceae	grasfamilien	grass family
Rosaceae	rosefamilien	rose family

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Appendix C

E slåttatæja

Du går så bratt ette allmannvæja
å fint bli fare frå fotå din.
Meinn vi ska møtast e sommå tæja,
når haustkvellsdåjja e skåra skin.

Du trø e ståppå så stronk å strakjin
å stor e status, så stør kan bli.
Meinn e trødd framme å kledd me nakjinn
å tedd me tuppåt e all mi ti.

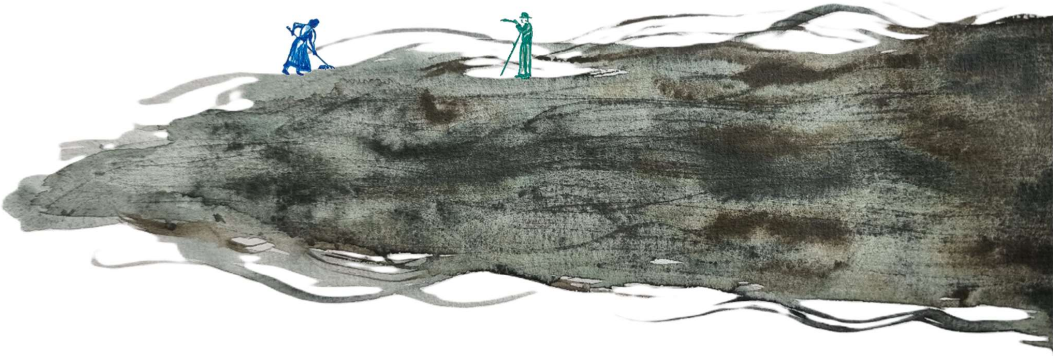
Meinn når vi kjem innåt elvafara
å kar'n me jåa he kvesst si klo,
så ska du sjå at på kjerkegara
der sett dem såt' tå åss båe to.

Å så æn mårgå ska såtåinn kastast,
da blir det spørsmål om vakkert ver.
Fær løinn skår lyt e sikkert lastast.
Meinn får du høytørk fær fager fer?

Hans Hyldbakk

Vårsøg
dikt i samling
2010

Paper I



Modern pollen–vegetation relationships in traditionally mown and unmanaged boreal rich-fen communities in central Norway

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Modern pollen–vegetation relationships in traditionally mown and unmanaged boreal rich-fen communities in central Norway

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ABSTRACT

Knowledge of the relationship between vegetation and modern pollen deposition is necessary to improve the interpretation of fossil pollen samples. We compared the cover of plant species and the modern pollen deposition in surface moss samples in 49 plots in rich-fen vegetation from the boreal vegetation zone in Norway in two areas (one oceanic and one more continental). These rich fens were used for traditional hay cutting until ca. 1950. Three management regimes are used: 1) biennial mowing, 2) quadrennial mowing and 3) unmown. The unmown areas were traditional hay fens, with no management since the 1950s. Of the 89 plant taxa and corresponding 65 taxa of pollen and spores, 29 and 22, respectively, were sufficiently represented in both vegetation and as pollen, to allow direct comparisons of the two data sets. Most of the plant and pollen taxa were found in the plots from both study areas and in plots with different mowing frequencies. Therefore, quantitative differences in vegetation cover and pollen percentages were the main focus in this investigation of plant–pollen relationships in mown and unmown vegetation. The relative difference in plant cover was largest between biennially and unmown plots. 12 species showed a significant positive correlation with difference in plant cover between mown and unmown areas ($p < 0.05$; Wilcoxon signed rank test), most pronounced for *Molinia caerulea* (most common in unmown plots), and *Carex dioica* and *Thalictrum alpinum* (most common in mown plots). A significant positive plant–pollen correlation (Spearman rank-correlation) was found for 10 pollen taxa. *Thalictrum alpinum* is a very good pollen indicator, and Cyperaceae, *Eriophorum*-type and *Pedicularis*-type are good pollen indicators of mowing. Poaceae/*M. caerulea* and *Succisa pratensis* are negatively correlated with mowing. The impact of mowing on species composition was similar in both study areas. Mown and unmown areas were differentiated in the vegetation data and could be identified by modern pollen data. These results will improve the interpretation of past land-use practices using pollen analysis of rich-fen vegetation.

1. Introduction

All over northern Europe fens have, for centuries, been important for production of hay for winter fodder. The fertile infields were often of limited extent, so the outfields were of great importance for haymaking, grazing and summer farming (e.g. Ellenberg, 1988; Hjelle et al., 2012; Solem et al., 2012). This long-term regular harvesting has influenced the fens, turning large areas into open semi-natural landscapes. The traditional use of the fens ceased many decades ago in most countries in western and central Europe, including southern Fennoscandia. In parts of central boreal Norway the traditional use of fens, including our study areas, lasted until the 1950s (Moen, 1990; Tretvik and Krogstad, 1999).

Cultural landscapes leave contemporaneous traces in the form of pollen assemblages in accumulating deposits. Pollen analysis is thus a widely used approach for reconstructing the history of past cultural practices and landscapes (e.g. Berglund, 1991). Investigations of the modern local plant–pollen relationship in areas with documented land-use regimes are a basis for reconstructing these practices back in time. The taphonomy of pollen in modern moss samples is comparable to pollen analytical data from peat cores. Pollen assemblages from vegetation dominated by dwarf-shrubs, graminoids or herbs reflect local sources of non-tree pollen (NAP) and thus small-scale vegetation variations (Hjelle, 1999a; Bunting, 2003; Bunting and Hjelle, 2010; Pardoe, 1996). The relationship between number of deposited pollen grains and the corresponding plant cover is complex (e.g. Sugita, 1994), and

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the pollen taphonomy must be taken into account when interpreting pollen assemblages (e.g. Fægri and Iversen, 1989).

Mowing leads to disturbance and changes in available resources and competition between species (Crawley, 1997; Grime, 2001). Species resilient to mowing will be favoured and plants with low and rosette growth forms, with meristems close to the ground or clonal growth, are tolerant to mowing (Klimešová et al., 2008). In addition, stress-tolerant species are less affected by mowing (Grime, 2001; Øien and Moen, 2001). Thus mowing affects the composition of vegetation and species abundance. For example the plant cover of *Thalictrum alpinum* and several *Carex* and *Eriophorum* species increases with mowing in boreal fens (Moen, 1995).

In order to reconstruct past vegetation communities from pollen data the relationship between the vegetation community and the pollen produced and deposited within it must be known. If good pollen–plant relationships exist and the plant community is reflecting a type of land use today, pollen types/species may be identified as indicator taxa for that land-use (cf. Behre, 1981). The present study aims to produce indicator taxa for mown fens which may be of international value when interpreting pollen diagrams. Also the whole pollen assemblage may be used in a comparative approach (Birks and Birks, 1980) to aid in the identification of past vegetation communities or land-use practices. The results from the present study will be combined with plant–pollen data from mown and grazed vegetation types in Western Norway (Hjelle, 1999a) to form a larger data set. This data will aid the interpretation of possible land-use practices (e.g. Gaillard et al., 1994; Hjelle, 1999b) for pollen diagrams from the rich fens in Tågdalen and Sølendet. The data set should also be useful as part of future pollen–plant databases, e.g. the European Pollen Database (http://www.europeanpollendatabase.net/index.php).

The aim of the present study is to assess the modern pollen–plant relationships in rich fens in two study areas. The areas are situated at the transition between the middle and northern boreal vegetation zones, but in different vegetation sections (regional differences oceanity–continentality, Moen, 1999). Both study areas were used for traditional haymaking until ca. 1950. Regular mowing (with a scythe) of permanent plots was reintroduced in the early 1970s and they have been mown regularly for nearly 40 years. The plant communities vary between the study areas, but with the same dominant species, where the impact of mowing on different species is similar (Moen et al., 2012). Further, differences between mowing regimes and unmown areas facilitate various species, giving mainly quantitative differences in plant cover (Moen et al., 2012). We study the correlation between the plants growing in fen vegetation and pollen deposited on a local scale. Three hypotheses are thus put forward: 1) there is a close connection between the taxa in fen vegetation and local pollen deposition, 2) there are small differences in local pollen–plant relationships between the two studied rich fens (regional differences), and 3) differences between mown and unmown vegetation can be detected from the contemporary pollen assemblages. The modern plant–pollen relationship in fens will provide a basis for interpretations of palaeoecological investigations of past land-use in the study areas.

2. Study areas and plant communities

The two study areas (Fig. 1) are both situated at the transition between the middle boreal and northern boreal vegetation zones of central Norway (Moen, 1999). Tågdalen is an oceanic inner-fjord area nature reserve and Sølendet is a continental nature reserve. Tågdalen is part of the markedly oceanic vegetation section while Sølendet is situated on the transition between the indifferent and slightly continental vegetation sections (sensu Moen, 1999). The 20 localities with 49 study plots presented in this paper were established as permanent plots 40 years ago, and vegetation and plant populations dynamics are described in a number of papers (e.g. Moen, 1990, 1995, 2000; Aune et al., 1996; Moen et al., 1999, 2012, 2015; Øien and Moen, 2001; Sletvold et al., 2010; Lyngstad et al., 2016). 10 localities are situated along a line over a distance of 940 m in Tågdalen (Fig. 2a). In Sølendet the 10 localities are situated in an area of just below 1 km^2 (Fig. 2b).

The duration of the growing season is similar in both areas, from the end of May until the first part of September. Tågdalen has an oceanic climate with high annual precipitation and a thick, long-lasting snow cover, while Sølendet has a more continental climate with less precipitation and cold winters (Table 1). The distance between the study areas is 145 km. In both areas calcareous Cambro-Silurian bedrock (Sigmond et al., 1984) is overlaid with base-rich till (Follestad, 1995).

The dominant rich-fen vegetation at Tågdalen and Sølendet forms a mosaic with birch woodland (*Betula pubescens*). Sloping fens (slope > 3°) cover large areas. At Tågdalen the slopes are between 3 and 12° and at Sølendet 3 and 5°. The depth of the underlying peat layer exceeds 50 cm at Tågdalen, and 20 cm at Sølendet. The study areas have the same historical land-use, where the traditional hay cutting declined during the 1930s, and ended in the 1950s. Experimental scything (hereafter called mowing) of permanent plots started in 1973 and was carried out in August, allowing flowering, seed production and dispersal to take place for important species. The localities were established in homogenous fen areas, and the studied plots have been mown regularly biennially or quadrennially since the 1970s, or they have been left unmown for ca. 60 years. The hay crop of the studied communities was estimated to about 110 g/m^2 and 140 g/m^2 (dry matter) in plots mown biennially and quadrennially, respectively (Moen, 1990; Moen et al., 2015; Lyngstad et al., 2016). Biennial mowing represents the traditional practice, where the harvest output was maximized in relation to labour invested. Quadrennial mowing is a possible equivalent to the mowing frequency during periods of extensive mowing, and during the period when hay-cutting was declining.

The terminology of mires follows the Fennoscandia tradition in mire ecology (sensu Sjörs, 1948), separating units related to the main local vegetation gradients. Rich fens are peat-forming mire sites with characteristic vegetation dominated by brown mosses (e.g. *Campylium stellatum*), and with base-rich water (pH above 6). Lawn communities of extremely rich fen vegetation (Sjörs, 1948; Moen et al., 2012; Jiménez-Alfaro et al., 2014) cover the study localities. Phytosociological analyses of the permanent study plots were included in multivariate analyses of 134 rich fen plots from the two study areas (Moen et al., 2012; the plots in this paper mainly belong to their communities II–IV). In the phytosociological classification system (e.g. Dierssen, 1982; Rybníček, 1985), the studied mires belong to the alliances *Caricion davalianae* Klinka 1934 at Tågdalen, and at Sølendet *Caricion atrofuscae* Nordh. 1936. The mean number of species in plots with an area of 12.5 m^2 ranged between 30 and 37 (Table 2 and Supplementary A in Moen et al., 2012). The most common vascular plant species in both areas are *Andromeda polifolia*, *Dactylorhiza* spp., *Equisetum palustre*, *Euphrasia wettsteinii*, *Parnassia palustris*, *Pinguicula vulgaris*, *Potentilla erecta*, *Selaginella selaginoides*, *Succisa pratensis*, *Thalictrum alpinum*, *Tofieldia pusilla*, *Carex dioica*, *Carex flava*, *Carex hostiana*, *Carex lasiocarpa*, *Carex panicea*, *Carex rostrata*, *Eriophorum angustifolium*, *Eriophorum latifolium*, *Molinia caerulea* and *Trichophorum cespitosum*. The bottom layer was dominated by *Campylium stellatum*, with *Aneura pinguis*, *Barbilophozia rutheana*, *Fissidens adianthoides*, *Gymnocolea borealis* and *Scorpidium cossonii* occurring in all or a large majority of the plots. At Tågdalen the western/lowland species *Drosera longifolia*, *Narthecium ossifragum* and *Schoenus ferrugineus* were present in some plots. At Sølendet a number of alpine/inland species were present, the most common being *Pedicularis oederi*, *Saxifraga aizoides* and *Kobresia simpliciuscula*.

3. Material and methods

3.1. Research design and vegetation plots

Ten localities with permanent experimental plots with and without mowing within each study area in similar vegetation units of rich fens were chosen for the present research design (Fig. 3). Each locality

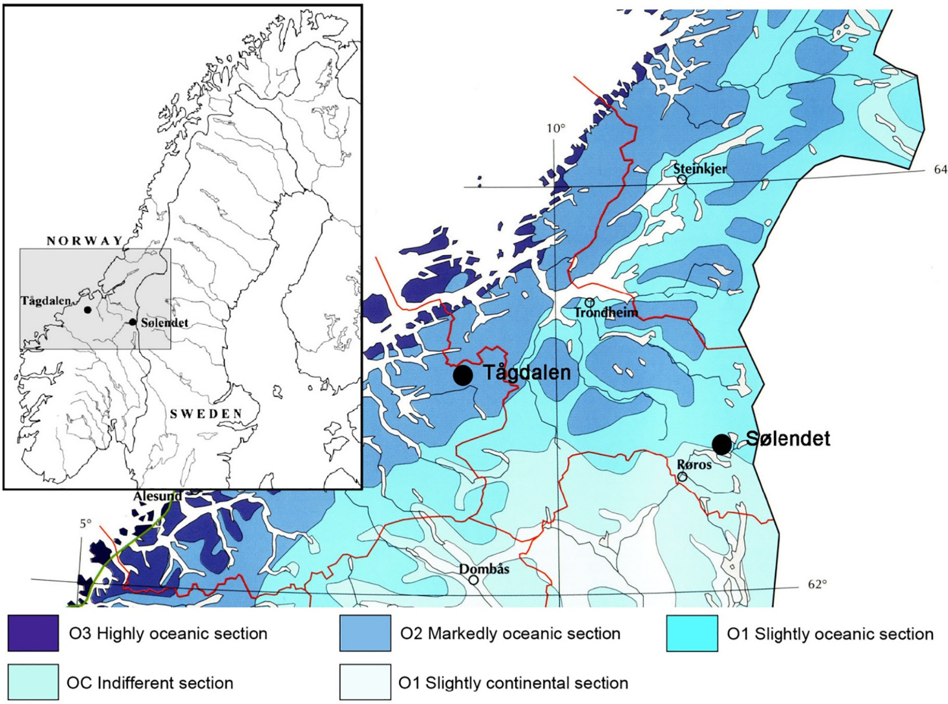

Fig. 1. The location of the two study areas, Tågdalen in the inner fjord area and the inland area Sølendet. Vegetation sections in central Norway after Moen (1999).

consisted of two or more permanent plots of 2.5 × 5 m (total 49 plots). The field work for this study was carried out in 2008. Inside each permanent plot one sample plot of 1 × 1 m was placed in the centre, thus reducing potential edge effects. The minimum distance from a sample plot to an area with different management regimes was 0.75 m. The minimum distance between the border of two sample plots was 1.5 m. Initial studies of different sizes of sample plots (from 0.25 m^2 to 4 m^2) revealed that intermediate-sized plots of 1 m^2 were representative of the plant composition of the stand (e.g. Mueller-Dombois and Ellenberg, 1974).

Three management regimes have been maintained since the 1970s: 1) biennial mowing, 2) quadrennial mowing and 3) unmown since the 1950s (Fig. 3). Management regimes 1) and 3) were present in all investigated localities. Six localities at Tågdalen and three localities at Sølendet included management regime 2). For management regime 1) mowing was done one year prior to investigation of plant cover and sampling; for management regime 2) mowing was done three years prior to investigation. The intensive mowing practice 1) represents the traditional mowing, and 2) reflects extensive mowing.

Plant nomenclature follows Lid and Lid (2005) for vascular plants and Frisvoll et al. (1995) for mosses (Table 2). The species cover was visually recorded using the following cover classes [percent range of cover — cover class mean]: 1 [1–2 plants — 0.25%], 2 [0–1% — 0.5%], 3 [1–2.5% — 1.75%], 4 [2.5–5% — 3.75%], 5 [5–10% — 7.5%], 6 [10–20% — 15%], 7 [20–30% — 25%], 8 [30–40% — 35%] and so on up to 14. For each taxon the mean plant cover from each management regime was calculated from the average of cover class means from all plots of similar management regime (Table 3). Species recorded in the vegetation are equivalent to the taxa included in "local terrestrial pollen" (see Section 3.3).

3.2. Surface pollen sampling

Moss polsters were collected from the sample plots as traps for pollen deposition (e.g. Hicks, 1977; Hjelle, 1998). Each moss sample consisted of five merged sub-samples, one from the centre of the plot and four in each direction out from the centre and half way to the sample plot border (Fig. 3). The result, a minimum distance of 1 m between a pollen sub-sample and different land-use, reduces the risk of strong plot-edge effects. If moss was absent, sampling was done as close as possible to these points. The modern analogue to a fossil sample from a peat core is a single moss sample, but collecting several sub-samples reduces the potential effect of outliers and of micro-scale differences in pollen content in moss polsters from neighbouring samples (Pardoe, 1996; Hicks, 2001). Moss samples were collected in late July 2008. The moss sample consisted of the whole moss turf from the top down to the soil surface. Thus several years of pollen deposition were probably included in the sample (e.g. Mulder and Janssen, 1999; Pardoe et al., 2010), integrating observed year to year fluctuations in fertility and pollen production (Hicks, 2001; Nielsen et al., 2010). Such samples are comparable to the vegetation community when single-year effects can be evened out, as well as to a peat pollen sample reflecting several years. By far the most frequently sampled moss in all localities was *Campylium stellatum*. Among other common species were *Scorpidium cossonii*, *Scorpidium scorpioides*, *Drepanocladus* spp. and *Sphagnum* spp.

3.3. Pollen processing and analysis

Moss samples were thoroughly rinsed through 450 μm sieves to remove the moss. Pollen preparation of the material passing through the sieve followed standard methods, with KOH and acetolysis (Fægri and Iversen, 1989), but without hydrofluoric acid treatment because the minerogenic content was negligible in all samples. The residue was mounted in glycerol for pollen counting. At least 500 terrestrial-plant pollen (range 563–1349) including more than 100 local terrestrial pollen (range 164–724) were counted per sample. Taxa were identified to the lowest possible taxonomic level by the use of keys (Moe, 1974; Fægri and Iversen, 1989; Moore et al., 1991; Beug, 2004) and the modern pollen reference collection at the University of Bergen. Pollen data-analysis was made using TILIA (Grimm, 1990). When possible, Cyperaceae pollen was identified to *Dulichium*-type, representing *Carex* spp., and *Eriophorum*-type pollen (sensu Fægri and Iversen, 1989).

The percentage calculation sum is the sum of local terrestrial pollen ($\sum$ LP). The pollen calculation sum for other pollen and microfossils is $\sum P + X$, where X is the microfossil in question. Local terrestrial pollen and spores represent pollen and spores from taxa belonging to the studied rich fen vegetation (e.g. Janssen, 1966). In this sense extra-local taxa are only or mainly recorded as growing on nearby mineral soil, such as Ericaceae, *Calluna vulgaris*, *Juniperus communis*, *Salix* spp. and *Betula* spp., which occur at low abundances or are absent in the fen plots (Moen et al., 2012). Pollen from *Betula* spp. is mainly a part of the regional pollen deposition, along with pollen from species not represented in the fen localities, like *Pinus sylvestris*. As the yearly moss growth rates may vary between and within moss taxa, as well as with mowing (Moen, 1995), the pollen trapping ability and concentration values will not be directly comparable between samples. Therefore percentages based on the sum of local pollen were used. The use of local terrestrial pollen as the calculation basis will minimize the problems of absolute variations in extra-local and regional pollen related to percentage calculations. Such variations are not related to the vegetation on the fen nor the local mowing.

3.4. Data analyses

In the data analysis comparing vegetation and pollen data, only the local terrestrial taxa are included. A comparison of species occurrences and pollen data requires comparable taxonomic groups. Therefore, the plant species were grouped according to the pollen taxa that represent them. Analyses of some species were carried out for both single plant species and for the corresponding palynological taxonomic groups, see Table 2.

3.4.1. Gradients in the data — ordination

Principal components analyses (PCA) implemented in CANOCO for Windows 4.5 (ter Braak and Šmilauer, 2002) was used to ordinate the 49 vegetation plots according to the pollen taxa they contained. Species centring with square-root transformed data was used. Species scores were divided by their standard deviation to obtain inter-species correlations. Pollen percentages (square-root transformed) from the same plots and taxa and the three management regimes were added as passive samples and environmental variables, respectively, and projected on the ordination diagram. The results were drawn using Canodraw for Windows 4.5 (Fig. 4a and b).

3.4.2. Paired comparisons from mown and unmown vegetation

A paired test was carried out comparing the vegetation composition in pairs of mown–unmown plots within each locality. The Wilcoxon signed rank test was used for the nonparametric data to identify taxa

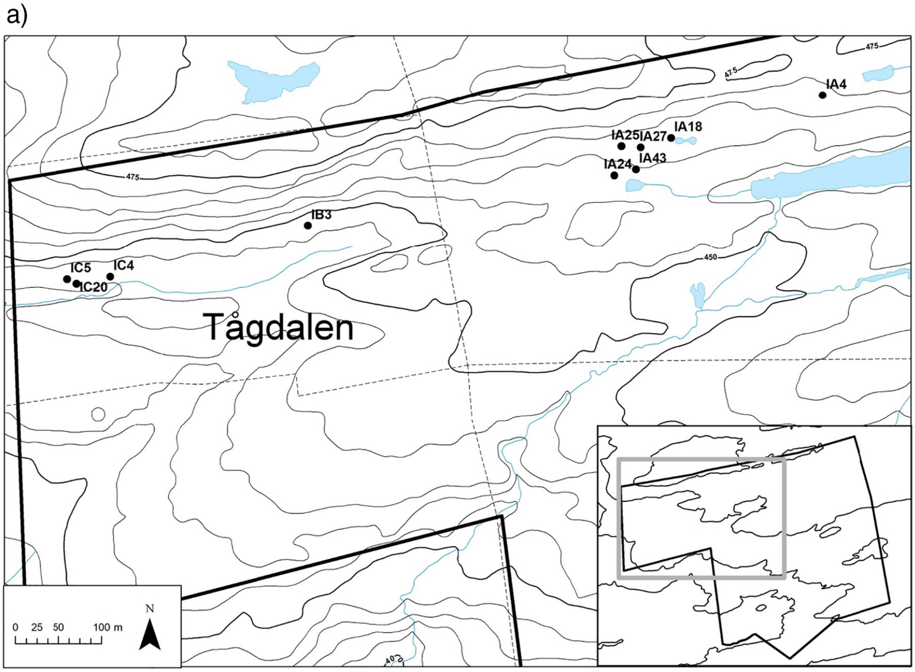

Fig. 2. The location of investigated localities in a) Tågdalen Nature Reserve and b) Sølendet Nature Reserve. The reserves are marked with black solid borders. Numbering of the plots follows the permanent plots in long-term studies from the reserves (Moen, 1990, 2000).

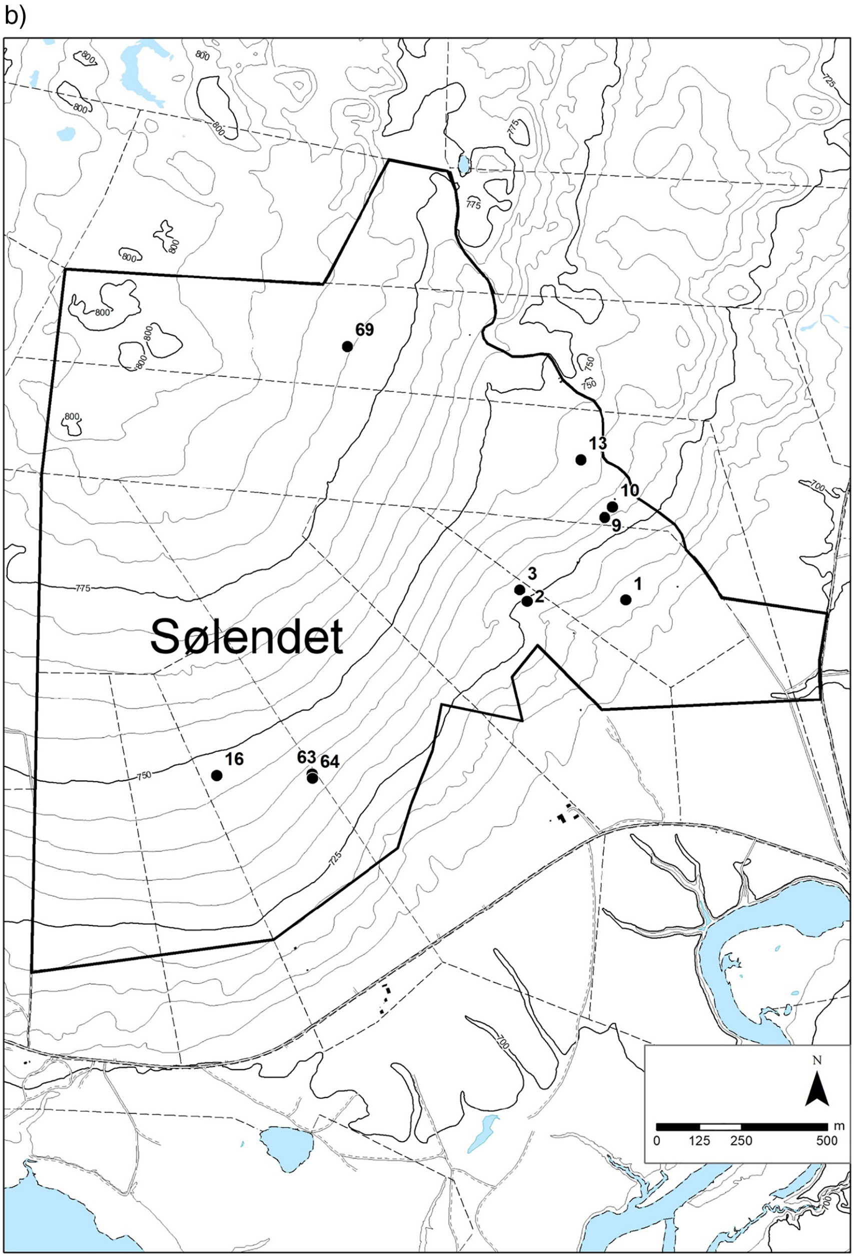

Fig. 2 (*continued*).

with a statistically significant difference in mean percentage plant cover between land-use regimes. It was run in R version 2.11.1 (R Development Core Team, 2010). An exact Wilcoxon signed-rank test was chosen as the grouped data-set has a potential for ties for the pairs. The data from Tågdalen and Sølendet were analysed jointly providing a maximum of 20 pairs. Three sets of tests were run: 1) plots from biennially mown and unmanaged plots, 2) plots mown biennially and quadrennially, 3) plots mown quadrennially and unmown plots. Taxa with plant cover registrations in ≥6 plots were included.

3.4.3. Analyses of differences in species plant cover between management regimes

The indices of difference (ID), Eq. (1), show whether and how often each taxon increases, displays no change, or decreases in cover from the

Table 1
Characteristics of the two study areas.
Climatic data from Norwegian Meteorological Institute (see Lyngstad et al., 2016, including Supplementary Material) for the study areas at Tågdalen nature reserve and Sølendet nature reserve. Vegetation zones and sections after Moen (1999).

	Tågdalen	Sølendet
Latitude (N)	63°03′	62°40′
Longitude (E)	9°05′	11°50′
Altitude (m a.s.l.)	440–460	715–785
Mean annual precipitation (mm)	1583	637
Mean annual temperature (°C)	3.0	0.6
Mean July temperature (°C)	11.2	10.5
Mean January temperature (°C)	−2.7	−9.5
Vegetation zone	Middle/northern boreal	Middle/northern boreal
Vegetation section	Markedly oceanic (O2)	Indifferent (OC)/slightly oceanic (O1)

unmown to the mown pairs of plots:

$$n_A(1) + n_B(0) + n_C(-1))\ (n_A + n_B + n_C)^{-1} \rightarrow (n_A - n_C)\ (n_A + n_B + n_C)^{-1} \quad (1)$$

where n_A is the number of pairs of plots where each taxon has larger vegetation cover in the mown plot than in the unmown plot, n_B is the number of pairs of plots with no difference, and n_C displays the number of pairs of plots where the taxa have lower vegetation cover in the mown plot than in the unmown plot.

3.4.4. Correlation between vegetation and pollen data

To investigate whether plant cover is correlated with the corresponding pollen percentages in the surface samples, the nonparametric Spearman rank-correlation coefficient, ρ (rho) (e.g. Webb et al., 1978), was used to measure statistical dependence between pollen percentages and plant cover for taxa in all plots for the three management regimes. The test was carried out in R version 2.11.1 (R Development Core Team, 2010), examining the absolute percentage differences of paired plots. The statistical significance level was set to 0.05. The dataset of 49 plots from both Tågdalen and Sølendet was used. The correlation test was run for only one study area when plant cover or pollen was absent from the other area. The tests were run for all taxa recorded in ≥6 pairs of plots in each paired comparison.

3.4.5. Indices of pollen association and representation

Based on presence/absence data of vegetation and pollen from all investigated plots, calculations of indices of association with coincidence (A), over-representation (O) and under-representation (U) (Davis, 1984; Hjelle, 1997; Bunting, 2003; Mazier et al., 2006) were made for each taxon. The definitions of the three indices are:

$$A = B_0(P_0 + P_1 + B_0)^{-1};\quad O = P_0(P_0 + B_0)^{-1};\quad U = P_1(P_1 + B_0)^{-1} \quad (2)$$

where B_0 is the number of plots where the pollen or spore type and the associated taxon are present, P_0 represents the number of plots where the pollen or spore type is recorded but this taxon is not present in the vegetation, and P_1 is the number of plots where the pollen or spore type is absent in the surface sample but the taxon is present in the vegetation. Based on the indices, taxa were grouped into associations: strongly associated types (SAT, $A > 0.65$), associated types (AT, A between 0.65 and 0.5), weakly associated types, (WAT, $A < 0.5$, positive O and U), over-represented type (ORT, $A < 0.5$, $U = 0$), under-represented type (URT, $A < 0.5$, $O = 0$) and unassociated type (UT, $A = 0$, positive O and U).

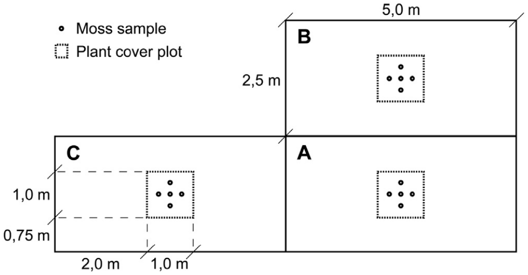

Fig. 3. Schematic presentation of a typical locality with permanent plots, investigated plots of 1 m^2 for the present study and collection points for moss samples. A = mown biennially, C = mown quadrennially and B = unmown.

Table 2
The 26 pollen and spore taxa with their corresponding 57 plant species present in the studied localities. Only taxa registered in both vegetation and pollen samples are included. T = pollen or plant only present in Tågdalen; S = pollen or plant only present in Sølendet. Nomenclature for pollen taxa follows Fægri and Iversen (1989), plant taxa follow Frisvoll et al. (1995) and Lid and Lid (2005).

Pollen/spore taxa	Plant species in the vegetation plots
Anemone	*Anemone nemorosa*^{T}
Asteraceae Cichorioideae	*Crepis paludosa*^{S}, *Leontodon autumnalis*^{S}
Betula	*Betula nana*, *Betula nana* × *pubescens*, *Betula pubescens*
Bistorta vivipara-type	*Bistorta vivipara*
Calluna vulgaris	*Calluna vulgaris*^{S}
Cyperaceae	*Carex* spp., *Eleocharis quinqueflora*, *Eriophorum* spp., *Kobresia simpliciuscula*^{S}, *Schoenus ferrugineus*^{T}, *Trichophorum* spp.,
Drosera rotundifolia-type^{T}	*Drosera longifolia*^{T}, *Drosera rotundifolia*
Dulichium-type	*Carex capillaris*, *Carex chordorrhiza*^{T}, *Carex dioica*, *Carex echinata*, *Carex flava*, *Carex flava* × *hostiana*^{S}, *Carex hostiana*, *Carex lasiocarpa*, *Carex limosa*^{T}, *Carex nigra*, *Carex panicea*, *Carex pauciflora*^{T}, *Carex rostrata*, *Carex vaginata*^{S}
Ericaceae	*Andromeda polifolia*, *Calluna vulgaris*^{S}, *Erica tetralix*^{T}, *Vaccinium uliginosum* ssp. *uliginosum*
Eriophorum-type	*Eriophorum angustifolium*, *Eriophorum latifolium*, *Eriophorum vaginatum*^{S}, *Trichophorum alpinum*, *Trichophorum cespitosum* ssp. *cespitosum*
Galium-type^{T}	*Galium boreale*
Juniperus communis	*Juniperus communis*
Menyanthes trifoliata^{T}	*Menyanthes trifoliata*^{T}
Pedicularis-type	*Pedicularis oederi*^{S}, *Pedicularis palustris*
Pinguicula-type^{S}	*Pinguicula vulgaris*^{S}
Poaceae	*Deschampsia cespitosa*^{S}, *Festuca ovina*^{S}, *Festuca vivipara*^{T}, *Molinia caerulea*, *Nardus stricta*
Potentilla-type	*Potentilla erecta*
Rhinanthus-type^{S}	*Bartsia alpina*^{S}, *Euphrasia wettsteinii*
Rosaceae	*Potentilla erecta*
Salix^{S}	*Salix glauca*^{S}
Saxifraga oppositifolia-type	*Saxifraga aizoides*^{S}
Selaginella selaginoides	*Selaginella selaginoides*
Solidago-type	*Solidago virgaurea*^{S}
Sphagnum	*Sphagnum warnstorfii*, *Sphagnum* Section *Subsecunda*
Succisa pratensis	*Succisa pratensis*
Thalictrum	*Thalictrum alpinum*

4. Results

89 plant species (77 vascular plant species and 12 moss species) were recorded from Tågdalen and Sølendet. Taxa present in both the vegetation data-set and the pollen and spore analyses were considered (Table 2). Thus 57 vascular plant taxa were represented in the pollen assemblages and grouped into 26 pollen taxa (Table 2).

Table 3
Number of plots with plant recorded (n), mean plant cover in vegetation plots based on 26 plots from Tågdalen (T) and 23 from Sølendet (S), and differences in cover between plots mown biennially (M2) and unmown (U). ^{T} = only from Tågdalen; ^{S} = only from Sølendet; – = not present. The difference in % values displays absolute differences on a % scale between plots mown biennially and unmown plots.

Plant taxa	n	T, mean %	S, mean %	Difference in % values M2 − U (T & S)
Bartsia alpina	29	2.5	0.5	−1.6
Betula nana	16	0.01	2.9	−5.7
Bistorta vivipara	19	0.1	0.6	−0.5
Carex capillaris	20	0.7	0.8	0.3
Carex dioica	40	2.2	1.1	2.2
Carex echinata	9	0.7	0.01	2.1
Carex flava	35	2.6	6.1	5.9
Carex hostiana	22	4.3	0.01	4.9
Carex limosa^T	25	2.8	–	2.4
Carex nigra	11	0.02	1.8	2.1
Carex panicea	48	2.2	4.0	1.2
Carex rostrata	30	3.1	2.3	4.8
Drosera longifolia^T	13	2.0	–	4.0
Eriophorum angustifolium	43	0.7	0.8	0.9
Eriophorum latifolium	44	7.8	6.4	5.7
Eriophorum vaginatum^S	10	–	0.3	−0.5
Euphrasia wettsteinii	25	0.8	1.4	0.0
Festuca ovina^S	12	–	0.7	−0.7
Menyanthes trifoliata	9	0.4	1.6	−5.4
Molinia caerulea	49	8.3	7.4	−13.6
Pedicularis oederi^S	11	–	0.5	−0.3
Pedicularis palustris	26	0.2	3.0	3.1
Pinguicula vulgaris	13	1.7	0.9	2.6
Potentilla erecta	44	9.2	5.2	0.4
Selaginella selaginoides	43	1.5	1.9	0.2
Succisa pratensis	32	3.5	1.6	−1.9
Thalictrum alpinum	49	10.8	13.9	10.6
Trichophorum alpinum	22	1.7	0.1	−0.4
Trichophorum cespitosum ssp. *cespitosum*	49	18.4	14.5	−1.9

Taxa only recorded in the vegetation, like *Dactylorhiza* spp., *Equisetum* spp. and most moss species, and taxa only identified in the pollen record, e.g. several tree species, were excluded.

4.1. Vegetation data

The most frequent species in both study areas were: *Trichophorum cespitosum* ssp. *cespitosum*, *Thalictrum alpinum*, *Molinia caerulea*, *Potentilla erecta*, *Eriophorum latifolium*, *Carex flava*, *Carex panicea*, *Carex rostrata* and *Succisa pratensis* (Table 3). *Molinia caerulea*, *T. alpinum*, *Eriophorum latifolium*, *Betula nana* and several *Carex* taxa displayed a large difference in plant cover between biennially mown and unmown plots (Table 3).

Twelve plant taxa had significantly different cover values in biennially mown and unmown plots (Table 4a). Highest cover values in biennially mown plots were found for: four *Carex* species, *Thalictrum alpinum*, *Pinguicula vulgaris*, *Eriophorum latifolium*, *Eriophorum angustifolium* and *Pedicularis palustris*. *Molinia caerulea* was much more abundant in unmown plots, and this was the only plant taxon displaying a difference in plant cover between all the management regimes. *Betula nana* and *Succisa pratensis* were more abundant in unmown plots than in biennially mown plots. Combining the plant taxa into pollen groups resulted in *Dulichium*-type (i.e. *Carex* spp.) displaying a difference in vegetation cover between all management regimes, whereas *Eriophorum*, Cyperaceae and Poaceae only displayed a difference between the two mown and the unmown plots (Table 4b). The difference in plant cover in biennially mown and unmown plots represented the main variation in plant cover in fen vegetation (Table 4a), most pronounced for *M. caerulea*, *Carex dioica* and *T. alpinum*.

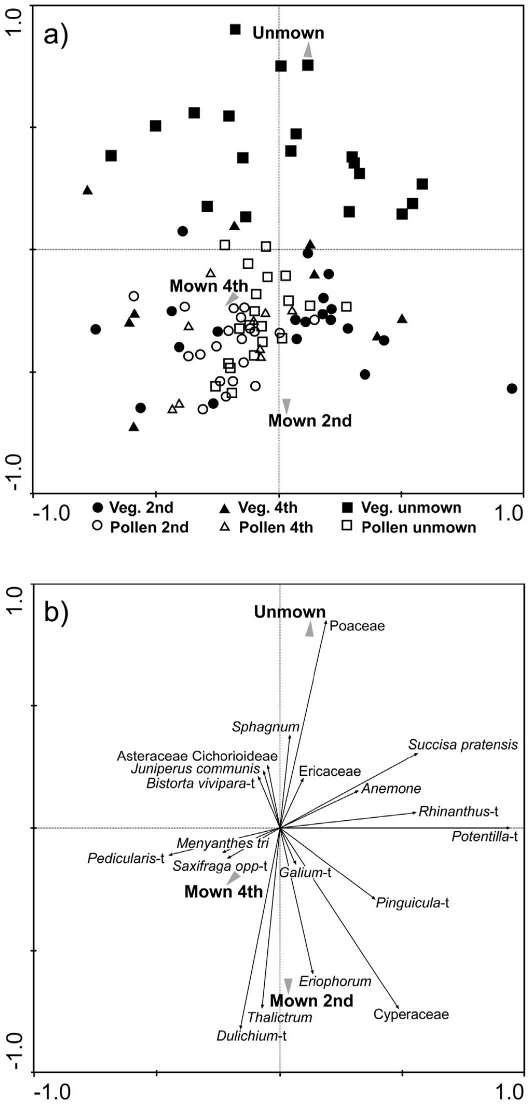

Fig. 4. PCA showing a) vegetation samples, pollen samples and environmental variables. Pollen samples and environmental variables are treated as passive samples and variables respectively. Veg. = vegetation samples, Pollen = pollen samples, 2nd = mown biennially, 4th = mown quadrennially. Grey triangles = environmental variables, three mowing regimes, b) plant species grouped into pollen taxa according to Table 2, based on 26 plots from Tågdalen and 23 plots from Sølendet. Pollen types close to the centre are not shown to increase readability. Abbreviations: t = type, *Menyanthes tri* = *Menyanthes trifoliata*, *Saxifraga opp* = *Saxifraga oppositifolia*.

4.2. Ordination of vegetation and pollen data

The first two axes of the PCA-ordination of the 49 plots (Fig. 4) had eigenvalues of 0.25 and 0.23 respectively. The other axes had eigenvalues lower than 0.10 (not shown). The vegetation samples representing different mowing frequencies were spread along the whole range of the first axis (Fig. 4a), but were separated on the second axis, reflected in both the dispersal of samples and the mean scores for

Table 4
Results (p-values) from paired comparisons of differences in a) mean percentage cover of plant taxa and b) sum of mean percentage cover of pollen taxa between management regimes in Tågdalen and Sølendet using the Wilcoxon signed rank test. The test was run for plots mown biennially and unmown plots (M2 & U), plots mown biennially and quadrennially (M2 & M4), and plots mown quadrennially and unmown plots (M4 & U). Numbers in bold display values statistically significant at a 0.05-level. – = not enough plots to compute the test. The rightmost column displays indices of difference (ID), range +1.0 to −1.0, between plots mown biennially and unmown (M2 & U). Positive values refer to taxa with an increase in plant cover with mowing, negative values vice versa.

	p-Values			ID
	M2 & U	M2 & M4	M4 & U	M2 & U
a) Plant taxa				
Molinia caerulea	**<0.0001**	**0.047**	**0.010**	−0.95
Carex dioica	**<0.0001**	0.25	0.22	0.89
Thalictrum alpinum	**<0.0001**	0.50	0.06	0.90
Pinguicula vulgaris	**0.001**	**0.031**	0.38	0.65
Carex hostiana	**0.002**	0.50	0.06	1.00
Carex flava	**0.002**	>0.99	0.13	0.60
Eriophorum latifolium	**0.003**	0.50	0.06	0.72
Eriophorum angustifolium	**0.012**	0.06	0.13	0.44
Pedicularis palustris	**0.017**	>0.99	0.50	0.58
Betula nana	**0.027**	--	--	−0.60
Succisa pratensis	**0.036**	>0.99	>0.99	−0.38
Carex limosa[T]	**0.047**	>0.99	0.38	0.60
Carex echinata	0.06	--	--	0.83
Drosera longifolia[T]	0.06	>0.99	0.25	0.83
Bartsia alpina	0.18	0.63	0.25	−0.40
Carex nigra	0.19	--	--	0.50
Eriophorum vaginatum[S]	0.22	--	--	−0.57
Carex panicea	0.23	0.25	0.25	0.40
Bistorta vivipara	0.27	--	0.38	−0.40
Carex rostrata	0.31	0.06	>0.99	0.25
Trichophorum alpinum	0.34	0.31	0.63	−0.29
Festuca ovina[S]	0.38	--	--	−0.29
Trichophorum cespitosum ssp. *cespitosum*	0.44	0.38	0.50	−0.15
Menyanthes trifoliata	0.50	0.75	0.88	−0.25
Carex capillaris	0.67	--	--	0.10
Euphrasia wettsteinii	0.70	--	--	−0.07
Selaginella selaginoides	0.72	0.06	0.25	0.05
Potentilla erecta	0.87	0.13	0.31	0.11
Pedicularis oederi[S]	0.94	--	--	−0.17
b) Plant taxa in pollen taxa group				
Dulichium-type	**<0.0001**	**0.047**	**0.039**	1.00
Cyperaceae	**<0.0001**	0.06	**0.012**	1.00
Poaceae	**<0.0001**	0.09	**0.008**	−0.95
Eriophorum spp.	**0.002**	0.14	**0.039**	0.60
Betula	**0.002**	--	0.38	−0.69
Pedicularis-type	**0.023**	>0.99	0.13	0.38
Drosera[T]	**0.031**	0.38	0.25	0.75
Eriophorum-type (incl. *Trichophorum*)	**0.040**	0.77	0.35	0.30

the environmental variables. On axis 2 the variable representing biennial mowing had a high negative mean score, while quadrennial mowing had a small negative mean score and unmown had a high positive mean score. The majority of pollen samples (passive data) had low scores on both axes. The pollen samples showed a similar pattern as the vegetation samples, where the pollen samples from the unmown plots to a large extent are separated from the plots with the two mowing frequencies, most pronounced for unmown and biennially mown plots.

Pedicularis-type had a negative score on the first axis of the PCA ordination of plant taxa (as pollen taxa groups, Fig. 4b) whereas *Potentilla erecta*, *Rhinanthus*-type and *Succisa pratensis* had high scores. *Dulichium*-type, *Thalictrum*, Cyperaceae and *Eriophorum* had lowest scores on the second axis whereas Poaceae had the highest score followed by *Sphagnum*.

4.3. Pollen data in relation to management regimes

Of the 65 palynological taxa found at Tågdalen and Sølendet, only 26 pollen and spore taxa represented the investigated, contemporary vegetation (Table 2). Pollen taxa present in >4 plots are displayed in Table 5.

At Tågdalen *Thalictrum* and *Eriophorum*-type pollen had their largest pollen percentages in mown plots, especially seen for *Thalictrum* in biennially mown plots in Tågdalen. Poaceae and *Potentilla*-type had the largest pollen percentages in unmown plots. *Dulichium*-type pollen had the largest pollen percentages in unmown plots, but in Tågdalen the differences are small. Cyperaceae had generally small relative changes to no differences between management regimes, and the standard error is large. *Succisa pratensis* had also small to no differences between management regimes in Tågdalen, where at Sølendet the largest pollen percentages were registered in unmown plots. *Pedicularis*-type pollen had a general low pollen presence. The *Pedicularis*-type pollen percentages were slightly higher in biennially mown than in unmown plots in Sølendet, and were absent in unmown plots in Tågdalen.

Table 5
Mean pollen percentages of local terrestrial pollen and spores from the two study areas, Tågdalen and Sølendet, for each land-use regime. SE = standard error; n = number of samples. Cyperaceae includes *Dulichium*-type and *Eriophorum*-type, Ericaceae includes *Calluna vulgaris*, Rosaceae includes *Potentilla*-type. *Menyanthes trifoliata*, Ericaceae, *Drosera rotundifolia*-type, *Saxifraga oppositifolia*-type and *Galium*-type from Tågdalen and *Anemone*, *Saxifraga oppositifolia*-type, *Bistorta vivipara*-type, *Pinguicula*-type and *Rhinanthus*-type from Sølendet, were found in few plots and with low percentages and are not included.

	Mown biennially			Mown quadrennially			Unmown		
Pollen/spore taxa	n (of 10)	Mean %	SE	n (of 6)	Mean %	SE	n (of 10)	Mean %	SE
Tågdalen									
Cyperaceae	10	80.0	1.8	6	78.2	3.2	10	80.8	1.4
Betula	10	32.7	1.9	6	29.7	3.5	10	29.1	1.3
Dulichium-type[a]	10	25.5	1.3	6	25.2	1.6	10	26.7	2.4
Eriophorum-type[a]	10	16.2	0.6	6	16.1	2.3	10	9.0	1.3
Selaginella selaginoides	10	15.1	1.5	6	11.0	2.2	10	17.4	3.7
Poaceae[a]	10	7.8	0.5	6	9.3	1.2	10	9.4	0.7
Thalictrum[a]	10	4.8	1.0	6	5.9	1.6	10	3.2	0.6
Rosaceae	9	2.4	0.5	6	2.6	0.4	10	2.9	0.3
Potentilla-type[a]	8	1.4	0.3	5	2.0	0.3	10	2.5	0.3
Juniperus communis	9	0.9	0.2	4	0.5	0.2	9	0.7	0.1
Sphagnum	7	0.6	0.2	5	0.6	0.1	7	0.6	0.2
Solidago-type[a]	3	0.4	0.2	1	0.1	0.1	3	0.1	0.05
Succisa pratensis[a]	5	0.2	0.07	1	0.2	0.1	3	0.2	0.1
Anemone[a]	4	0.2	0.08	1	0.06	0.04	4	0.2	0.07
Pedicularis-type[a]	3	0.2	0.09	3	0.3	0.1	0	0	0
Menyanthes trifoliata[T] [a]	1	0.1	0.03	1	0.08	0.05	2	0.05	0.03
Sølendet									
Cyperaceae	10	78.5	4.1	3	90.4	2.2	10	83.7	2.8
Betula	10	32.4	3.0	3	18.2	2.6	10	30.2	2.9
Eriophorum-type[a]	10	28.9	2.2	3	35.9	1.9	10	14.9	1.1
Selaginella selaginoides	10	19.2	3.1	3	9.6	1.2	10	11.3	1.8
Dulichium-type [a]	10	18.4	1.2	3	21.6	2.4	10	24.4	1.2
Thalictrum[a]	10	12.6	3.9	3	5.4	2.6	10	3.9	1.1
Poaceae[a]	10	4.6	0.6	3	2.7	0.5	10	7.2	1.3
Juniperus communis	8	1.0	0.2	3	0.5	0.1	8	0.6	0.1
Pedicularis-type[a]	7	0.6	0.1	2	0.6	0.3	7	0.4	0.1
Asteraceae Cichorioideae[Sa]	9	0.5	0.1	1	0.1	0.1	5	0.5	0.2
Sphagnum	6	0.4	0.1	3	0.7	0.2	10	0.5	0.1
Ericaceae	5	0.3	0.1	1	0.2	0.2	6	0.3	0.1
Calluna vulgaris	5	0.3	0.1	1	0.2	0.2	4	0.2	0.1
Salix[S]	6	0.3	0.1	2	0.3	0.1	7	0.4	0.1
Rosaceae	8	1.0	0.2	0	0	0	9	2.1	0.5
Potentilla-type[a]	7	0.7	0.2	0	0	0	9	2.0	0.5
Solidago-type[a]	4	0.2	0.1	0	0	0	4	0.3	0.1
Succisa pratensis[a]	4	0.2	0.1	0	0	0	2	0.6	0.3

[a] Displays pollen taxa included in the local terrestrial pollen sum.

From Sølendet only three plots represent quadrennially mown fen, giving a potential for uncertainties regarding the result. In Sølendet the pollen data does not always follow the trend from Tågdalen, as for *Thalictrum* and Poaceae.

4.4. Pollen–vegetation relationships

Spearman rank-correlation coefficients relating plant cover to pollen percentages are presented in Table 6, along with the indices of association and association types which reflect relationships between presence/absence of plants and their pollen. As *Molinia caerulea* formed the majority of the Poaceae plant cover (Table 3), both *M. caerulea* and Poaceae plant cover were individually correlated to the Poaceae pollen data. *Eriophorum*-type pollen was compared to both *Eriophorum* spp. and *Eriophorum*-type vegetation.

Most of the strongly associated plant-pollen types (SAT) and the associated plant-pollen type (AT) had a statistically positive correlation between plant cover and pollen percentages (Table 6). These were Rosaceae, *Potentilla*-type, *Pedicularis*, *Thalictrum*/*Thalictrum alpinum*, *Selaginella selaginoides*, *Eriophorum*-type/*Eriophorum* spp., Poaceae/ *Molinia caerulea* and Cyperaceae. *Succisa pratensis* and *Menyanthes trifoliata* had significant plant–pollen correlations, but had weak associations with their corresponding pollen types as they displayed a trend towards pollen under-representation.

The remaining taxa in Table 6 did not have a significant relationship between the vegetation cover and pollen percentages. However, common species in the vegetation, such as Poaceae, *Eriophorum* spp. and *Carex* spp., were also common in the pollen assemblages, reflected in a strong association. Underrepresented taxa were insect pollinated species which were poorly presented in the pollen assemblages, but they were present in the vegetation when present as pollen, e.g. *Drosera rotundifolia*-type, *Bistorta vivipara*-type and *Saxifraga oppositifolia*-type.

Table 6

Correlation between plant cover (transformed to pollen taxa) percentages and pollen percentages, and indices of association (A, U, O) based on presence/absence data. Abbreviations: T = test only from Tågdalen; S = only from Sølendet; ρ (rho) = Spearman rank-correlation coefficient. Correlation coefficient significant at $p < 0.05$ in bold. The indices of association were classified into SAT = strongly associated types, AT = associated types, WAT = weakly associated types, ORT = over-represented type, URT = under-represented type and UT = unassociated type. See Section 3.4.5 for further description. *Anemone* (WAT), *Calluna vulgaris* (ORT), *Juniperus communis* (WAT), *Salix* (UT) and *Solidago*-type (WAT) were present in too few plots with plant or pollen to conduct the test.

Pollen taxon	ρ	A	U	O	Association
Rosaceae	**0.47**	0.83	0.11	0.07	SAT
Potentilla-type	**0.44**	0.8	0.16	0.05	SAT
Pedicularis-type	**0.43**	0.59	0.34	0.14	AT
Succisa pratensis	**0.43**	0.38	0.59	0.13	WAT
Thalictrum	**0.35**	1	0	0	SAT
Menyanthes trifoliata	**0.31**	0.25	0.67	0.5	WAT
Selaginella selaginoides	**0.30**	0.88	0	0.12	SAT
Eriophorum/*Eriophorum* spp.	**0.25**	0.98	0	0.02	SAT
Poaceae/*Molinia caerulea*	**0.25**	1	0	0	SAT
Cyperaceae	**0.24**	1	0	0	SAT
Drosera rotundifolia-type$^{\mathrm{T}}$	0.21	0.06	0.94	0	URT
Poaceae	0.20	1	0	0	SAT
Asteraceae Cichorioideae$^{\mathrm{S}}$	0.18	0.19	0.25	0.8	WAT
Bistorta vivipara-type$^{\mathrm{T}}$	0.11	0.06	0.94	0	URT
Betula	0.05	0.43	0	0.57	ORT
Rhinanthus-type$^{\mathrm{S}}$	0.04	0.13	0.87	0	URT
Ericaceae	0.02	0.19	0.74	0.57	WAT
Galium-type$^{\mathrm{T}}$	−0.05	0	1	1	UT
Sphagnum	−0.13	0.21	0.11	0.79	WAT
Dulichium-type	−0.16	1	0	0	SAT
Pinguicula-type$^{\mathrm{S}}$	−0.22	0	1	1	UT
Saxifraga oppositifolia-type	−0.96	0.13	0.88	0	URT
Eriophorum-type	−0.01	1	0	0	SAT

5. Discussion

Rich fen vegetation is widely distributed in Europe. Vegetation plots from our two study areas are included in a European study, and are classified as boreal fens (Jiménez-Alfaro et al., 2014, cluster 3a). The relationships between vegetation and pollen assemblages in our two fen areas add to the database of surface-pollen samples from a variety of vegetation types and land-use regimes (e.g. Gaillard et al., 1994; Hjelle, 1999a; Mazier et al., 2006; Ejarque et al., 2011; Waller et al., 2017). These data contribute to modern-pollen studies and long-term investigations. However, there are few studies that consider rich fens. An exception is the nemoral rich fens of Waller et al. (2005, 2017) which include a number of species in common with our studied fens; e.g. *Potentilla erecta*, *Carex nigra*, *Carex panicea*, *Carex rostrata* and *Molinia caerulea*. These are among the most common species in our two study areas as well as in the two study areas in southern and eastern England. The annually cut “Sedge fen” included in Waller et al. (2017) has many features in common with our fens, and represents a community with close relationship between vegetation and local pollen deposition.

Comparable to our study, Waller et al. (2017) found that nemoral rich fen vegetation subject to different types of management, including different cutting regimes, produces distinctive pollen signatures. Their study area is in a nemoral vegetation zone, with somewhat different plant communities and species, compared to our boreal rich sloping fens. Also, de Klerk et al. (2017), in arctic fens, state that pollen deposition reflects vegetation, and that regional pollen deposition relates to different biogeographical regions.

5.1. Plant cover and pollen deposition

The pollen recovery from moss samples is a measure of plant representation based on fertility and pollen production, and not only plant cover. However, there is a close connection between plant cover, plant biomass and flowering of a large number of species, as shown in the long-term population and vegetation studies in the two study areas (Moen, 1990, 1995; Aune et al., 1996; Lyngstad et al., 2016). Mowing leads to a reduction in above ground biomass and plant cover and a reduction in flowering for several tall-growing species, e.g. *Molinia caerulea* and shrubs (Table 3). A number of low growing species, with most of the above-ground biomass close to the surface (not reached by the scythe) increased in biomass, cover and flowering, e.g. *Thalictrum alpinum* and *Carex dioica*. Thus pollen recovery is regarded an approximation of plant cover of a taxon.

There can be a large variation in annual flowering, pollen production and pollen deposition between years (e.g. Hicks, 2001; Hättestrand et al., 2008), and several years of pollen deposition should be sampled (Pardoe et al., 2010). Although moss samples may contain only one or two years of pollen deposition (Räsänen et al., 2004), it is generally assumed that moss polsters contain several years of pollen deposition (Bunting et al., 2013). The annual pollen productivity for species of boreal trees such as *Pinus*, *Betula*, and *Picea* has been found to be related to summer temperature of the year prior to pollen emission (Autio and Hicks, 2004). Our moss samples were gathered in late July 2008. The meteorological stations in the two study areas recorded summer temperatures close to the 30-year normal for the summers 2007 and 2008 (Lyngstad et al., 2016). Both 2007 and 2008 were normal/good flowering years for most of the studied species; e.g. for *Eriophorum latifolium* (Lyngstad et al., 2016), indicating that even if only a few years are represented in the moss samples, the pollen data are probably representative.

The investigated plots are designed for vegetation studies (e.g. Lyngstad et al., 2016), where different management regimes (and collected moss polsters) are very close, but still there were differences between pollen assemblages taken 1–4 m apart. The differences in pollen percentages corresponded well with the vegetation from different management regimes, indicating that a substantial part of pollen was derived locally and that rich fens are suitable for local-scale plant–pollen studies. Comparable studies have also demonstrated a strong correspondence between local vegetation and pollen assemblages for herbs and dwarf-shrubs (e.g. Pardoe, 1996; Hjelle, 1999a; Waller et al., 2017) and a relevant pollen source area (sensu Sugita, 1994) of only a few meters is found within mire communities (Bunting, 2003; Bunting and Hjelle, 2010).

5.2. Identification of management regimes by modern pollen assemblages

Most plant species occurred in both study areas, and in plots with different mowing regimes. Those with high cover in all plots were *Trichophorum cespitosum*, *Thalictrum alpinum* and *Molinia caerulea*. Six other vascular plant species occurred in at least 80% of the plots: *Carex dioica*, *Carex panicea*, *Eriophorum angustifolium*, *Eriophorum latifolium*, *Potentilla erecta* and *Selaginella selaginoides*. Many bryophytes occurred in the plots, e.g. the dominant and constant rich-fen species *Campylium stellatum* and *Scorpidium cossonii* (Moen et al., 2012). Several rare species distinguish between the fens of the two areas, leading to the classification of the oceanic and the more continental fens in different alliances in the phytosociological system (Moen et al., 2012). All of these species had low pollen percentages, and they are not included in this discussion.

The differences in plant cover and pollen assemblages between the management regimes were mainly quantitative. Earlier studies from these localities have shown that the variation in vegetation cover of plots from similar land-use between localities can be larger than between plots from different management regimes within the same locality, and that permanent plots with different management regimes inside each locality belong to the same plant community/vegetation cluster (Moen et al., 2012; Lyngstad et al., 2016). The differences between vegetation plots from different management regimes were more pronounced than the differences between pollen samples from these regimes (Fig. 4a). Generally, the plant compositions in plots mown biennially and quadrennially were more similar than to unmown vegetation (Fig. 4a and b), whereas this to a lesser degree was found for pollen data (Fig. 4a). Similar results for plant cover were found in the same areas (e.g. Aune et al., 1996), as well as for plant and pollen data from other studies of mown vegetation (e.g. Hjelle, 1999a).

Palynological studies of rich fens have received little attention in comparison to lakes and raised bogs (Waller et al., 2017). Our results are a contribution to knowledge established in earlier studies from fen vegetation (e.g. de Klerk et al., 2017; Waller et al., 2017) demonstrating that fen vegetation produces distinctive pollen signatures with indicator taxa and should be used also for palaeoecological studies.

To detect past types of land use and changes in land use by pollen analysis, taxa that show responses to land use regimes, in the present case mowing, and have pollen deposition that correlate with plant cover, must be identified. Here five groups of pollen taxa with different potential for land-use reconstruction were identified (Table 7).

5.2.1. Very good and good pollen indicators for management regimes

In rich fens *Thalictrum* is sensitive to land-use changes, and the contemporary pollen percentages correlate with the local plant cover. *Thalictrum alpinum* occurred in all plots, with the highest cover in biennially mown plots compared with unmown plots (Fig. 4b), absolutely (Table 3) and relatively (Table 4a). This is in accordance with previous studies from Sølendet, which also report increased biomass, cover and flowering with mowing frequency (Moen, 1995; Aune et al., 1996). A difference in cover of *T. alpinum* between biennially and quadrennially mown plots is not clear from this study. Its growing point is at the soil surface and is little affected by mowing, so it becomes more abundant in mown fens where competition is reduced. The effect of competition was demonstrated by Klanderud and Totland (2005), who removed neighbouring vegetation in an alpine community and found increases in the number and cover of leaves and reduction in the length of the flowering stems of *T. alpinum*. However, *T. alpinum* is also present in grazed communities in outfields, as in Budalen, located between our two study areas (Austrheim et al., 1999), and without comparing mown and grazed communities one cannot exclude *Thalictrum* as an indicator of more than one land-use practice. The strong association of the presence of both plant and pollen and absence of pollen when plants are lacking, indicates a limited pollen-dispersal distance from these plots with a minimum distance of 1 m. *Thalictrum alpinum* is wind dispersed, but dispersal can be limited by the short flower stems. This means that *Thalictrum* pollen is a good indicator of local plant presence, and an increase in plant cover can indicate land use like mowing (Table 7). Increased percentages of *Thalictrum* pollen in peat profiles have been used as an indicator of mowing in vegetation history studies of rich fens in boreal areas of central Norway (Gunnarsdóttir, 1999; Solem et al., 2012).

Table 7
Pollen indicator taxa for management regimes in boreal rich fens based on the results from the Wilcoxon signed rank test (relationship between vegetation and management regime) and the Spearman rank-correlation coefficient (relationship between plant and pollen percentages). The effect of traditional mowing on the relative vegetation cover (plants expressed as pollen taxa) in fens is displayed as: + positive effect of traditional mowing, • no effect, − negative effect. Results from earlier studies in the study areas are displayed in brackets (after Moen, 1990, 1995; Moen et al., 1999); see text for further details.

Pollen–vegetation relationship	Pollen/spore taxa	Effect of mowing
Very good pollen indicator	*Thalictrum*	+
Good pollen indicators	Cyperaceae	+
	Eriophorum-type	+
	Poaceae	−
	Succisa pratensis	−
	Pedicularis-type	+[a]
Potential pollen indicators	*Potentilla*-type	(−)
	Rosaceae	(−)
	Selaginella selaginoides	(+)
Pollen type reflecting unidentified factors in present study	*Menyanthes trifoliata*	(+/•)
Pollen types reflecting plant cover in earlier studies	*Anemone*	
	Asteraceae Cichorioideae (*Leontodon* spp./*Crepis* spp.)	(+/−)
	Betula	(−)
	Bistorta vivipara-type	(+)
	Calluna vulgaris	(−)
	Dulichium-type	(+/•/−)
	Drosera rotundifolia-type	(+)
	Ericaceae	(−)
	Galium-type	
	Juniperus communis	(−)
	Pinguicula-type	(+)
	Rhinanthus-type (*Euphrasia* spp./*Bartsia* spp.)	(+)
	Salix	(+/−)
	Saxifraga oppositifolia-type	(+)
	Sphagnum	(−)
	Solidago-type	(−)

[a] *Pedicularis*-type pollen mainly increases with mowing, but single species are reduced with mowing.

The interpretation of the pollen representation of Cyperaceae undiff. is more challenging. The family is generally well adapted to mowing, although with variations and opposite trends for single species, as for *Carex* species (Table 4a) (e.g. Moen, 1990, 1995). Both mowing regimes differed from unmown plots in total Cyperaceae plant-cover percentages, but the differences between mowing intensities could not be detected in modern pollen samples. The differences in the Cyperaceae pollen percentages between management regimes are small. The strong plant–pollen correspondence from these closely situated plots suggests a limited dispersal distance for Cyperaceae, which was reported by Bunting and Hjelle (2010) to be between 1.5 and 3.5 m. The present investigation has shown the value of separating *Dulichium*-type pollen, which in our area consists of *Carex* spp., from Cyperaceae undiff. pollen.

Eriophorum-type pollen includes three *Eriophorum* species and two *Trichophorum* species. *Eriophorum* spp. and *Trichophorum* spp. (included in Cyperaceae) were most abundant in vegetation mown biennially (Fig. 4b). *Eriophorum angustifolium*, *Eriophorum vaginatum* and the more widespread species *Eriophorum latifolium*, were well adapted to mowing, which also promoted increased flowering according to Moen (1990, 1995), Aune et al. (1996) and Lyngstad et al. (2016). *Trichophorum cespitosum* ssp. *cespitosum*, the dominant species in the rich fens, was indifferent to mowing, as found in earlier studies (e.g. Moen, 1995; Aune et al., 1996) and the difference between management regimes was relatively small.

There was a positive plant–pollen correlation between *Eriophorum*-type pollen and total *Eriophorum* species, but not for the pollen type and all five individual species. Most of the pollen type might be from *Eriophorum* if *Trichophorum* pollen deposition was reflecting the small variation in *Trichophorum* vegetation cover. The difference in *Eriophorum* spp. plant cover between the two mowing regimes and unmown plots could be detected from pollen analysis, as found from other studies (Hjelle, 1998), indicating that *Eriophorum*-type pollen should be separated from Cyperaceae undiff. if possible to increase its value in the interpretation of past communities.

Molinia caerulea is the most abundant grass in the plots but the pollen taxon Poaceae can also include *Deschampsia cespitosa*, *Festuca ovina* and *Nardus stricta*. *Molinia caerulea* is clearly most abundant and very fertile in unmown plots (Moen, 1990, 1995; Aune et al., 1996). The plant cover of *M. caerulea* decreased with the intensity of mowing, whereas the cover of Poaceae only differed clearly between the mowing regimes and unmown plots (Tables 3 and 4). The main reason for the decrease of *M. caerulea* in mown fens is the exposure of the elongation zone to the mower (scythe), strongly reducing the plants. Under moist conditions grazing also reduces plant cover of *M. caerulea* (Hulme et al., 1999). In boreal shrub-dominated plant communities and in areas with mowing every 5–10 years (Aune et al., 1996) and in temperate tall-growing fen communities (Rowell et al., 1985) *M. caerulea* increases in biomass and cover with mowing. On the generally nutrient-poor boreal fens *M. caerulea* suffers from the removal of reserves by intensive cutting during a short growing season (Øien and Moen, 2001). In more fertile localities, strong competitors like shrubs and tall herbs are removed by mowing. In such areas, and under mowing with higher stubble, the *Molinia* tussocks can develop. In addition, the fertility of *M. caerulea* is reduced in mown plots on boreal rich fens (Moen, 1995). The modern Poaceae pollen percentages correlated with the plant cover of *Molinia*, but not with all Poaceae species (Table 6). This indicates that most of the Poaceae pollen originated from *M. caerulea*. *Molinia caerulea*/Poaceae displays a difference in plant cover and pollen percentages between areas mown biennially and quadrennially from Tågdalen, whereas the data from quadrennially mown areas in Sølendet are few and difficult to interpret. Overall, mowing of the rich fens results in a reduction of Poaceae plants and pollen and an increase of Cyperaceae plants and pollen. This is in accordance with investigated fen communities in the UK where Cyperaceae (including *Carex nigra*, *Carex panicea* and *Carex rostrata*) have high values in intensively managed communities and decrease with longer cutting rotation when Poaceae (including *Molinia*) increases (Waller et al., 2017). The results from fens seem therefore to contrast to pollen assemblages from dry meadows dominated by high Poaceae pollen values and relatively low values of Cyperaceae (Hjelle, 1999a).

Succisa pratensis was present throughout the rich fens, with its largest cover in unmown plots, as reported in Moen (1995) (Fig. 4b, Tables 3 and 4). In other communities a decrease in competition following mowing allows an increase in plant cover of *S. pratensis* (Moen, 1995). However, with relatively little competition in the boreal rich-fens the effect of reduced biomass had an important impact on this species. In mesic to dry grasslands *S. pratensis* increase in cover with grazing (Herben et al., 2006), making both vegetation type and type of land use important for *S. pratensis* plant cover. The cover of *S. pratensis* in the plots was low and the differences between management regimes were small. It is insect-pollinated and has a limited dispersal distance (Hjelle, 1997, 1998), reflected also in this study by a strong plant–pollen relationship, but with a tendency of being under-represented. This makes the species suited for interpretation of local vegetation, but less important for differentiating the investigated management regimes in the present study.

Pedicularis-type pollen included *Pedicularis palustris* and *Pedicularis sylvatica* at Tågdalen and mainly *Pedicularis palustris* and *Pedicularis oederi*, in addition to the rare *Pedicularis sceptrum-carolinum* at Sølendet (Moen, 1990, 2000). The pollen percentages of *Pedicularis*-type related well to the cover for *Pedicularis* spp., possibly because *P. palustris* is the main pollen source as well as the main plant in the studied vegetation. As an associated type *Pedicularis* species were common, but not dominant in either vegetation or in pollen deposits. Both *Pedicularis* spp. and *P. palustris* had greatest cover in mown plots, with a trend to greater abundance in quadrennially mown plots. Only biennially mown and unmown plots displayed a difference even if the percent values are small. Earlier studies (e.g. Moen, 1995) confirm this, along with increased flowering frequency in mown plots. *Pedicularis* has a very low pollen representation, so even small differences in pollen percentages may represent substantial differences in number of plants between plots. *Pedicularis palustris* is a biennial species mainly occurring in mud bottoms and carpets with a scattered field layer, i.e. localities with low competition. *Pedicularis oederi*, a common species in lawns and open fen margins at Sølendet (Moen, 1990) occurred in only 11 of 49 plots. This species shows reduced plant biomass and lower flowering frequency in response to mowing, especially intensive mowing, and is also reduced by abandonment during succession. The pollen data showed a correlation with plant cover, in contrast to the usually rare occurrence of *Pedicularis* in pollen diagrams. Bunting (2003) found no association between plant and pollen in surface studies of heathland communities in the UK. Our results indicate that *P. palustris* has a larger potential of being recorded than the other species, which may indicate that *Pedicularis* may be regarded as an indicator of mown fens.

There are short distances between areas of different land-use in the investigated plots. The strong plant–pollen relationship and strong association of presence indicate a local pollen source area of approximately 1 to a few meters for taxa defined as very good and good pollen indicators for management regimes.

5.2.2. Potential pollen and spore indicators for management regimes

Within the homogenous rich-fen community a wide distribution of both plants and pollen gave a high probability of association for many taxa (cf. Hjelle, 1997; Mazier et al., 2006). However, for several of these taxa there was no identified plant response to different management regimes. From other studies *Potentilla erecta* displays larger cover and increased flowering in unmanaged plots compared to mown fens (Moen, 1995; Aune et al., 1996). A reduction in plant cover of *P. erecta* has been documented from grazed vegetation on moist soil (Hulme et al., 1999). With the high cover, the relatively coarse resolution for abundant taxa in the chosen cover scale (e.g. Bunting and Hjelle, 2010), and substantial variations between and within management regimes, potential vegetation trends were not identified in the present study (Fig. 4b). Rosaceae undifferentiated pollen correlated with *P. erecta*, its only species in the vegetation, thus Rosaceae pollen was interpreted to mainly representing *P. erecta*. With a good plant–pollen correlation *P. erecta* reflects local vegetation, it is a good indicator of grazing (e.g. Hjelle, 1999a, 1999b; Mazier et al., 2006) and can, in the present study, represent a pollen indicator type of open vegetation more than mowing. High moisture levels might limit the plant cover of *P. erecta* on these rich fens, playing a more important role in plant distribution than land use.

Selaginella selaginoides is known to be favoured in mown fens (Moen, 1995; Aune et al., 1996). In the studied fens the spore recovery was a good indicator of its plant presence, but no statistical relationship between plant cover and management regime has been identified. With low percentages on the investigated fens, any trends have been difficult to decipher. There was a tendency of increased plant presence with mowing from pairwise comparisons (Tables 3 and 4), even if the general tendency in the plots is a slight decrease with mowing (Fig. 4b). If its land-use response is identified from further studies, *S. selaginoides* could be an indicator-type of mowing.

5.2.3. Pollen types reflecting unidentified factors or not reflecting plant cover

Menyanthes trifoliata was rare but still demonstrated a positive plant–pollen correlation on these rich fens. Its main distribution on the fens was outside the investigated localities, in the wettest places in the fens and in small lakes (Moen et al., 2012). However, in lawn and carpet communities, the cover of *Menyanthes* increases and flowering decreases with mowing (Moen et al. unpublished data).

Two sub-groups of pollen types not reflecting plant cover were identified:

a) Mowing regime affected the species cover, but there was no significant plant–pollen correlation. The strong association between plant and pollen was due to their large abundance. *Carex* species display a variety of plant responses to mowing regarding biomass, cover and fertility (Moen, 1995). Several *Carex* species and the genus as a whole were most abundant in mown plots (Fig. 4b; Moen, 1990; Aune et al., 1996). The low taxonomic precision of *Dulichium*-type pollen and variations in pollen production within the genus (Randall et al., 1986; Hjelle, 1998) were probable reasons for a lack of plant–pollen correlation. *Dulichium*-type pollen has a potential in palaeoreconstruction if the plant–pollen relationship can be interpreted locally. *Betula* species as a whole, and the main species *Betula nana* and *Betula pubescens* were mainly found in relation to succession on the fen, along the margins and as surrounding vegetation (e.g. Moen, 1990). The over-represented and variable pollen recovery from *Betula* was probably from the extra-local and the regional vegetation. Thus *Betula* pollen has limitations in reconstructing local vegetation, but an increase in pollen may indicate fen succession and increased tree cover on extra-local and regional scales. The cover of *Drosera* spp. at Tågdalen and *Pinguicula vulgaris* at Sølendet increased with mowing, as shown by Moen (1995). As entomophilous and cleistogamous species, respectively, their strongly under-represented and unassociated pollen document the presence of the plant, but they are not suitable to represent variation in the vegetation.

b) The second sub-group includes taxa with no identified plant response to different land-use and no plant–pollen correlation on the rich fens (Table 7). These were rare in this vegetation type, but could be common in nearby herb and heather woodland (Moen, 1990, 2000). The pollen might mainly be extra-local. These taxa are of limited value in local land-use reconstructions in such boreal fens, but can be valuable in reconstructions of extra-local vegetation, succession and fen dynamics.

Changes in climate and fen characteristics might change the effect mowing plays on single taxa through time as well as geographically. Still, the ecological effect of mowing will be similar for many taxa under various conditions, and thus comparable between regions (e.g. Hjelle, 1999a).

6. Conclusion

The differences in plant cover between mown and unmanaged plant communities on the boreal rich-fens were mainly quantitative, where the same taxa are present in the vegetation in mown and unmown fens, but in varying amounts (Table 3). For several taxa management regimes explained a substantial part of the plant-cover variation on the boreal rich-fens. The relative changes of several taxa in the vegetation rather than the presence or absence of any single pollen-indicator taxon indicate land-use changes on these fens.

A correlation between the plant cover of taxa constituting the majority of the vegetation on the rich fen and their contemporary, deposited pollen on a local scale was documented. The short distances between different management regimes in this study indicate a local pollen source area from 1 and up to a few meters for important taxa in the mown fens, like *Thalictrum alpinum*, Cyperaceae and *Succisa pratensis*. Thus, presences of their pollen in peat samples can generally be assumed to reflect presence in the vegetation.

Modern pollen assemblages, with correlation to plant cover, display a difference in pollen percentage between biennially mown and unmown vegetation. Further, several taxa have a potential for indicating mowing quadrennially, even if the two mowing regimes are not clearly separated in the present study. A modern pollen assemblage indicating mowing on these rich fens has high percentages of *Thalictrum*, *Eriophorum*-type and Cyperaceae undiff. pollen. *Pedicularis* pollen percentages are generally higher than in unmown vegetation, and Poaceae (*Molinia caerulea*) and *Succisa pratensis* pollen percentages are lower than in unmown vegetation. *Potentilla*-type and Rosaceae, pollen together representing *Potentilla erecta*, decrease with mowing of the fens, whereas an increase in *Selaginella selaginoides* spores potentially indicates mowing. In combination, these changes in pollen percentages from such species can be considered a fingerprint for mowing regimes on rich fens. In other vegetation types and under different land use, some of these species would display a different combination of increase and decrease in plant cover and pollen deposition.

This study emphasises the importance of identification of pollen to as low a taxonomic level as possible. The separation of *Eriophorum*- and *Dulichium*-type (i.e. *Carex* spp.) pollen from Cyperaceae undiff. is essential as the two former, partly in different ways, are important taxa in identifying land-use regimes.

This study has shown a close connection between taxa in fen vegetation and the local pollen deposition in the two contrasting climate regimes (oceanic and continental) of the middle and northern boreal vegetation zones, confirming hypothesis 1. Boreal rich-fens in the two areas have the same dominant species and the same species producing the majority of the pollen, supporting hypothesis 2. The difference between mown and unmown vegetation can be detected from the contemporary pollen assemblages, particularly between biennial mown and unmown vegetation, supporting hypothesis 3. In this study *Molinia caerulea*/Poaceae display a difference in plant cover and pollen percentages between areas mown biennially and quadrennially. This difference between biennially and quadrennially mown areas was not identified for most taxa, and should be further investigated. The results from the present paper contribute to a better understanding of vegetation–pollen relationships on rich fens and separation of mown and unmown fens, based on pollen assemblages. Our findings will aid in the interpretation of fossil pollen assemblages in terms of local land use on fens in the boreal zone.

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